Detailed Project Report

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (UAVs, ROVs, etc.) under DST NM-ICPS

DST Sanction No.: DST/NMICPS/TIH10/IITH/2020

SUBMITTED BY

IIT HYDERABAD

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CERTIFICATE

Name of the TIH: NMICPS Technology Innovation Hub on Autonomous Navigation Foundation

Technology Vertical: Autonomous Navigation and Data Acquisition systems (UAV, RoV, etc.)

1. This is to certify that the Detailed Project Report (DPR) on the Technology Vertical **Autonomous Navigation and Data Acquisition systems (UAV, RoV, etc.)** is prepared and submitted to Mission Office, NM-ICPS, DST is as part of implementation of Technology Innovation Hub (TIH) at **Indian Institute of Technology Hyderabad, having registered office IITH Main Road, Kandi, Sangareddy, Telangana – 502284, India** under National Mission on Interdisciplinary Cyber-Physical System (NM-ICPS).

2. This is to certify that this DPR has been checked for plagiarism and the contents are original and not copied/taken from any one or from any other sources. If some content was taken from certain sources, it is duly acknowledged and referenced accordingly.

3. The DPR will be implemented as per the Terms, Reference and Clauses stated in Tripartite Agreement signed on **10th December 2020** between Mission Office, DST, **Indian Institute of Technology Hyderabad and NMICPS Technology Innovation Hub on Autonomous Navigation Foundation (TiHAN).**

Date: 17.09.2021
Place: IIT Hyderabad

(Prof. P. RAJALAKSHMI)

Name(s) and Signature(s) of Project Director (s)

Endorsement from the Head of the Institution

1. Certified that the Institute welcomes participation of **Prof. P Rajalakshmi** as the Project Director for the Technology Innovation Hub (TIH) and that in the unforeseen event of discontinuance by the Project Director, the **Indian Institute of Technology Hyderabad** will identify and place a suitable faculty as Project Director for fruitful completion of the TIH activities.
2. Certified that the Host Institute shall provide basic facilities, faculty support and such other administrative facilities as per Terms and Conditions of the award of TIH, will be extended to TIH.
3. As per Tri-partite Agreement, the Host Institute (HI) shall play its role and fulfill its responsibilities for the success of TIH.

Date: 17.09.2021
Place: IIT Hyderabad

Name and signature of Head of Institution

1. Executive Summary

The **DST NM-ICPS Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (UAVs, RoVs) - TiHAN,** described in this proposal is a multi-departmental initiative, comprising of researchers from Electrical Engineering, Computer Science and Engineering, Mechanical and Aerospace Engineering, Civil Engineering, Mathematics, Liberal Arts and Design at IIT Hyderabad with collaboration and support from other reputed institutions, R&D labs and industry. This hub importantly focuses on the development of novel and cutting-edge next generation autonomous navigation and data acquisition technologies with applications primarily in different verticals: Intelligent and Autonomous Transportation Systems, and Agriculture. As our nation is currently progressing towards the realization of two important visions: "Digital India" and "Smart Cities", the development of intelligent and automated Cyber-Physical Systems (CPS) technologies for the afore-mentioned application verticals and their efficient integration with the state-of-the-art information and communication (ICT) technologies is the need of the hour. These technological advancements and adoption play a crucial role in making India a global technology leader in the domain of Cyber-Physical Systems (CPS). ***TiHAN at IIT Hyderabad, is envisioned as the Hub for Safe, Sustainable and Next Generation Smart Mobility Solutions, leading to be the destinations for collaborative research between academia, R&D labs and industry – both National and International.***

Currently with the world moving towards autonomous systems which collaboratively perform tasks utilizing the environment perception and interaction with the peer systems, they have profound applications in both the intelligent and autonomous transportation systems, agriculture, infrastructure, security, surveillance and various other domains. A few of such important applications which can improve the quality of life and strength of our nation along with broad challenges involved are listed in Fig. 1. For example, the autonomous ground vehicles, revolutionize the current passenger or goods transportation, enhances safety, reduces the accidents, improves the logistics, etc. The autonomous aerial vehicles of different categories such as nano, micro, small, medium and large - have significant use cases in the areas of urban air mobility, payload delivery, surveillance, remote environment monitoring, in agriculture such as crop improvement programs which include high throughput crop phenotyping, reconnaissance, etc. Also, in addition to the above discussed use cases, policy and regulations, these technologies will open up many new avenues of applications which were never thought of earlier.

Although many nations across the globe are working towards the efficient and reliable realization of the autonomous navigation technologies for intelligent transportation and agriculture, many of these technologies may not be directly utilizable in Indian context. Out of the many, prominent reasons for this are: these technologies rely on the demographics (such as local traffic patterns, driving behavior, available infrastructure, safety, and legal regulations); and for India to become a global player, the development of future technologies that are specifically catering to the needs of the nation is a crucial aspect. Hence, in order to leverage the true potential of Digital India and Smart Cities, the development of technologies which can be realized efficiently and reliably while offering the technological scalability in the future need to be targeted. This hub considering the above aspects, will aim to realize efficient and highly secured autonomous navigation and data acquisition systems for their use in terrestrial, aerial and water surface applications. The primary applications that will be targeted by the hub are summarized in Fig. 1 and include: aerial vehicles for urban air mobility, development of broad categories of drones (nano, micro, small, medium and large) for various applications, UAVs for remote water/air quality monitoring, autonomous navigation systems for power-line inspection, infrastructural monitoring, gas pipeline monitoring, railway track inspection, UAVs for smart farming and high throughput crop phenotyping, livestock monitoring, etc. Hence, the **vision** of this hub is to become a global destination for next generation smart mobility technologies that utilize reliable and efficient autonomous navigation and data acquisition systems in the next five years. The **mission** of this hub is to accelerate the adoption of the autonomous navigation and next generation smart mobility technologies for use in the intelligent transportation and agricultural applications, not only in the Indian but also in global context. The hub envisages to create an advanced collaborative ecosystem (both national and international) focusing on the development and realization of these advanced autonomous navigation and data acquisition systems with various stakeholders from reputed academia, R&D institutions, industry within India and across the globe.

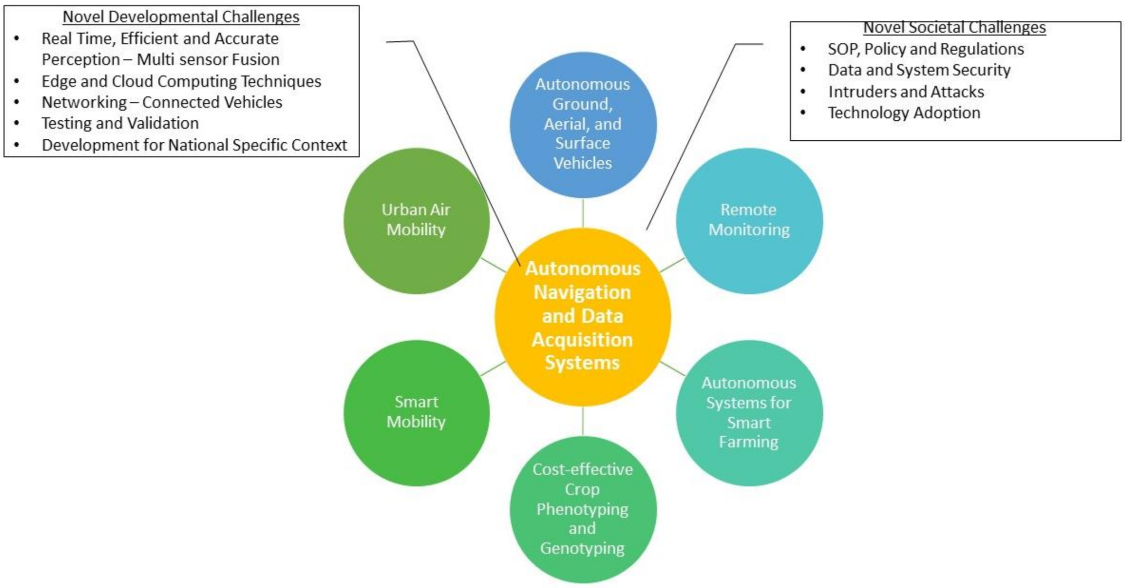


Figure 1: Potential applications of focus with developmental and societal challenges for the autonomous navigation and data acquisition systems at TiHAN, IIT Hyderabad.

The development of these technologies comprises of several inherent complexities and challenges as depicted in Fig. 1. Primarily, these challenges can be broadly classified into developmental and societal. As the important focus of the hub is to tightly connect these technologies to the Indian context, the development of these technologies will demand careful consideration of the aspects such as the traffic pattern, available infrastructure, requirement of low-cost solutions, safety aspects, legal regulations, etc. Also, the development of data acquisition systems should be optimal with minimal sensors on-board while achieving higher perception accuracy. The processing of this information in real-time also poses new challenges. Although, the cloud technologies can be utilized, intelligent architectures have to be developed which can efficiently use the existing communication infrastructure while maintaining compatibility with the upcoming networking technologies for provisioning the processing over edge and cloud. The development of autonomous vehicles is also posing several new societal threats, of which the important ones are the system security which lead to unauthorized access to the data thus affecting the national security. Many a times, these technologies are being used for remote attacks or warfare. Hence, the system developed should always consider these aspects and the security frameworks developed will have to be constantly verified and updated moving forward. While the development of the technological systems that address the above challenges is important, the adoption of these technologies is also equally important. The adoption of these technologies is a critical challenge especially in India due to their slow penetration into the daily lives. Hence, new models for technology adoption have to be explored.

In view of the above aspects, an advanced facility for the development of the autonomous navigation and data acquisition systems is being planned to be constructed comprising of state-of-the-art simulation tools, high speed computing facilities, vehicle integration facilities (terrestrial, aerial and surface), advanced sensor interfaces (imaging, LiDAR, ultrasonic, etc.), communication technologies (5G, Millimeter-wave, etc.), but not limited to. One another essential aspect of the development of these autonomous navigation systems is to test them for reliability and safety conformance. Hence, the hub is planning to build a first of its kind (in India) and state-of-the-art testbed for the validation of the systems and vehicles developed in real-time.

A first of its kind state-of-the-art ***Testbed for Autonomous Navigation (Aerial/Terrestrial)*** is being developed at TiHAN IIT Hyderabad. The Facilities includes Proving Grounds, Test tracks, Mechanical integration facilities like Hangers, Ground control stations, Anti drone detection systems, State of the art Simulation tools (SIL, MIL, HIL, VIL), Test tracks/circuits, Road Infra – Smart Poles, Intersections, Environment Emulators like Rainfall Simulators, V2X Communications, Drone Runways & Landing area, Control Test centers. The testbed will comprise of several features including: various road types, scenario emulation tools (for obstacles, environmental conditions, etc.), state of the art networking infrastructure for data acquisition and communication in real-time, air space management centers, urban traffic management facility, intruder detection facility, etc. This testbed will facilitate researchers, industries, institutions to utilize the developed autonomous navigation technologies. Also, we sincerely believe this will be an asset of national and International importance.

Also, the manpower training in the advancing areas of science and technology plays a major role for the development of our nation. Through this hub, we aim at training and development of the manpower at various levels including graduates, post graduates, PhDs, and Postdocs by offering various fellowships and internships. To encourage the faculty members from the institutes of national importance for contributing towards the research and development of the autonomous navigation and data acquisition systems, the hub plan to offer several research fellowships. Various skill development programs such as conducting periodic workshops will increase the momentum of students and working professionals to undertake a career option in the broad fields of autonomous navigation systems. All these activities are aligned towards strengthening the government policies such as **National Policy on Electronics, Skill India, Digital India Program**, etc.

With technology development being one aspect of this hub, the commercialization of these technologies and introducing new business players in the broad areas of autonomous navigation technologies to the world is one another important goal of this hub. To achieve this the hub will encourage both the young and experienced entrepreneurs who are working on the cutting-edge autonomous navigation technologies development and envisages to be the destination for launching their dream ventures. Various schemes such as PRAYAS, Entrepreneur in Residence, Seed Support System, Accelerator Program, Incubation, etc., will be considered for implementation that can significantly benefit the budding entrepreneurs of India. Also, these initiatives will significantly aid the much-appreciated policy of the government **“Startup India”**. The hub also leverages possible international collaboration for the technology development and transfer of the technologies developed to the other nations thus making sure the hub has a global footprint. In the rest of this DPR, the following important responsibilities of the hub are discussed in detail:

1. Technology and application verticals of the hub.
2. Challenges hindering the real-time adoption of the autonomous navigation technologies.
3. Comprehensive analysis of the existing systems/technologies and the planned developmental activities in collaboration with various stakeholders and considering the target beneficiaries.
4. Strategy and initiatives planned for development of technology, skill, entrepreneurship, collaborations, etc., while aligning with the policies of the Indian government.
5. Management structure of the hub and progress monitoring along with time frames.

2. Context and Background

Through this hub, we lay our primary focus on the research and development of inter-disciplinary cyber-physical systems based reliable and accurate autonomous navigation and data acquisition technologies for autonomous vehicles (terrestrial, aerial, water surface). Thus, developed technologies by the hub will enable creation of value applications, especially in the Indian context, under the following sectors: 1) Intelligent and Autonomous Transportation Systems and 2) Agriculture as shown in Fig. 2. **Specifically, we plan to develop and deploy a real-time CPS system utilizing autonomous UAVs and ground/surface vehicles for the above two application sectors.** A living lab for the research and development of Autonomous Vehicles (Ground/Aerial) and a test facility center is also planned to be established as part of this Technology Innovation Hub at IITH.

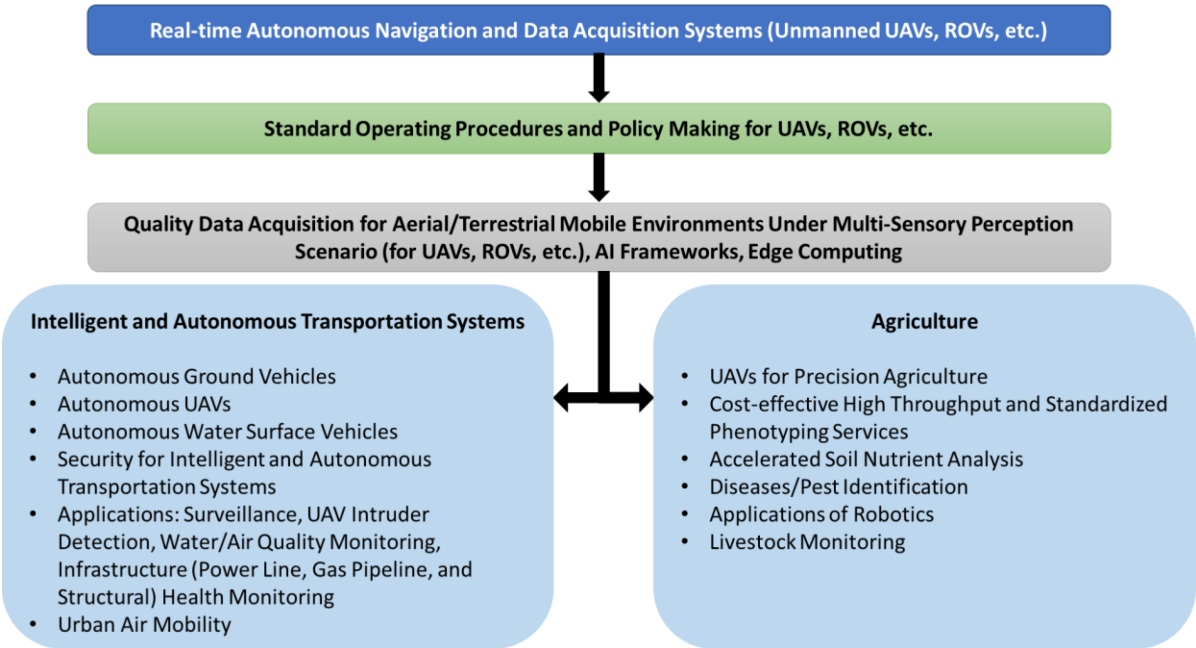


Figure 2: Focus of TIH at IIT Hyderabad along with application sectors.

However, before realizing efficient and reliable autonomous navigation systems for both intelligent and autonomous transportation, and agricultural applications, important challenges hindering the real-time adoption of unmanned autonomous vehicles as depicted in Fig. 3 and discussed in detail below need to be addressed.

Figure 3: Challenges in Autonomous Navigation Systems

- **Multi-sensory perception:** In general, the autonomous vehicles utilize information from various sensors for accurate navigation. These sensors include inertial and navigation system-global navigation system (INS-GNSS), visible light sensor, etc for navigation. Also due to the diversified use cases, every application demands for diversified sensors to be integrated onto the vehicle and operating procedures to be followed. Hence, the on-board sensor information fusion, quality and reliable data acquisition and processing from the on-board sensors at the edge remains a challenging task. In terms of operation, the UAV being utilized for monitoring the crop growth or disease identification should be flown at a certain height (which is different when utilized for traffic sensing) and during a specific time on a day. Hence, **development of standard operating procedures for UAV based data acquisition** considering the application under interest is a need of the hour.
- **Swarming:** A whole new plethora of applications will be available by utilizing swarm of autonomous vehicles. Primary advantage of the swarming technology is to reduce the time for task accomplishment by task sharing and distributed decision making with lesser human intervention and low latency. However, the interaction among the autonomous vehicles participating in the swarm is a significant challenge. Multiple challenges such as the dynamic network reformation, reliable data acquisition and transmission, and inter swarm communication still remain open and need a lot of emphasis.
- **Payload:** In many applications autonomous vehicles such as UAVs operate on the battery power supply with limited form factor, thereby limiting the payload carrying capabilities and flight time. Hence, intelligent and dynamic data acquisition methodologies will significantly aid in collecting the most useful information within the available flight time.
- **Communication:** The autonomous vehicles depending on the application demand for diversified communication requirements. Although multiple wireless communication technologies (both ad-hoc and cellular) exist, the integration is at a nascent stage. Many applications trending currently store the collected data on-board and is not very suitable for many practical applications such as disaster

management, surveillance, traffic management etc. Hence, both theoretical and experimental analysis of existing communication technologies for different application categories have to be investigated thoroughly. Also, definite performance bounds have to be defined.

- **Stability:** The stability of the autonomous vehicles is affected by various parameters which include sensitivity of the navigation sensors, environmental conditions, electromagnetic interference from power lines, etc. Hence, the on-board navigation system should be resilient to the above sources to prevent fatal or economic losses.
- **Computing:** Due to the limited on-board resources on many of the autonomous vehicles (such as UAVs, surface vehicles, battery operated vehicles), high complex computation at the edge is unaffordable. Also, due to the strict latency constraints for many of the applications, the traditional cloud computing architecture is not a viable option. In this view, we plan to develop faster parallel processing frameworks on GPU enabled edge computing platforms.
- **Security:** Although the autonomous navigation and data acquisition systems have multiple benefits, they also suffer from severe security issues. There is a stringent need for development and constant upgradation of security frameworks used by autonomous vehicles which are vulnerable to attacks.
- **Regulations:** We strongly feel that the standard operating procedures being developed in this proposal as part of addressing the challenge "Multi-sensory perception" will significantly aid in formulating the regulations and operating policies for different applications in the Indian scenario.

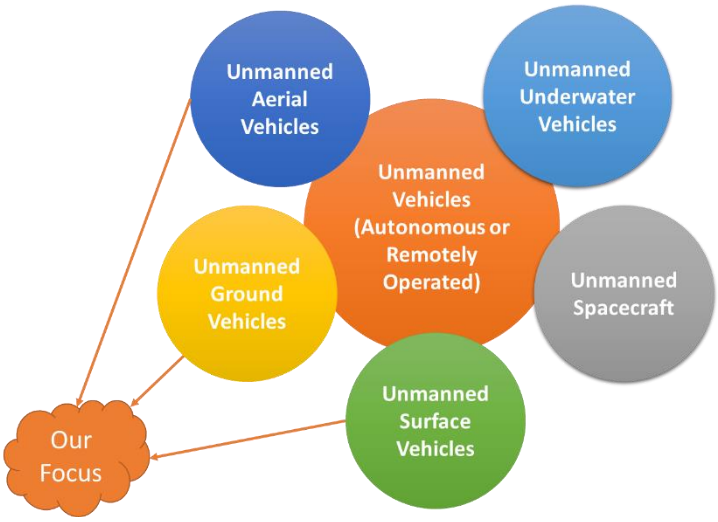


Figure 4: Broad categories of unmanned vehicles and our targeted areas.

In this proposal, we lay our primary focus on addressing the challenges described above thus realizing the adoption of autonomous navigation systems in real-time use cases for **(i) Intelligent and Autonomous Transportation Systems and (ii) Agriculture**. Broadly unmanned vehicles can be classified into five different categories based on their operation: 1) unmanned ground vehicles (UGVs), 2) unmanned surface vehicles (operates on water surface, USVs), 3) unmanned underwater vehicles, 4) unmanned aerial vehicles (UAVs), and

5) unmanned spacecraft as shown in Fig. 4. However, in this proposal we would like to constrain our technology research and developmental activities along with commercialization to applications under the above-mentioned sectors that utilize **unmanned ground vehicles, unmanned aerial vehicles, and unmanned surface vehicles**. In the following, we summarize the important technological goals of the hub:

2.1 Intelligent and Autonomous Transportation Systems

The goal here is to realizing safe autonomous terrestrial, aerial, and water surface vehicles for their usage in various applications including smart and next generation mobility, urban air mobility, remote sensing, traffic monitoring, drone swarms, smart grids, power-line monitoring, smart infrastructure monitoring, gas pipeline monitoring, railway track inspection, surveillance, agriculture, livestock, etc. This requires development of several components such as sensing modalities, processing architectures, insights and actuations, data networking, etc., and the development of drones of various categories (micro, small and standard sizes) for various air mobility applications. One of the major challenges in the development of these autonomous vehicles is achieving a matchable performance compared to the human decision making. In this proposal, we aim at developing advance and dynamically adaptable AI/ML techniques which can render high performance decision making for autonomous navigation in UGVs and UAVs using the on-vehicle multi-sensory perception system.

Foremost requirement for realizing an accurate and reliable autonomous vehicle is the availability of accurate data about the environment, which can be obtained by appropriately choosing and placing the sensors. Considering the amount of data these sensors generate, the communication and processing of this data in real-time is also a challenging task which requires novel architectures to be developed. In this context, it is proposed to develop a real-time CPS system and standard operating procedures for multi-sensor based quality and efficient data aggregation with calibration. To meet the data processing and communication requirements, new communication strategies and processing architectures (exploring parallel processing, edge, cloud, etc.) will be explored.

Currently, the UAVs are penetrating into several applications such as surveying, monitoring, etc. However, many of these applications are utilizing single drone for achieving the targets. However, the future technologies utilize a network of UAVs (UAV swarms) for performing the designated tasks by coordinating within them. Hence, in this proposal, we aim to develop automated drone swarming with adaptive network recovery, reformation, intelligent inter-drone swarm coordination and communication. Also, in many applications, the size of the drones plays a key role in determining the quality of service delivered. Therefore, the developed aerial vehicles in this proposal will vary from micro-UAVs to standard UAVs that are capable of carrying payloads in the order of 10s of kilograms. Using thus developed UAVs suitable commercially viable applications such as urban air mobility, environment monitoring, infrastructure monitoring, agricultural use cases, livestock monitoring, power-line monitoring, gas pipeline monitoring, railway track inspection, etc., will be developed.

The developed UGVs in this proposal considers all the scenarios of Indian context such as traffic patterns, driver behaviour, available infrastructure, etc., along with the multiple on-vehicle sensors such as LiDAR, RADAR, ultrasonic, etc., for accurate navigation. It comprises of efficient edge and cloud partitioning for information processing while reducing the effective amount of the data to be

communicated from the vehicle to the other participating entities such as cloud, other vehicles, pedestrians, etc. With autonomous vehicles having significant usage in the logistics, the proposal also explores the development of multi-vehicle platooning techniques where multiple autonomous vehicles coordinate each other to perform the deliveries from a source to a destination.

The developed water surface vehicles can be used for various applications such as surveillance, disaster management, and reconnaissance missions and will have potential defense applications. Also, these can be utilized for natural resources exploration such as oil and gas, and to conduct hydrographic, oceanographic and environmental surveys over the oceanic surfaces.

With the evolution of multiple researchers, developers and manufacturers of the autonomous vehicles, many of the architectures developed are non-interoperable and hence, they are significantly limiting the adoption of these technologies. Considering the huge cost involved in the developed end system, the more inter-operability of the individual components in building the system will directly improve the usage of the autonomous navigation technologies while also improving the opportunities and applications. Hence, in this proposal, one of the important goals is to develop a standardized and optimized architecture for the development of autonomous vehicles (aerial, ground and water surface) which can be adopted by various stake holders internationally and can be used for various applications like intelligent transportation, surveillance, reconnaissance, environment monitoring, infrastructure monitoring, etc.

Finally, the establishment of a living lab and testbed at IIT Hyderabad for the development and real-time testing of autonomous vehicles (both aerial and terrestrial), autonomous navigation frameworks and data acquisition systems. Specifically, the context of Indian roads and traffic conditions will be considered whilst building these facilities thus benefiting Indian markets and policy making. Several infrastructural aspects such as various road types, simulation tools (SIM, MIL, HIL, and VIL), networking infrastructure for real-time data communication from the vehicles, command control centres, air space management, intruder detection facility, urban traffic management facility, hangars for UAVs, vehicle integration facilities, computational resources, etc. are being considered to be integrated into this living lab and testbed. This testbed is envisaged to be the destination for all the manufacturers, researchers, institutions for testing their developed technologies in realistic environments across the globe.

2.2 Agriculture

Agriculture plays a key role in deciding the economy of India. Also, in the recent times, we have witnessed the struggling framers plight considering the unpredictable yield due to the changing climatic conditions. Agricultural scientists are continuously working on the development of advanced genotyped crops which can offer higher yield and are better resistant to the current climatic and disease conditions. The genotyping of a crop is a word used to describe the genetic make - up of the crop under interest. In general, a crop developed with optimal genotype and when cultivated under optimal agronomic inputs will offer the maximum yield. The genotyping procedure has been a daunting task for agricultural scientists due to a lot of manual intervention involved. Usually, in the process of genotyping analysis, a crop with a specific genotype is cultivated and performance of the cultivated crop genotype is measured in terms of plant traits such as plant height, flowering count, canopy coverage, disease resistance, stress analysis, etc. This process of analysing the quality of a specific genotype is usually referred to as crop phenotyping. Traditionally, these parameters are measured manually, and with the growth of technology, now the research communities are aggressively working towards automation of the phenotyping procedure thereby reducing the time to development for better crop varieties. Also, the agricultural industry must try to use available resources to the maximum extent in order to cope with the population growth. In such scenarios Precision Agriculture (PA) can play a significant role in reaching this goal. This proposal considers the development of the tools and methodologies to enable the cost-effective, high throughput and standardized phenotyping services to assist crop-improvement programs using autonomous UAVs and autonomous robots. These vehicles will be capable of equipping with various sensors such as RGB, Multispectral, Hyperspectral, Thermal, LIDAR, etc. for accelerating the data collection in a standardized way. Many a times the soil nutrient profile gives immense information pertaining to the yield of the crop and optimizing the nutrients presence in the farm is one of the important practices to be adhered for improving the productivity. Hence, we plan to develop a UAV based soil nutrient analysis system which leads to eradicating the need for traditional ground deployments and maintenance thereof in the future.

Also, one another challenge which reduces the crop yield is the presence of disease and pests. The loss can be reduced significantly if these are identified at a very early stage. In many cases, by the time farmer identifies these, the damage will have been done. Hence, in this proposal, we aim at developing a UAV based system which captures the imaging data from the field and with the use of state-of-the-art AI/ML techniques will predict the presence of diseases or pests at an early stage thus minimizing the impact on the crop yield. Finally, the usages of the UAVs and autonomous robots in the monitoring of livestock feed will also be explored in collaboration with agricultural scientists.

3. Problems to Be Addressed

3.1 Comprehensive Analysis

The detailed comprehensive analysis of two verticals such as Autonomous Transport Systems (ATS) and Agriculture are illustrated in Fig. 5. The proposed technological developments and targeted applications are mentioned as follows:

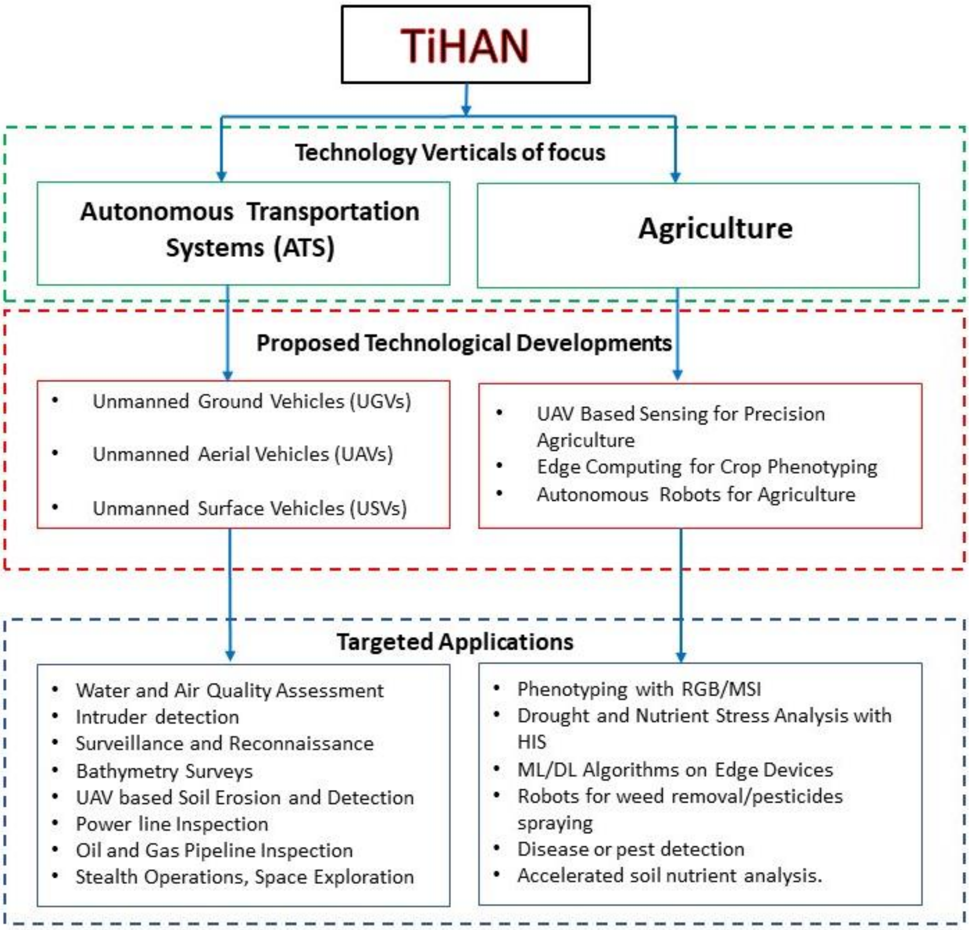


Figure 5: Brief description of NMICPS TiHAN technology verticals

3.1.1 Intelligent and Autonomous Transport Systems

3.1.1.1 Unmanned Ground Vehicles (UGVs):

Autonomous vehicles, which are inherently different from human-operated vehicles, have certain unique potential factors to consider, including proper operation, reliability of vehicle-related services, cost of the technology, etc. AV technology is heralded by various positive and negative effects on several sectors. The NHTSA has reported that driver errors are the number one cause of 90 percent of road accidents (NHTSA, 2008). More than 40 percent of fatal accidents have other causes, such as alcohol, distraction, drug use, and fatigue, other than driver inattention, distraction, or speeding. While the non-AV driver can reduce the risk of accidents due to driver error, AV performance challenges cannot currently be ignored or completely eliminated in a safe environment. Designing a system for AV with the ability to recognize objects on the road is essential. Various objects with variable activity detection make the AV sensor complex with advanced artificial intelligence strategies. However, AVs, often referred to as "crash-free cars," would prove to be safer in the future with the next advanced sensor installation.

It is also assumed that in addition to the expected benefits, autonomous vehicles also have complex negative external effects. Although autonomous vehicles play an important role in ensuring the safety of transportation systems, they would also face safety challenges. in its infancy with our existing technological capabilities. In the event of a disaster or the failure of a single AV component, the entire vehicle network can be disrupted. In other cases, if the on-board computer system executes an incorrect command, traffic safety and the lives of the passengers would be endangered. The data would influence the location of the AV and could lead to traffic disruptions or the risk of accidents. In addition to technological problems, there are also economic obstacles as major obstacles to the spread of autonomous vehicles. High manufacturing and operating costs could hinder mass production and would not be consumer friendly. Other challenges related to AV technology include passenger privacy and safety concerns, insurance regulations, licensing functions, cybersecurity, and legal and liability issues, as well as piracy and ethical issues. The table below shows the benefits and challenges of introducing automated vehicles in India.

Camera, Lidar and Radar are mainly used in autonomous vehicles. Each sensor has their own advantages and disadvantages. The perception sensors like cameras, LiDAR or radar have their own advantages and drawbacks in different environment scenarios. Camera gives the rich color and visual information but it lacks in providing the depth information. LiDAR gives the depth information of objects but it is very sparse and does not have the color information. Radar is not affected by illumination and has a high range. Radar uses radio frequency waves, so it has a lower resolution as compared to LiDAR. Lidar is used for high level accuracy of autonomous vehicles with medium range. But both lidar and camera are affected by bad weather. While Radar has a higher range. It also works in bad weather conditions as it emits radio waves which can penetrate in rain and fog. But Lidar has the highest accuracy as compared to the counterparts in price of high cost. So, we need a vehicle consisting of Lidar, Radar and Camera for all weather conditions. Sensor fusion is one of the key enabling technologies for autonomous vehicles. Raw data from various sensors are fused for the environment perception. Also, we can do late fusion in which results from different sensors are matched with an intersection of union (IOU) method.

For autonomous vehicles latency in the sensor responses should be reduced as much as possible. Sensors should be well calibrated and faster algorithms should be implemented to avoid this problem in order to use it for real time application for autonomous vehicles. Lidar sensor works mainly at 5 to 15Hz, camera should not work at very low or very high frame rate. If the frame rate is too high, it gives less time to detect the obstacle. So, the frame rate of the camera should be in between 20 to 30 fps. Computational complexity of algorithms should be low for faster implementation and planning. High computation devices or platforms can be used to reduce the latency.

Position errors increase rapidly when the terrain obscures the sky, preventing GPS receivers from receiving signals from a sufficient number of satellites. This is a real concern in the heart of cities, where tall buildings form "urban canyons" where GPS capabilities are severely limited. A suitable sensor configuration for a flat environment may not be suitable for steep hills that require the sensors to point up or down. Different terrains may require different sensor configurations that may not be easily changed. Adjustable brackets to accommodate this problem add complexity and cost.

Our research on off-road autonomy is not only concerned with the self-driving car on the autobahn or in extreme off-road situations. It's about helping both the driven car and the autonomous car to navigate safely through any terrain and any driving situation future autonomous car. Because the sensors are always active and able to create a complete picture of the environment around the vehicle, this advanced detection ultimately provides the high level of artificial intelligence the car needs to think for itself and plan the route on any surface.

The ethics of independent motors play a key role.
These include problems pertaining to the data shared, legal and liability aspects. As part of this research, we focus on identifying these aspects which helps in better policy making.

- Responsibility for self-driving inflicted accidents: From a legal point of view, an important question is who would hold responsibility for self-driving inflicted accidents. Would it be the responsibility of the driver, car manufacturer, or the engineer who developed the software? We aim to do thorough research on such legality and come up with a set of guidelines that can help in policymaking.
- Dilemma: Another important ethical issue is how self-driving vehicles behave in case of failure. For example, let us consider a situation of failure in which five pedestrians are crossing a road and there are two passengers sitting inside the car. In such a scenario, there is a dilemma: whose life should be saved, passengers or pedestrians? How is our AV going to handle such a situation? So, in this context we aim to develop generic guidelines to ensure human death is minimized and autonomous vehicles shouldn't discriminate between individuals based on age, gender, or any factor. Also, Human lives should also always be given priority over animals or property. We also want to come up with policies based on extensive surveys to handle such situations.

3.1.1.2 Unmanned Aerial Vehicles (UAVs):

TiHAN plans to work on different categories of e-VTOLS/drones including Nano, Micro, Small, Medium and Large catering to different applications. Some of the envisaged activities include the following:

In Nano/Micro category drones, Bio-Inspired drones like Quad-wing UAV (Dragon fly based) and Flapping Wing Micro Aerial Vehicles (Aerial Birds based), Nano drone swarms, which are used for various applications including Defense Applications: Reconnaissance, stealth operations etc., Space Exploration: Insect based UAVs are more suitable for exploration of Mars, Jupiter and Titan planets that have low gravity atmospheres, etc.

In Small category drones, TiHAN is focusing on technology development for integration of high end sensors like Hyperspectral cameras, Multi-spectral cameras, Lidars, thermal imagers, etc. on to UAVs which are useful for applications like agriculture, land surveillance, healthcare, etc.

In Medium/Large category drones, TiHAN is focusing on developing solutions for next generation urban air mobility – air cargos, air taxis, air metros, air ambulances etc. As a means of solving traffic congestion in the downtown of large city, the interest in urban air mobility (UAM) using electric vertical take-off landing personal aerial vehicle (eVTOL PAV) is increasing.

Urban Air Mobility (UAM): By efficiently utilizing the three-dimensional airspace, eVTOL aircraft can reduce traffic congestion on the ground, increasing worldwide. While flying taxis were envisioned as a means of transportation in the current technological breakthroughs, predictions indicate that they will become a reality in the next few decades. Urban Air Mobility (or UAM) is a current concept that aims to provide an economical alternative to ground transportation in congested urban areas. The concept of urban air mobility with eVTOL vehicles and their vertiports is shown in Fig. 6. Although UAM has several advantages (cost savings and increased transportation capacity), it also has several problems surmounted to ensure safe and efficient operations. UAMs have been in operation since the 1940s, using helipads to transport people but were discontinued after a series of tragic incidents. Current aviation technology has matured enough to conduct on-demand and planned operations employing quiet and efficient crewed or uncrewed vehicles. Consumer demand has been increasing in many cities worldwide to develop an air taxi system in the urban ecosystem. According to the market research, the USA's airport shuttle and air taxi sectors alone have a market worth of $500 billion. Recent technological advancements enabled the construction and flight testing of various eVTOL aircraft designs. Over a dozen companies, such as Jobby Aviation, EHang Airbus A3, Volocopter, are working hard to make VTOLs a reality. Despite their design differences, they all use a distributed electric propulsion (DEP) system, improving power-to-weight, efficiency, dependability, and operational flexibility in eVTOLs compared to conventional helicopters rotors. Although helicopters are capable of VTOL operations, the noise they produce has prompted communities to take legal action against their use in UAM. In comparison, DEP-powered eVTOLs have a higher downstream velocity, allowing for a faster vertical descent without approaching a vortex ring state. When paired with fuel management errors, engine failure contributes to 18% of general aviation accidents, which can be minimized by eVTOL systems. eVTOLs are divided into three categories by the Vertical Flight Society: wingless, lift + cruise, and vectored thrust. The E-Hang 216 eVTOL is an upgraded and altered version of the ordinary multi-rotor vehicle. It is one of the vehicles effective in a hover but has a restricted range and velocity, making them appropriate for short-distance travel. Wing-borne lift is required when the desired mission is of more extended range, such as in both lift + cruise and vectored thrust categories. Lift + cruise eVTOL uses two propulsion systems: one for vertical motion and another for wing-borne cruising. For example, the Kitty Hawk Cora takes off vertically with twelve propellers and cruises with one pusher propeller. Though the propulsion systems in the lift + cruise configuration can be customized for a specific flight segment, they contribute to unwanted weight and drag to the eVTOL when they are not required. Using the same thrust and cruise mechanism, eVTOLs with vectored propulsion aim to avoid this problem, but their efficiency decreases in each phase. Vectored thrust eVTOLs tilt the propulsion systems, thereby rotating the thrust vector during the transitional period. For example, the Lilium jet tilts its 36 electric ducted fans to an angle to enable hovering and cruising. Other UAM airspace integration challenges, such as safety and efficiency, must be negotiated in addition to these UAM vehicle-related operations. Safety involves the advancement of technological procedures to ensure isolation from terrain, urban barriers, and other aircraft, for example.

Furthermore, methodologies for sequencing, scheduling, and spacing UAM aircraft at constrained resources, such as take-off and landing locations (e.g., vertiports), are crucial for proper operations. UAM vehicles and systems must be interoperable with UAM vehicles and networks and other existing aviation entities to eliminate fundamental safety and reliability limitations of aerospace integration. The proposed UAM based PAV at TiHAN IIT Hyderabad is shown in Fig. 7.

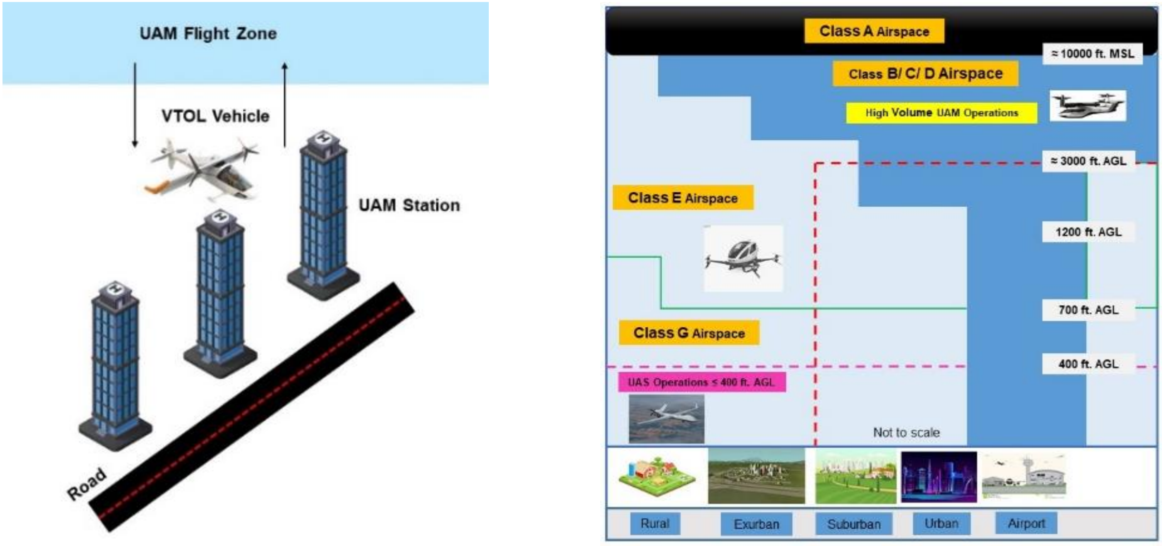


Figure 6: (a) UAM Transportation (b) UAM Airspace Requirements

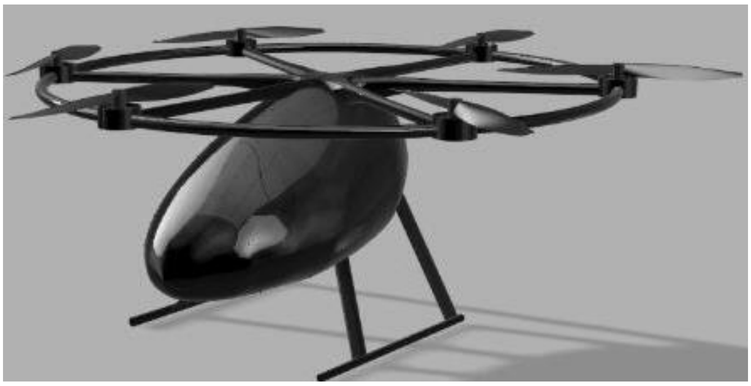


Figure 7: Proposed UAM Based PAV

Bioinspired drones for stealth and space exploration programs:

The usage and development of Unmanned Aerial Vehicles (UAVs) have increased rapidly in agriculture, health care, and the military. Based on the weight, MAVs are classified as Nano, Micro, Small, Medium, and Large Aerial Vehicles. More precisely, Nano, Micro, and small UAVs are widely used for the defense applications such as Intelligence, Surveillance, and Reconnaissance. Micro Aerial Vehicles (MAVs), which come under a weight less than or equal to 2kg, are preferable for Surveillance applications. Due to the lightweight and flapping effect, the autonomous flight of MAVs is a significant challenge in robotics. An autonomous MAV includes independent operations like take-off, cruising, and landing. Among all these operations, landing is the most crucial one. During the landing, maintaining the constant speed and glide path is a challenging task for a MAV. Also, it has to predict the exact point of landing within a less amount of time. An autonomous Bio-inspired flapping wing MAV is designed and developed for space, search and rescue, stealth operations. This MAV consists of two flapping wings with a supporting chassis subjected to sustain hovering, maneuverability, and more efficient

forwarding flight shown in Fig. 8(a). Avian bird is considered as the inspiration for the designed model. In this paper, we proposed a bio-inspired MAV using a Pixhawk flight controller for autonomous navigation and conducted preliminary experiments on the prototype MAV. The overall expected outcome of the current effort is to generate a simplified independent Bio-Inspired functioning MAV model with an efficient mechanical and electrical system. The bioinspired MAV with quad wing propulsion is shown in Fig. 8(b).

Figure 8: (a) Bioinspired MAV with Autonomous Navigation (b) Dragonfly based MAV for space exploration

Intelligent drones and Drone Swarms:

In sectors such as film and entertainment, security and emergency response, delivery, defense, inspection, and mapping, the drone platform offers various technologies to support evolving applications and new use cases. We design and develop UAVs for autonomous collision avoidance and navigation in an unmapped, GPS-denied environment with unknown obstacles. This custom-built UAV consists of the hardware platform equipped with an onboard computer, pre-calibrated stereo and tracking sensors, and a high-resolution FPV image sensor (Fig. 9a). The MAV navigates intelligently in unfamiliar GPS-denied environments using a fully assembled and calibrated VOXL flight controller kit using Visual Inertial Odometry (VIO). The autonomous drone swarms are shown in Fig. 9b and Fig. 9c.

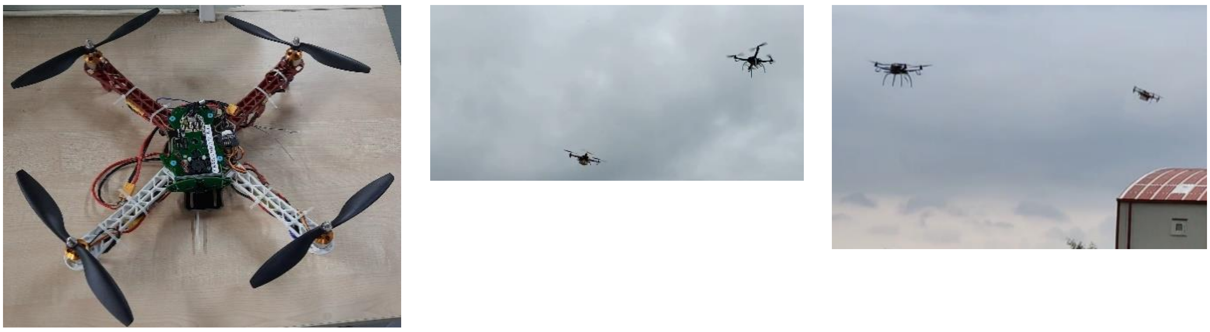


Figure 9: (a) Navigation with Obstacle Avoidance (b) Drone swarms in path following mode (c) Drone swarms in loitering mode

3.1.1.3 Unmanned Surface Vehicles (USVs):

The high levels of safety and efficiency that autonomous ships can achieve are considered to have the ability to give solutions for problems in the maritime industry, such as preventing marine accidents and improving the work environment. From the first part of the 2020s, autonomous ships are expected to be used as coastal vessels in several regions across the world. Fully unmanned autonomous ships are predicted to be accomplished in the future when ships become outfitted with increasingly complex automation functions, beginning with ships employing IoT. The proposed USVs at TiHAN is shown in Fig. 10.

Fig. 10 Autonomous Surface Ships (ship-technology.com)

3.1.2 Agriculture

The quality, , and security of food is a global challenge that needs to be addressed in the view of a growing population. The climate changes like a decrease in rainfall and increase in heat stress, pose challenges to the agriculture sector. On the other hand, there is a reduction in agricultural land due to industrialization and urbanization. Agriculture being the backbone of the Indian economy has witnessed significant advancement over the years, but still is in a nascent stage in terms of technology adoption. As part of the crop improvement program, the agricultural scientists from both the developed and developing nations are increasingly focusing on creating new breeds of crops that are stress-tolerant, disease-resistant, and also provide high yields with optimized inputs. However, the major bottleneck in this process is the assessment of thousands of genetic lines under field conditions called plant quantity phenotyping and mostly done visually. The traditional techniques that have been in use till now for crop improvement are manual, destructive, time-consuming, laborious, faulty, and also require expertise. The advancements in digitization such as sensors, the internet of things, remote sensing can accelerate the crop improvement programs like crop phenotyping, optimizing inputs (water, fertilizer, herbicides) while minimizing environmental impacts. The Unmanned Aerial Vehicle (UAV) based remote sensing is emerging quickly in many fields due to many advantages like a wide field of coverages, high spatial and temporal resolutions, low operating costs, etc. UAVs are being used in some of the fields like construction, mining, environmental monitoring, and surveillance, but in agriculture at the beginning stage. In agriculture, many developed countries are already benefiting from remote-sensing imaging techniques for monitoring the health and security of the crop, and UAV-based imaging has proven to have the potential to accelerate and automate crop-phenotyping and agricultural practices. In India, the use of UAVs is at the very beginning stage in agriculture. Also, there are no standardized practices available for different sensor integration, quality data acquisition, and data processing techniques for the use of UAVs for remote sensing of agriculture. In crop-phenotyping, the breeding scientists require to estimate some of the traits such as canopy coverage, plant height,

plant count, 50% flowering time, plant biomass, nutrients analysis (nitrogen, phosphorus, potassium), drought and heat stress analysis, disease and pest analysis, etc. depending on what they are targeting. Finding out the type of imaging sensor suitable for the specific traits is another challenge to be addressed for deriving the optimal benefit. Therefore, the overarching aim of the project is to develop the tools and methodologies to enable the cost-effective high throughput and standardized phenotyping services to assist crop-improvement programs. The scope of the project will include support to integrate efficient UAV-based imaging systems such as RGB, Multispectral, Hyperspectral, Thermal, LiDAR, etc; to develop and validate the standard operating procedures (SOPs) and algorithms for capturing high-quality imaging data; development of novel, low complexity, and cost-effective machine learning/ deep learning (ML/DL) based algorithms for extracting the main agronomic features from the imaging data and to estimate plant phenotypic traits using the images generated by various sensors carried by the suitable unmanned aerial vehicle (UAV); implementation of the ML/DL-based crop trait estimation algorithms on edge computing platforms for real-time applications. These also will involve access to the field trials and the generation of ground truth observations for the traits of interest. In India, the use of drones for agriculture has just begun, nevertheless, being hindered by evolving country regulations and lacking expertise and capacities to handle the required operations. Once these obstacles are crossed, UAVs utilization in agriculture can contribute to achieving the country's goal to improve production, efficiency in the agricultural sector.

3.2 Challenges to be addressed

3.2.1Intelligent and Autonomous Transport Systems

3.2.1.1 Unmanned Ground Vehicles (UGVs)

- **Multi-sensor Integration**: Camera, Lidar, and Radar are mainly used in autonomous vehicles. Each sensor has its own advantages and disadvantages. For autonomous vehicles latency in the sensor, responses should be reduced as much as possible. Sensors should be well-calibrated and faster algorithms should be implemented to avoid this problem in order to use it for real-time application for autonomous vehicles. Lidar sensor works mainly at 5 to 15Hz, the camera should not work at a very low or very high frame rate. If the frame rate is too high, it gives less time to detect the obstacle. So, the frame rate of the camera should be between 20 to 30 fps. The computational complexity of algorithms should be low for faster implementation and planning. High computation devices or platforms can be used to reduce latency.
- **Ethical issue**: Two important ethical issues need to be considered. The first is about, legally who is accountable in case of fatality due to accidents caused by self-driving vehicles. Another important ethical issue is how self-driving vehicles behave in case of failure. So, in this context, it is important that policy be made in a way that saving human life be given topmost priority.
- **Challenging weather in the Indian subcontinent**: In the Indian context fog and rain poses a great challenge for the realization of self-driving vehicles. North India, which is engulfed in thick fog every year in the months of December and January, sees the most number of road accidents. Another challenging weather in India is the rainy season. Rain causes both low visibility and skidding of tires. Considering the challenges faced by drivers due to varied weather conditions in India, it is important to develop a perception system, which should include multiple sensors. Vision sensor cameras that depend upon visibility must be complemented by other sensors like Radar or LiDAR.
- **Lane detection and changing**: India contains a large variety of lane markings (different colors, unclear marking, or no marking). This makes lane detection and changing a difficult problem. Voluminous data must be collected to develop an algorithm for lane detection.

- **Passing through potholes and unmarked speed bumpers safely**: Another difficult task with respect to Indian scenarios is passing safely through bad conditions such as potholes, and unmarked speed bumpers. This is a unique challenge in Indian context.
- **Edge computing**: Developing parallel processing architecture so that the entire pipeline of obstacle detection, avoidance for autonomous navigation can be implemented on edge computing devices is another challenging task. Different sensors generate data at different rates and volumes. Few challenges in this direction are to integrate libraries used for sensor data processing with GPU, use deep learning models trained on India dataset on edge, real time implementation and validation at testbed using suitable edge computing device e.g. NVIDIA Jetson TX2, Intel NUC.

3.2.1.2 Unmanned Aerial Vehicles (UAVs):

- **Nano-vehicle challenges - Bioinspired Micro Aerial Vehicles (MAVs):**

The development of Nano aerial vehicles based on insects or avian birds itself a challenging task. Achieving kinematic similarity between bioinspired flying insects/birds and robots is still an unresolved problem. The design and integration of flight controllers, high end sensors in Nano robots possess huge difficulties in Nano aerial vehicle technology.

- **Drone Swarms with Obstacle Avoidance Features:**

In recent years, swarm intelligence has gained more research importance. Drone swarms and their effective deployment rely heavily on effective communication protocols. A large-scale swarm necessitates a completely dispersed communication system that scales effectively and maximizes "many-to-many" communication.

- **Urban Air Mobility (UAM):**

The major challenges associated with UAM transportation are aircraft requirements, vehicle concepts, range and speed, cruise and hover efficiency, operating and maintenance costs, certification, policies, ground infrastructure (vertiports) and UAM traffic management. The conventional VTOL vehicles based on IC engines had environmental effects in terms of emissions such as SO_x, NO_x, noise pollution and requires large ground based infrastructure etc. This problem will be addressed through eVTOL vehicles in TiHAN at IIT Hyderabad.

- **Connected vehicles in the air:**

This challenge also addresses V2V communications between different eVTOL vehicles and the ground control station in adverse situations like weather, jamming, intruder attacks etc.,

- **Position Accuracy for Navigation:**

Technology to achieve high level of position accuracy for navigation is very important for landing/takeoff also. Geo fencing requirements. BVLOS operations.

- GNSS Vulnerability

3.2.1.3 Unmanned Surface Vehicles (USVs):

If ships reach the level of unmanned control, ships may be controlled and operated independently in the future, without the need for human interaction. The use of new technologies, such as integrated bridge systems, environmental information perception, collision avoidance path planning, cyber-physical systems, track control, internet of things, cloud computing, big data, automation, remote control, satellite and communication, fault diagnosis, and so on, will undoubtedly place new demands or challenges on autonomous ships.

3.2.2 Agriculture

- For analyzing the imaging data, deep learning methods are used which are data-hungry, and require large amount of labelled data. However, in the remote sensing field there is limited availability of labelled data due to tedious and very expensive annotation. Developing ML/DL based techniques which give accurate predictions with limited available labelled data is a challenging task. Few-shot and self-supervised learning-based algorithms will be developed that can solve the problem of limited labelled data availability of remote sensing with UAVs.

- Establishing ground rules before flying UAVs over fields can help in efficient image capturing and hence the image analysis. The quality image acquisition from UAV is challenging as they depend on many technical aspects such as UAV set-up: altitude, speed, overlap; Camera set-up: aperture, shutter speed and environmental parameters (e.g. wind speed, solar radiation). Also, the flight altitude has to be chosen depending on the type of the target crop and crop stage or DAS (Days After Sowing). Hence, there is a need for standard operating procedures (SOPs) for acquiring quality data with UAVs equipped with different imaging sensors (RGB, Multi, Hyperspectral) for different phenotyping applications in agriculture.
- High speed network connectivity is required to upload the huge amount of data generated from UAV based sensing, to utilize the cloud compute platforms, which is generally the greatest challenge in the agricultural fields. Also, due to high processing times, the decisions to be taken gets delayed. Efficient Edge computing architectures and platforms are potential solutions to these problems, but the computation, space and time complexities are the major challenges. Integrating the developed AI/ML algorithms on edge computing devices, where the image quality assessment and crop trait estimation can be done, giving real-time alerts/feedback to the pilot or end-user as and when the data is collected is the need of the agriculture sector.
- Monitoring the agronomic crops in terms of nutrients, diseases, pest attacks, water stress, and overall plant health is very important in successful agriculture. Early detection of nutrient and water-related issues, stress due to diseases and pests in field crops will help in taking measures in advance and improving the health of the crop and hence reducing the yield loses. RGB imaging which can identify only visual symptoms and multispectral imaging with limited spectral information is not suitable for these studies. However, the rich spectral information provided by hyperspectral sensors in hundreds of narrow spectral bands has the potential to precisely study these changes and early detection of stress-related issues. ML/DL based algorithms will be developed to analyse the hyperspectral images of the canopy for early detection abiotic and biotic stress in the crops.

- Livestock animals are an important part of the agriculture-based farming community in India. Grazing has long been the principal source of feed to these domestic animals that have now drastically declined due to changes in land use, land degradation, and population pressure. The challenge for crop improvement teams is now not only to increase the quantity of crop biomass but also to enhance the quality of crop residue. Conventional laboratory analysis cannot efficiently cope with the large set of sample entries from multidimensional crop-improvement programs. Advanced technology like UAV-based phenotyping can boost the multi-dimensional crop improvement for crop residue quantity and quality programs for crop-livestock smallholder farming communities. ML/DL-based algorithms will be developed for the analysis of crop residue yield, stover nitrogen, and stover digestibility of crops using UAV-based hyperspectral and multispectral imaging.

4. Aims and Objectives

The important aim of the TiHAN Hub is the Research and Development of interdisciplinary technologies in the area of “Autonomous Navigation and Data Acquisition systems”, where it importantly focuses on addressing the technical and social challenges such as multi-sensory perception, communications, real-time computing, swarming, stability, payload, security, policies and regulations, hindering the real-time adoption of unmanned autonomous vehicles for both civilian and defense applications.

A first of its kind state-of-the-art **Testbed for Autonomous Navigation (Aerial/Terrestrial)** is planned to be developed at TiHAN IIT Hyderabad. The Facilities includes Proving Grounds, Test tracks, Mechanical integration facilities like Hangers, Ground control stations, Anti drone detection systems, State of the art Simulation tools (SIL, MIL, HIL, VIL), Test tracks/circuits, Road Infra – Smart Poles, Intersections, Environment Emulators like Rainfall Simulators, V2X Communications, Drone Runways & Landing area, Control Test centers. The testbed will comprise of several features including: various road types, scenario emulation tools (for obstacles, environmental conditions, etc.), state of the art networking infrastructure for data acquisition and communication in real-time, air space management centers, urban traffic management facility, intruder detection facility, etc. This testbed will facilitate researchers, industries, institutions to test and utilize the developed autonomous navigation technologies. Also, we sincerely believe this will be an asset of national and International importance leading to collaborative research between academia, R&D labs and industry.

4.1 Intelligent and Autonomous Transportation Systems

The main focus is to develop machine learning techniques for computer vision to help realize safe autonomous navigation for terrestrial and aerial vehicles. We develop algorithms that can adapt quickly to dynamic environments for better and safer decision-making. These will lead to next-generation deep learning models that match up with human decision-making in driving vehicles. The important objectives include:

- Development of standardized architectures for autonomous Unmanned Ground Vehicles (UGVs) and autonomous Unmanned Aerial Vehicles (UAVs) to be used in many applications like intelligent transportation, surveillance, reconnaissance, environment monitoring, infrastructure monitoring, etc.
- Development of UAV with Image and Video Streaming of defense standards.
- Develop a real-time CPS system and standard operating procedures for multi-sensor-based quality and efficient data aggregation with calibration.
- Establish a living lab and testbed at IIT Hyderabad for developing and real-time testing of autonomous vehicles (both aerial and terrestrial), independent navigation frameworks, and data acquisition systems. Specifically, Indian roads and traffic conditions will be considered, thus benefiting Indian markets and policymaking.
- The TiHAN testbed includes UAV Based Ground Command control station (Swarm Intelligence, Intruder detection, Anti-drone detection systems).

- Efficient processing and transmission of the enormous amount of data collected from the multiple sensors.
- For UGVs analyzing and model driver behavior, Indian traffic flow and accidents with optical flow and semantic segmentation.
- Understanding the driver behaviour towards in-vehicle driver assistance system in mixed traffic conditions.
- Connected vehicles (both aerial and terrestrial vehicles) – V2X.
- Prioritizing the road safety applications for connected vehicles in mixed traffic conditions.
- Analysing the driver behaviour in traffic mixed with conventional vehicles and autonomous vehicles using the driver simulator.
- Developing and analysing the microsimulation model for connected vehicle driving scenarios in real-world mixed traffic conditions using VISSIM.
- Enabling System Security in UGV systems to prevent hackers from gaining control of these vehicles.
- Development of real-time autonomous CPS system using UAVs for intruder detection.
- To manage the dynamic traffic volume at the intersection.
- To minimize the emergency response time of emergency vehicle.
- A thorough characterization of the possible security attacks on the ML-based components of an ADAS system. A library of countermeasures against these attacks will be developed, which vary in robustness, performance overhead, power overhead, and cost.
- Development of a lightweight framework for adopting speech technologies for autonomous navigation.
- Automated drone swarming with adaptive network recovery, reformation, intelligent inter-drone swarm coordination, and communication.
- Define performance bounds (both theoretically and experimentally) for intra-swarm and inter-swarm communications using state of the art wireless technologies (both ad-hoc and cellular).
- Development of autonomous robotic systems for farming, healthcare, and social interaction with speech recognition and synthesis.
- Development of algorithms for power line (including poles, cross arms, etc.) detection, 3D modeling of the power lines. Development of algorithms for detecting hotspots, corona discharge, power line strands, power thefts, and lousy conductivity. Include capabilities of sending real-time alarms upon detection of foreign materials like vegetation interference over power lines.
- Develop an end-to-end UAV-based autonomous and scalable water/air quality monitoring system for distributed water bodies.
- Development and deployment of sensor devices capable of monitoring pollutants levels in water bodies.
- Development of water pollution control system which can identify and pick the waste from water body automatically using drone and computer vision techniques.

- Real-time monitoring of the Musi river bed in Hyderabad for algae growth and mosquito-spread.
- Development of standard operating procedures for the utilization of UAVs and ROVs for railway track, gas pipeline, and infrastructure health monitoring applications.
- To develop an Indigenous Autonomous Water Surface Vehicle for Disaster management, Surveillance and Reconnaissance, sample collection for water quality monitoring, dam surveys, Oil and Gas Exploration, Oceanographic Data Collection, Hydrographic, Oceanographic, and Environmental Surveys.
- Study the legal and ethical issues of autonomous vehicles, which aid in policymaking and enact legal frameworks.
- Testing and demonstration of the developed UGV s, UAVs, and the autonomous navigation architecture.
- To develop advanced deep learning models for computer vision and autonomous navigation, capable of modelling uncertainty, which are more robust and ease the model selection process.
- Build a swarm system of UAVs where the UAVs are co-ordinated to each other and detect real-time objects with high accuracy and high speed.
- Evaluate the security performance of the swarm of UAVs while detecting multiple objects.
- Developing an algorithm for drone swarms, mapping and path planning, coordination. The objective is to develop the algorithm and implement it in a simulated environment.
- The constraint of the dynamic channel condition and obstacles should be considered while tracking the object by getting the environment's feedback.
- Development of data acquisition system using multiple sensors including LiDAR, RADAR, Ultrasonic, RGB Cameras, Stereovision.
- Integration of sensors to the computing system (NVIDIA/MABX platforms).
- Development of autonomous navigation frameworks under constrained obstacles (starting with pedestrian, car, and bicycle).
- Integration of the system to the test vehicle.
- Multi-sensory data collection for perception and planning.
- For the passenger drones and identify suitable software and hardware interface for accomplishing the same.
- This will be followed by identifying sensor mounting positions for deployment and integration of subsystems using model-in-loop simulation. Once the sensor models are tested and validated, they can be replaced by absolute sensors for testing using actual hardware connections.
- We are developing a Video Object Segmentation and tracking method for autonomous vehicle environment perception using the current state of art model with some novelty. The system can be used in real-time.
- Improve existing algorithms and come up with new algorithms for the realistic translation of traffic data.

- We are developing and Modelling scheduling and routing of a fleet of autonomous vehicles.
- Development of electrical charging station needed to achieve the above objective.
- Implementing autonomous navigation of micro and Nano aerial vehicles.
- Development of bioinspired Drone Swarm Intelligence for stealth operations.
- Developing UAM based infrastructure at TiHAN testbed.
- Development of eVTOL Passenger Aerial Vehicle (PAV) based Urban Air Mobility (UAM) transportation.

4.2 Agriculture

Due to the adverse climatic conditions, the agriculture sector is becoming unpredictable in yield and crop sustainability. However, agricultural scientists are continuously developing advanced genotyped crops that can offer a higher product and are better resistant to the current climatic and disease conditions. The genotyping of a crop is a word used to describe the genetic make-up of the crop under interest. A crop developed with optimal genotype and cultivated under optimal agronomic inputs will offer the maximum yield. The genotyping procedure has been a daunting task for agricultural

scientists due to the many manual interventions involved. Usually, in the process of genotyping analysis, a crop with a specific genotype is cultivated, and the performance of the cultivated crop genotype is measured in terms of plant traits such as plant height, flowering count, canopy coverage, disease resistance, stress analysis, etc. This process of analyzing the quality of a specific genotype is usually referred to as crop phenotyping. Traditionally, these parameters are measured manually. With the growth of technology, the research communities are aggressively automating the phenotyping procedure, thereby reducing the time to develop better crop varieties. Also, the agricultural industry must try to use available resources to the maximum extent to cope with the population growth. In such scenarios, Precision Agriculture (PA) can play a significant role in reaching this goal. Agriculture is one of the primary livelihoods in India, and we propose to lay our primary focus on the following essential aspects (but not limited to):

- The over-reaching aim of the collaboration includes developing the tools and methodologies to enable cost-effective, high throughput, and standardized phenotyping services to assist crop-improvement programs.
- Utilization of UAVs or drones equipped with various sensors (RGB, Multispectral, Hyperspectral, Thermal, LIDAR, etc.) for accelerating the data collection in a standardized way.
- Development of UAV-based soil nutrient analysis for optimization of the agronomic inputs.
- Deployment of ground sensor networks for acquiring soil parameters and UAVs for autonomous data acquisition from the deployed ground sensor networks.
- Pest and disease detection using hyperspectral images captured from UAVs.
- Drought and nutrient stress analysis using drone-based hyperspectral sensing.

- Development of UAV-based autonomous remote sensing framework to monitor the different growth stages of crop.
- Analysis of different physical traits of plants and estimation of growth stage using the collected aerial images.
- Development of artificial intelligence-based frameworks for predicting phenotypic traits, stress, pest, and disease identification for deciding the best genotype faster and less human intervention.
- Development of an intelligent farmer assistance system which will collect input from farmers, the process using computer vision processing unit, and send expert advice to the farmer regarding crop disease and remedies
- Adapting and optimization of the developed AI-based frameworks for edge computing platforms with minimal latency execution.
- Autonomous robots for weed removal and pesticide spraying etc.,
- Crop residue yield and quality analysis for Stover nitrogen and Stover digestibility using UAV based imaging which is useful for the crop-livestock farming community.

5. Previous Experience in the Proposed Area

5.1 Research Undertaken

5.1.1 Accelerated Crop Phenotyping and Genotyping Using UAVs (in Collaboration with the University of Tokyo, Japan, ICRISAT and Prof. Jayashankar Telangana State Agricultural University PJTSAU)

The genomic study for plants focuses on inventing different breeds of crops which offer high yield while being stress tolerant and disease resistant. Whereas, crop phenotyping aims at quantification of plant quality, development, growth, productivity, sustainability to varied environmental conditions of plants. This helps agricultural scientists in the development of better variety of crop genes. The techniques used for phenotype analysis are the bottleneck in the growth of genomic-study. Typically, this procedure is performed manually and important metrics considered for the analysis include head detection and counting, plant height, biomass estimation, panicle count, and yield estimation, etc. However, this manual procedure requires manpower, is time consuming and also is prone to errors. Also, with the rapidly changing climatic conditions, the faster the phenotyping procedure is, the more advantageous for the agricultural scientists and farmers. In such scenarios, UAVs will significantly aid in addressing the afore described challenges. In this research we importantly focused on utilizing drone based imaging for faster crop phenotyping. For this, a collaboration has been made with ICRISAT, Telangana, India & PJTSAU, Telangana, India.

At ICRISAT, drone mounted with RGB, Multispectral cameras are used to capture images of the field (Fig. 3) to analyze the different traits of plant to improve yield. Cereals (sorghum, millet, etc.), Legumes (mungbean, chickpea, etc.) are mostly studied. Data is collected at LeasyScan platform (Fig. 3) and an experimental field RCW18B (Fig. 11). Leasyscan Platform consists of 8 trenches (A, B, C, D, E, F, G, H) and each trench has 576 sectors and a total of 4800 sectors where each sector is considered as one experimental unit or plot (Fig. 11). Image of sector is shown in Fig. 12. Each experimental unit/sector is one genotype and there are 4 replications for all genotypes present in sectors. Each of these sectors as a plot, in which plants are cultivated in each sector at a density similar to the field (for example 24–32 plants per square meter for chickpea or mung bean or 16 plants per square meter for pearl millet or sorghum).

Figure 11: Experimental field (RCW18B) (left), LeasyScan Platform (right)

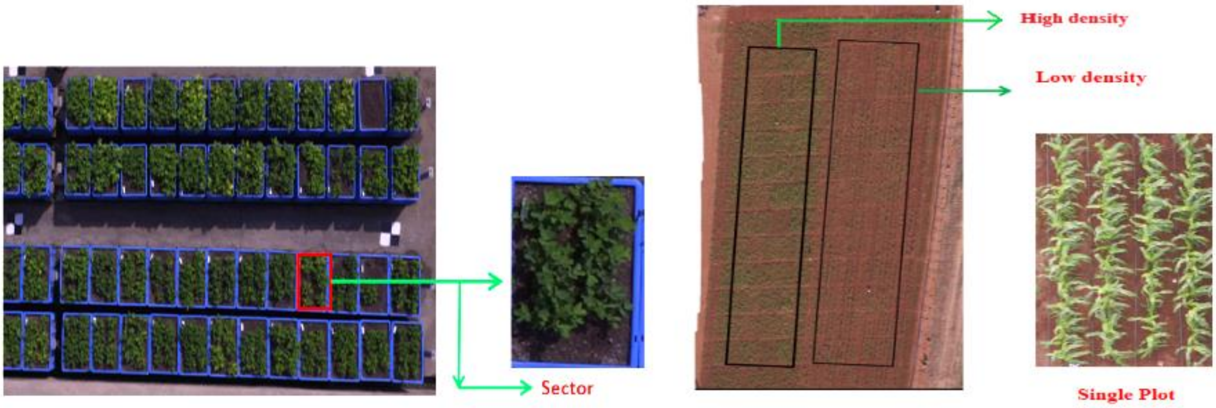


Figure 12: Image of Sector (left), top view of field (RCW18B) (right).

The LeasyScan platform has the capacity to generate rigorous ground truth for various physical traits (LAI, Height, etc.) through the plant eye scanner (Fig. 13) for every two hours which helps in the development of algorithms for crop improvement through UAV images. It has a laser scanner which gives 3D point clouds. Parameters computed with plant eye scanner are Plant Growth, Digital biomass, Plant height, 3D leaf area, Projected leaf area, Leaf inclination, Leaf area index, Leaf Angle, Light penetration depth. This system is helpful to study a variety of genotypes in crops and can help breeders to identify the good genotype.

The cereals, legumes are planted in experimental field RCW18B (Fig. 14) and configured in 48 plots with 16 genotypes, and 3 replications each planted in high (30 plants/m2) and low (15plants/m2) densities. The algorithms developed at the platform can be validated at the experimental field(RCW18B), where the ground truth collected is manually or through sensors.

Figure 13: Planteye Scanner at LeasyScan platform

Figure 14: Deployment of ground based IoT network for monitoring soil parameters

At Professor Jayashankar Telangana State Agriculture University (PJTSAU), Hyderabad, Telangana, ZigBee and LoRa based low power IoT network for monitoring important soil parameters (such as soil moisture, soil temperature, ambient temperature, etc.) has been deployed in the rice and maize fields. A drone mounted with RGB camera is then used to collect images of the field to analyze different physical traits of plant and estimate the growth stage of the crop. The collected images of a single field is then used to create a orthomosaic, and thus developed orthomosaics of different dates are then used for analyzing the maize and paddy crops. We have considered 220 varieties of paddy crops cultivated for the analysis and data acquisition using drone, and then classified them into dense, medium, and sparse based on their canopy coverage and growth rate estimated to select the variety having faster growth rate Fig. 15. The different growth stages, namely, vegetative and reproductive of the maize crop have been estimated using Faster-RCNN based framework. The plots are successfully classified into stressed and unstressed the periodically collected images acquired using UAV.

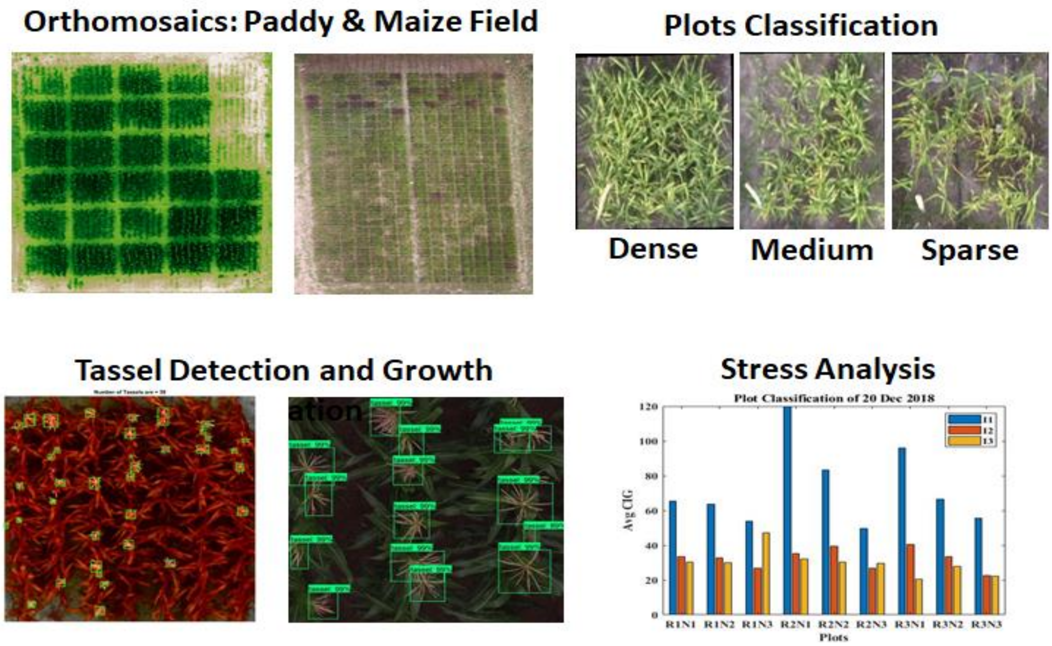


Figure 15: Drone based image acquisition and orthomosaic creation for crop growth classification

Currently, as part of this research work, we are also targeting at developing AI based frameworks for measuring germination rate, prediction of 50% flowering day, prediction of yield to select the best variety among the developed genotypes. A UAV based autonomous remote sensing framework will also be developed to monitor the different growth stages of crop to reduce manual efforts. For maize crop, the optimization of agronomic inputs will be performed by performing stress analysis and monitoring the crop-growth-stages and irrigation condition of the field using UAV based remote sensing.

The goal of this project to develop mechanism and guidelines for reducing CO2 emissions and thereby making a low-society. The project involves acquiring data related to traffic conditions using multiple

5.1.2Multimodal Regional Transport System - Smart Cities for Emerging Countries based on Sensing, Networking, and Big Data Analysis (In collaboration with University of Nihon, Japan and Nagoya Electrics, Japan - JICA funded)

The goal of this project to develop mechanism and guidelines for reducing CO2 emissions and thereby making a low-society. The project involves acquiring data related to traffic conditions using multiple sensors, analyzing these traffic big data, and developing actionable insights and intervention mechanisms for improving traffic scenario and CO2 emissions.

5.1.2.1 LiDAR for Intelligent Transportation

Currently most of the developed and developing countries are importantly focusing on the development of autonomous vehicles. In this on-going research, we importantly focus on the development of object detection and tracking technologies for autonomous navigation of terrestrial vehicles using Light Detection and Ranging (LiDAR) sensors. Object detection and tracking are two important aspects of any autonomous vehicle for avoiding collisions. Also, LiDAR mounted UAVs and terrestrial vehicles have multiple use cases across various application domains. Compared to RGB cameras which provide two dimensional information, LiDAR provides a three dimensional point cloud information of the surroundings up to a vicinity of 100-200m including depth. This aids in determining the object location precisely in Cartesian coordinate system. An example point cloud acquired using a 64 channel LiDAR is shown in Fig. 16.

Figure 16: Example 3D point cloud data collected using 64 channel LiDAR at IIT Hyderabad

- Interfacing/mounting of LiDAR terrestrial vehicles for real-time data acquisition: terrestrial vehicles mounted with LIDAR and other sensors such as RGB and multi-spectral cameras can be of useful assets with multiple applications such as traffic sensing, accurate autonomous navigation, agriculture, land surveying, etc. However, due to environmental disturbances such as speed winds will distort the camera view and hence, mounting the LiDAR which is resilient to these environmental disturbances is a challenging task.
- Development of low-complex LiDAR data acquisition system: A complete real-time data acquisition system using commercially available Ouster OS-1 LiDAR with Nvidia Jetson TX2 for data aggregation is developed (shown in Fig. 17).
- Compression and reduction of LiDAR 3D point cloud data generated for low-latency transmission to the server and faster processing: An Octree based novel compression techniques is proposed for compressing the point cloud information at the sender side. An average of 30% compression is achieved when tested in real-time while achieving a latency of 1.2 ms on average.
- Profiling of bandwidth and latency measurements for acquiring point cloud information in the view of V2X communications: A thorough analysis on the transmission latency and minimum bandwidth requirement is performed using various ad hoc and cellular communication technologies present in the view of upcoming V2X communications.
- Development of AI based frameworks for grid based ground points removal: The in-house developed ground points removal methodology has shown significant performance improvement compared to existing studies. The developed method divides the point cloud information into square grids in the XY plane and utilizes the Z-statistics of points in the grids for the removal.

- Development of object detection and tracking frameworks: An intelligent low-complex Kalman filter based real-time object tracking mechanism is developed. The proposed methodology estimates true value like position, velocity etc. of the object being measured.

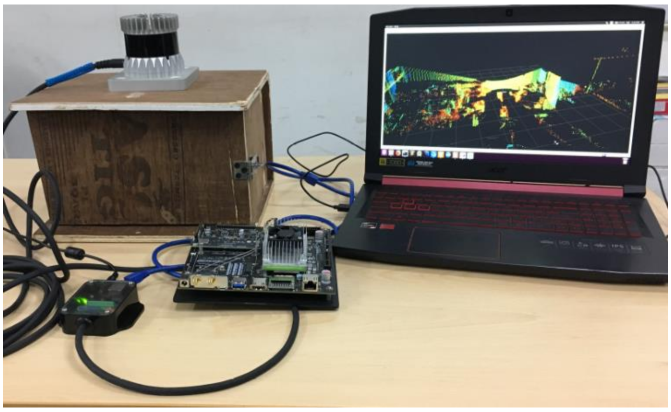


Figure 17: Developed real-time LiDAR acquisition system at IIT Hyderabad

In addition to the above discussed projects, the following projects are being executed/completed.

5.1.3 Autonomous Passenger Drone

IIT Hyderabad is executing a project titled "Design and fabrication of autonomous passenger drone," three institutes (IIT Hyderabad, IIIT Hyderabad, IIIT Sri City) to implement in a collaboration, funded by Meity. IIT Hyderabad is lead institute to implement this project. As part of this project deliverables, two passenger drone prototypes will be built with Autonomous features. The project team has multi-disciplinary knowledge relevant to Mechanical systems, Navigation, IoT, Flight control, vision and AI. Under this project, the sensor integration with drone has been initiated. LiDAR sensor integration to drone is shown Fig. 18.

Figure 18: LiDAR sensor integrated with drone

5.1.4 Connected Vehicles

C-DAC implemented R&D projects titled SAFEDRIVE, and SAVER, funded by CC&BT Group, MeitY in the area of connected vehicles.

SAFEDRIVE - As part of the project, an indigenous Dedicated Short Range Communication (DSRC) System for vehicles comprising of On Board Unit (OBU) and Road Side Unit (RSU) with DSRC Software Stack and demonstrable applications has been developed, deployed and showcased

SAVER - In this project, a proof of concept of DSRC based communication was prototyped to evaluate communication aspects of the wireless radio like latency during high mobility, power consumption, radio range, data rate, etc.

Research in Origin-Destination for Urban Transportation Enhancements (ROUTE) - As part of this area, research was undertaken in Origin – Destination (OD) leading to the development of OD Matrices for City and Urban Transportation Planning using, Ubiquitous Computing Technologies.

Autonomous Transportation Systems (ATS) - C-DAC has been involved in undertaking R&D mission program for the development of various transportation applications such as Vehicle Actuated (VA) Traffic Signal Controller (UTCS), ATCS Compatible Wireless VA Controller (WiTraC). etc., leading to Autonomous Transportation Systems (ATS).

Network and System Security Solutions - Concerning the area of security, the team has developed a number of products like M-Kavach, USB Pratirodh, AppSamVid through R&D initiatives undertaken at C-DAC Hyderabad.

IoT System Development for Smart Cities and Agriculture - The team is also working on a project titled 'Development of systems and solutions using IoT for Smart Cities' through a MeitY funded R&D project. IoT devices like Smart Bin, Smart Water Meters, Smart Water Level Sensing, Smart surveillance etc. are being developed targeting multiple application domains.

In the area of agriculture, the team has developed and prototyped an IoT system for pest and disease forewarning in groundnut and castor crops. The technology has been field prototyped and demonstrated for various clients such as CRIDA, Government of AP, ICAR-IIOR etc. This was implemented through an R&D initiative titled Ubiquitous Agriculture through MeitY funded project on Ubiquitous Computing

Surface Vehicles - Has a significant expertise and working prototypes in the domain of autonomous surface vehicles including sonar system, collision avoidance system, bottom profiler, side scan sonar.

5.2 Projects Implemented/Ongoing

1. **Name:** AI Based High Throughput Phenotyping to Accelerate Crop Improvement Through Crop Images Captured from Unmanned Aerial Vehicle (UAV) with On-Vehicle Sensors.

   Duration: November 2018 to November 2021.

   Funding Agency: Ministry of Electronics and Information Technology (MeitY), Govt. of India.

   Brief Summary: Development of UAV based techniques for accelerating the measurement of plant traits such as plant height, canopy coverage, etc., for faster and accurate crop phenotyping using AI based frameworks.

2. **Name:** On Data Science-based Farming Support System for Sustainable Crop Production under Climatic Change (DSFS).

   Duration: 6 Feb 2018 to 5 Feb 2022.

   Funding Agency: Department of Science and Technology (DST), Govt. of India.

   Brief Summary: Development of precision farming techniques using UAV images and ground sensor networks.

3. **Name:** Multimodal Regional Transport System - Smart Cities for Emerging Countries based on Sensing, Networking, and Big Data Analysis.

   Duration: June 2017 - March 2022.

   Funding agency: 30 Crores (Approx.) by JICA, Japan.

   Brief summary: The goal of this project to develop mechanism and guidelines for reducing CO_2 emissions and thereby making a low-society. The project involves acquiring data related to traffic conditions using multiple sensors, analysing these traffic big data, and developing actionable insights and intervention mechanisms for improving traffic scenario and CO_2 emissions.

4. **Name:** Design and Development of Facial Paralysis Quantitative Analysis Model Using Computer Vision and Machine Learning Tools for Clinical Assessment in India.

   Funding Agency: MEITY, Govt. of India.

5. **Name:** Design and Fabrication of Passenger Drone.

   Duration: 15 March 2019 to 14 March 2022.

   Funding Agency: Ministry of Electronics and Information Technology (MeitY), Govt. of India.

   Brief Summary: Development of passenger drone with autonomous capabilities.

6. **Name:** An Efficient Software Framework for developing Reliable Multi-Threaded Applications for Multi-Core Architectures.

   Funding Agency: IMPRINT - MHRD & Meity.

7. **Name:** Design and Development of Real-Time Transportation Safety Monitoring System for Smart Cities.

   Funding Agency: DST-JSPS, GOI.

8. **Name:** Development of system modelling platform to guide agro-ecosystem specific interventions to enhance post-rainy sorghum production in India.

   Duration: 2018-2020.

   Funding Agency: CGIAR big data initiative.

9. **Name:** Toolbox for sorghum biomass improvement focused on Africa & Asia.

   Duration: 2017-2020.

   Funding Agency: Bill Melinda Gates Foundation.

10. **Name:** SAFEty alert systems using Dedicated Short Range communication for on road VEhicles (SAFEDRIVE).

    Funding Agency: CC&BT Group, Ministry of Electronics & Information Technology (MeitY).

11. **Name:** Safety Alert & Advisory Information system using VEhiculaR Communication (SAVER).

    Funding Agency: CC&BT Group, Ministry of Electronics & Information Technology (MeitY).

12. **Name:** Advanced Research in Ubiquitous Computing (ARUC).

    Funding Agency: C-DAC Core Funding.

13. **Name:** Autonomous Transportation Systems (ATS).

    Funding Agency: MeitY, GoI.

14. **Name:** Characterization of User Datagram protocol based data transfer for bulk data transfer applications in high speed and wireless networks (UDT).

    Funding Agency: MeitY, GoI.

15. **Name:** Design and Development of an Anti-Malware Solution for Web Application and Mobiles.

    Funding Agency: CDAC Core Funding.

16. **Name:** Design and Development of Mobile Device Security Solution.

    Funding Agency: MeitY, GoI.

17. **Name:** Design and Development of Malware Prevention System.

    Funding Agency: MeitY, GoI.

18. **Name:** Design and development of a solution for detecting malware in embedded system.

    Funding Agency: MeitY, GoI.

19. **Name:** Establishment of Distributed Centre of Excellence in Blockchain Technology.

    Funding Agency: MeitY, GoI.

20. **Name:** Design and Development of a solution for Predicting Multistage attacks using Machine Learning.

    Funding Agency: MeitY, GoI.

21. **Name:** Development of Tool(s) for Enabling Binary Program Analysis.

    Funding Agency: MeitY, GoI.

22. **Name:** Design and Development of a Solution for Vulnerability Detection in Embedded Device Firmware.

    Funding Agency: MeitY, GoI.

23. **Name:** Hardening of Android Operating System.

    Funding Agency: MeitY, GoI.

24. **Name:** Design and Development of Systems and Solutions for Smart Cities, using Internet of Things

    Funding Agency: MeitY, GoI

25. **Name:** Establishment of National Level Ubiquitous Computing Research Resource Centres – Ubiquitous Agriculture (u-Agri)

    Funding Agency: MeitY, GoI

26. **Name:** HARITA-PRIYA – WSN based Precision Farming for Groundnut crop in Anantapur, AP

Funding Agency: Govt. of AP

27. **Name:** Development of Castor Gray Mold Disease Forewarning System using IoT

    Funding Agency: ICAR IIOR

28. **Name:** Climate Resilient Chickpea

    Duration: 2014-2019

    Funding Agency: US-AID - Feed the Future Innovation Lab

29. **Name:** Modeling Driver Behaviour Profiles using Naturalistic Driving Data for Road Safety Analysis.

    Duration: 2018 - Ongoing

    Funding Agency: DST, Govt. of India

30. **Name:** TIGRRESS - Transforming India's Green Revolution by Research and Empowerment for Sustainable Food Supplies

    Duration: 2018-2022

    Funding Agency: UK

31. **Name:** Genetic biofortification of carotenoid content of grain legumes for novel market types as high-value fresh vegetables and in processed foods

    Duration: 2018-2021

    Funding Agency: USDA-NIFA-AFRI Foundational program

32. **Name:** Control of Multi-Agent System with Human-intervention

    Duration: 2018-2021

    Funding Agency: SERB

    Brief summary: This project aims at developing control laws for cooperative control of multi-agent systems while one or more of the systems are operated by a Human operator. The agents are typically double-integrator systems which need human intervention for some critical inputs. The human operator provides such input based on visual and haptic feedback. The distributed control laws are being developed for execution of such tasks taking human input into account.

33. **Name:** Big Data Aware High Capacity Wireless Network Architecture Using Caching and Machine Learning

    Duration: Ongoing

    Funding Agency: UKIERI

    Brief summary: The project aims at developing machine learning based algorithms that optimizes cache hit in a cellular network based distributed content network.

34. **Name:** A Unified Broadband and Internet-of Things (loT) Base-station with Energy Efficient Resource Allocation and Caching Capabilities

    Duration: Ongoing

    Funding Agency: SERB IMPRINT 2C

Brief summary: The project aims at developing a unified broadband + IoT BSs with efficient resource allocation capabilities. The developed prototype will be used to test the developed algorithms for resource allocation.

35. **Name:** Synchrophasor Assisted Efficient Ancillary Services in Smart Grid

    Duration: Ongoing

    Funding Agency: SERB SPARC

    Brief summary: The project intends to study the impact of renewables on ancillary services like primary frequency reserve in Smart Grid. The power output from the renewables vary with time, hence reserve available from renewables should be monitored for pricing for the primary frequency reserve. Therefore, the first objective is to estimate the reserve available from renewables. Because of small scale distributed generation, it is difficult to know the amount of load connected to grid. However, total amount of load and load damping constant is needed for predicting system frequency response after any frequency disturbance. Therefore, second objective of this project is to estimate the amount of load connected to grid and load damping constant. Presently, automatic generation control (AGC) scheme measures system frequency and control the frequency deviation by changing the mechanical power input to thermal or hydro generators. Power output from renewables can be controlled faster than conventional renewable energy resources. Therefore, with increased penetration of renewable energy in grid, primary frequency control can be done with renewable energy resources. Third objective of the project is to allocate primary frequency reserve such that in reduces cost and increases power system dynamic security.

36. **Name:** Articulate +

    Duration: Ongoing

    Funding Agency: SERB IMPRINT 2C

37. **Name:** Nasospeech

    Duration: Ongoing

    Funding Agency: DBT

38. **Name:** 2D Layered Materials based Biosensors for Early Diagnosis of Lung Cancer

    Duration: Ongoing

    Funding Agency: SERB

39. **Name:** Development of Smart Sensors Mounted on Under-Canopy Robots for Precision Agriculture

    Duration: 2019 - 2021

    Funding Agency: MHRD

40. **Name:** Development of Reduced Graphene Oxide based Gas Sensors for Efficient Detection of Explosive Vapors

    Duration: 2019 - 2022

    Funding Agency: CSIR

41. **Name:** Design and Development of 4D Printing for Fabrication of Multi-material and Multi-functionality

    Duration: 2019 - 2021

    Funding Agency: SERB-SRG, DST

Brief Summary: 4D Printing is a specific evolution in a 3D printed structure by changing either its shape, property or workability. Modelling is required beforehand for the design of placement of various materials in the structure. 4D printing is a targeted evaluation of the 3D printed structure in terms of shape property and functionality. It is capable of achieving self – assembly, multi functionality and self- repair. It is time dependent, printer- independent and predictable. 3D printed parts has flexibility in geometry, material, cost over traditional manufacturing like thin film coating for soft robotics, actuator, sensors in which materials mixing is limited. Ongoing research work on 4D printing and funded by SERB-DST work.

42. **Name:** IoT-based 3D printed time lapse smart microscope for embryo monitoring in IVF clinics

    Duration: 24 December 2018 to 24 December 2021.

    Funding Agency: Science and Engineering Research Board (SERB), Department of Science and Technology (DST), IMPRINT, Govt. of India.

    Brief Summary: A real-time embryo growth monitoring system development with IoT technologies integrated for use in In-vitro fertilization.

43. **Name:** 5G Testbed

    Duration: April 2018 to April 2021

    Funding Agency: Department of Telecommunications (DOT), Govt. of India.

    Brief Summary: Development and prototype of 5G testbed for performance analysis and enhancement.

44. **Name:** Advanced Vision Technologies for Road Mobility and Safety

    Duration: May 2019 - May 2022

    Funding Agency: SERB/DST IMPRINT

45. **Name:** Vision and Learning with Limited-to-No Supervision: Applications to Autonomous Navigation and Beyond

    Duration: 2018 - 2019

    Funding Agency: Intel Corporation

46. **Name:** Towards Next-Generation Deep Learning: Faster, Smaller, and Easier

    Duration: 2018 - 2021

    Funding Agency: DST ICPS Data Science Program

47. **Name:** Detection and Prediction of Anomalous Aerial Vehicle Behaviour using Explainable Artificial Intelligence

    Duration: 2018 - 2021

    Funding Agency: MHRD Uchhatar Avishkar Yojana (UAY) Program (co-supported by Honeywell)

48. **Name:** Thermal Image Processing and Deep Learning Algorithms for Human Detection

    Duration: 2019 - 2020

    Funding Agency: Detection, Defense Research and Development Organization (DRDO), Govt of India (CARS project)

49. **Name:** Understanding Error Surfaces of Deep Neural Networks

    Duration: 2018 - 2021

Funding Agency: DST MATRICS (Mathematical Research Impact Centric Support) Program

50. **Name:** Thermal Image Processing and Deep Learning Algorithms for Human Detection, Defense Research and Development Organization (DRDO)

    Duration: 2019 - 2020

    Funding Agency: Govt. of India (CARS project)

51. **Name:** Conversion between natural language and structured queries.

    Duration: 2019 - 2020

    Funding Agency: Honeywell

52. **Name:** Machine Learning Models using Alternative Data Sources.

    Duration: 2019 - 2020

    Funding Agency: Accenture Labs

53. **Name:** Center for Healthcare Entrepreneurship

    Duration: 3rd December 2015 - Ongoing.

    Funding Agency: Rajesh Mashruwala and Avinash (Avi Nash LLC)

    Brief Summary: Development of healthcare technologies and IITH incubation for healthcare startups.

54. **Name:** Converged Cloud Communication Technologies

    Duration: 2014 to 2019.

    Funding Agency: Department of Information and Technology (DeiTy), Govt. of India.

    Brief Summary: Technology research for edge, fog and cloud computing for both cellular and ad-hoc networks.

55. **Name:** Building an End-to-End 5G Test-Bed

    Funding Agency: DoT, Govt. of India.

    Brief Summary: Development of 5G Testbed

56. **Name:** CCRAN: Energy Efficiency In Converged Cloud Radio Next Generation Access Network

    Funding Agency: Intel India.

57. **Name:** Network Slice Life-Cycle Management for 5G Mobile Network

    Funding Agency: SPARC, MHRD, India.

58. **Name:** Towards Understanding the Diffusion of Misinformation in Online Social Networks: Application to Vaccination Rumour Detection

    Duration: 2017-2020

    Funding agency: SERB

    Brief summary: Understanding the Diffusion of Misinformation in Online Social Networks

59. **Name:** Next Generation Deep Learning

    Duration: 2019-2022

Funding agency: DST (ICPS)

Brief summary: Developing novel deep learning algorithms for vision and language processing

60. **Name:** Machine Learning for Astrophysical Data Analysis

    Duration: 2019-2022

    Funding agency: DST (ICPS)

    Brief summary: Developing novel machine learning and deep learning algorithms for astrophysics data.

61. **Name:** Machine Learning Models using Alternative Data Sources.

    Duration: Sep 2019 - Aug 2020.

    Funding agency: 17.5 Lakhs by Accenture Labs

    Brief summary: In this project, we consider data from multiple data sources and develop machine learning algorithms to fuse these signals appropriately, specifically for performing prediction tasks in low data scenario.

62. **Name:** Cable-stiffened flexible link manipulator for pick-and-place tasks

    Duration: 3 years

    Funding agency: 23 lakhs, SERB

    Brief summary: A two link cable-stiffened flexible manipulator was built to evaluate its performance against traditional two link rigid and flexible link manipulators for pick-and-place tasks which are common in material handling jobs occurring in industries. The proposed manipulator system was found to have very low inertia and perform at par with rigid link manipulators. It also does not have the typical problems associated with flexible link manipulators like requirement of sophisticated controller to handle undesirable oscillations.

63. **Name:** Development of quadruped robot with flexible body

    Duration: 2 years

    Funding agency: 24 lakhs, DRDO

    Brief summary: A 12 dof quadruped robot was built to demonstrate various gaits of quadruped like crawl and trot. This was built and delivered to Center for Artificial Intelligence and Robotics, DRDO.

64. **Name:** Development of Deep Network Architecture on Legacy Embedded Hardware

    Funding Agency: RCI, DRDO

65. **Name:** Deep Learning for Embedded Computer Vision

    Funding Agency: RCI, DRDO

66. **Name:** Transportation Flow Modeling and Visualization for Disaster Management Applications

    Funding Agency: Advanced Numerical Research and Analysis Group, DRDO

67. **Name:** Mathematical models and morphological analysis based algorithms for image comparison and classification in computer based vision system

    Funding Agency: DST, FRBR

68. **Name:** Prosodically Guided Phonetic Engine for Searching Speech Databases in Indian Languages

Funding Agency: MEITY, Govt. of India

69. **Name:** IoT for Smarter Healthcare

    Duration: March 2013 to Feb 2016.

    Funding Agency: Department of Information and Technology (DeiTy), Govt. of India.

    Brief Summary: Development of ECG wearable chipset which can predict and identify cardiac abnormalities with IoT integration.

70. **Name:** Semantic Analysis of Banking Regulatory Documents

    Duration: Sep 2017 – Mar 2018

    Funding agency: 10.35 Lakhs

    Brief summary: The goal of this project was to understand the semantic interpretations of the contents of large documents or manuals. This understanding will facilitates better localization of search results and better understanding of the topical contents in the document. The algorithms and techniques developed in the project are generic to common across all domains.

71. **Name:** Mobile Sensor Networks Technologies

    Duration: March 2011 to April 2015.

    Funding Agency: KDDI R&D Labs, Japan

    Brief Summary: Development of optimal deployment advisor tool for use in Wireless Sensor Networks. Involved both theoretical and experimental study.

72. **Name:** Cyber Physical Systems

    Duration: 2011 to 2016.

    Funding Agency: Department of Information and Technology (DeiTy), Govt. of India.

    Brief Summary: Development of real-time cyber physical systems to be used in healthcare, and smart homes using heterogeneous technologies.

73. **Name:** Substract Uneasy and Dangerous Scene Related Traffic Accident and Congestion in Asia.

    Duration: Completed

    Funding Agency: Toyota ITC, Japan

74. **Name:** Evaluation of Road Traffic Accident data and Assessment of Potential for A

75. TS V2X Safety Applications in India.

    Duration: Completed

    Funding Agency: Toyota ITC, Japan

76. **Name:** Semantic Analysis of Banking Regulatory Documents

    Duration: Completed

    Funding Agency: Parabole India Pvt. Ltd.

77. **Name:** Low Latency Network Architecture and Protocols for 5G Systems and IoT.

    Duration: Completed

Funding Agency: SERB, Govt. of India

78. **Name:** Ultra-Reliable Low Latency Protocols for 5G

    Duration: Completed

    Funding Agency: STINT, Sweden

79. **Name:** DNS/IPv6 for IoT Security

    Duration: Completed

    Funding Agency: NASSCOM

80. **Name:** Surrogate Safety Measures at Unsignalized Crossings and its Applications in V2X Technology for Asian Mix Traffic.

    Duration: Completed

    Funding Agency: Toyota ITC, Japan

81. **Name:** Level of Service and Level of Safety Analysis for Uncontrolled Road Intersections and Mid-Block Openings using Surrogate Safety Measure

    Duration: Completed

    Funding Agency: Seed Grant-IITH.

82. **Name:** IOT-eHealth

    Duration: Oct 2012 to June 2015.

    Funding Agency: Department of Science and Technology (DST) under IUATC Project, Govt. of India.
    Brief Summary: Development of AI based automated ultrasound diagnosis framework capable of working on edge devices with smaller computational capabilities.

83. **Name:** Pervasive Sensor Environment

    Duration: Sept 2009 to Sept 2012.

    Funding Agency: Department of Science and Technology (DST) under IUATC project, Govt. of India.

    Brief Summary: Development of smart homes, smart cities and industries using CPS technologies.

84. **Name:** Cognitive Radio

    Duration: 2010 to 2013.

    Funding Agency: Department of Information and Technology (DeiTy), Govt. of India.

    Brief Summary: Exploring spectrum sharing methodologies and optimization in the cognitive radio technology.

85. **Name:** Taking Vision to the Skies: Understanding Humans from Unmanned Aerial Vehicles (Drones)

    Funding Agency: IBM Shared University Research Award

86. **Name:** Deep Learning for Visual Recognition in Aerial Images, Defense Research and Development Organization (DRDO)

    Funding Agency: Govt of India (CARS project)

87. **Name:** Automatic Recognition of Hand-drawn Sketches for Learning Environments

Funding Agency: IBM Students for a Smarter Planet Program

88. **Name:** Automatic Recognition of Hand-drawn Sketches for Learning Environments

    Funding Agency: State Govt of Telangana

89. **Name:** Mathematical Foundations of Probabilistic Conformal Prediction and its Applications in Machine Learning

    Funding Agency: EPSRC-DST Indo-UK Initiative in Applied Mathematics (grant for workshop organization)

90. **Name:** e-DRIShTI: Automatic Determination of Student Engagement for Personalized e-Learning

    Funding Agency: IBM Students for a Smarter Planet Program

91. **Name:** Assistive Social Situational Awareness Aids for Individuals with Disabilities

    Funding Agency: US National Science Foundation

92. **Name:** Person-centered Technologies and Practices for Individuals with Disabilities

    Funding Agency: US National Science Foundation

93. **Name:** Commercially Valuable Sorghum Lines with Drought Tolerance and Photoperiod Insensitivity

    Funding Agency: EarthNote, Japan

94. **Name:** Climate Resilient Sorghum

    Funding Agency: Feed the Future Innovation Lab

95. **Name:** Multi-link communication technology

    Funding Agency: KDDI R&D

96. **Name:** Wireless Networks

    Funding Agency: Urumi Systems

97. **Name:** DNS/IPv6 for IoT Security

    Funding Agency: NASSCOM

98. **Name:** Improving Post-Rainy Sorghum Varieties to Meet the Growing Grain and Fodder Demand in India

    Funding Agency: Australia

5.3 Collaborative Initiatives in the Related Area

1. Collaboration with **University of Tokyo, Japan**
   Brief Summary: Accelerating crop phenotyping and genotyping procedures using UAVs.

2. Collaboration with **University of Nihon, Japan, Nagoya Electrics**
   Brief Summary: Multimodal Regional Transport System - Smart Cities for Emerging Countries based on Sensing, Networking, and Big Data Analysis

3. Collaboration with **Ritsumeikan University, Japan**
   Brief Summary: Development of autonomous vehicles ground and aerial vehicles

4. Collaboration with **ICRISAT, Hyderabad**
   Brief Summary: Accelerating crop phenotyping and genotyping procedures using UAVs.

5. Collaboration with **International Institute of Information Technology Sricity**
   Brief Summary: Development of passenger drones

6. Collaboration with **DRDO Labs**
   Brief Summary: Development of Low power IoT systems

7. **Kansas state university – USA**
   Brief Summary: UAV technology for agriculture

8. **CERAAS – Senegal**
   Brief Summary: UAV technology for agriculture

9. **Excellence in Breeding –** global CGIAR platform
   Brief Summary: UAV technology for agriculture

10. Collaboration with **Prof. Jayashankar Telangana Agriculture University, Hyderabad, IIT Bombay, IIIT Hyderabad**
    Brief Summary: Accelerating crop phenotyping and genotyping procedures using UAVs

11. Collaboration with **Terra Drone, Japan** (MoU with IIT Hyderabad)
    Brief Summary: Development of drone based technologies for remote sensing

12. Collaboration with **Skoruz Technologies**
    Brief Summary: Working on commercialization aspects of smart cities technologies developed at IIT Hyderabad

13. Collaboration with **Honeywell**
    Brief Summary: Collaboration in the area of AI and ML for diverse applications

14. Collaboration with **Suzuki Motor Corporation**
    Brief Summary: Collaboration for technology development, establishment of living lab and test facilities

15. Collaboration with AIST Japan
    Brief Summary: Collaboration in the area of AI and ML for diverse applications

16. Q-Labs
    Brief Summary: Collaborations in the area of Data computations.

6. Technology/Product Development

6.1 Testbed Facility at NMICPS TiHAN IIT Hyderabad

The planned testbed facility (Ref: Layout) is developed which supports the testing of autonomous navigation technologies for ground and aerial vehicles or systems. Envisaged testbed/living labs to be constructed in the campus of IIT Hyderabad, the following subsections describe the important features of this testbed.

a) Test Tracks Infrastructure for Autonomous Vehicles:

Importantly the layout comprises of various roadway types that involve Urban roads, multilane highways, collector streets, local streets, cement roads, curved sections, rough unpaved and unmarked village roads, open roads, S-course and crank course, etc. The basic objective is to investigate how the connected and unmanned vehicles react and adapt to different roadway types in terms of maintaining safe speeds, performing smooth navigation, etc. In addition to the basic roadway layout, as described above, several additional features such as signalized and signalized intersections, roundabouts, bus stops, bus bays, pedestrian crossing facilities, speed management measures (such as, speed humps and rumble strips), parking zones, etc., will also be available for emulating real environmental scenarios.

b) Supporting Infrastructure for Autonomous Ground Vehicle Testing:

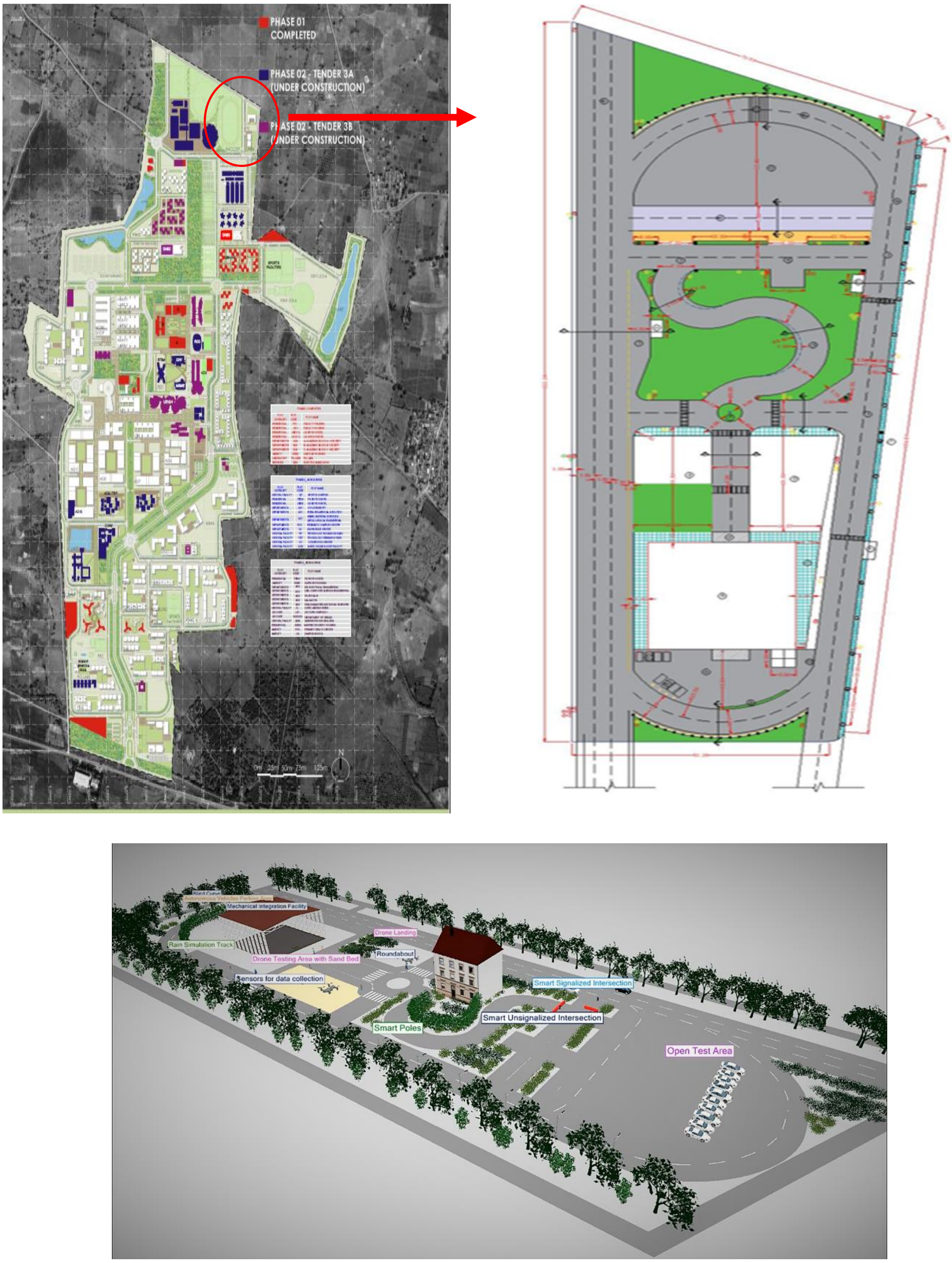
The testbed provides various facilities including: Signalized/Signalized Intersections, Multilane Facility, Fog/Rainfall Emulation on Roads, Traffic Signals, Pedestrians and Bicycles Emulations using Dummy Objects (can be assembled immediately after disassembly), Emulations of various vehicles (cars, motorcycles, heavy vehicles) using dummy objects, Scourse roadway, Parking Zones (Parallel, Perpendicular, and Angular), Krebs, Traffic Signs, Mechanical Integration Facility for vehicle and system engineering, computing facilities, Wireless and Wired Networking/Communications Infrastructure for communication across vehicles, infrastructure, road-side units and computing facility, Smart Poles with networking support, Toll-gates, Barriers (cones or boom barriers), etc.

c) Proposed facilities for Autonomous Drones and UAVs

The supporting facilities in the testbed for testing the aerial vehicles include: A multilane drone runway; A controlled drone test center; A drone landing area; Hangar and Mechanical Integration Facility for Drone Engineering. A command control station for air space management.

d)Other Infrastructure

In addition to the above infrastructure, the testbed supports common facilities such as Control Room for monitoring and controlling the testbed environment remotely, Research Space for conducting research in the area of autonomous navigation and data acquisition systems (comprises of workstations and sitting spaces, Computing Facility for hosting servers and GPUs, Networking room comprising of backbone networks for wired and wireless connectivity within the testbed facility.



Layout: Testbed Facility at TiHAN IIT Hyderabad.

6.2 Intelligent and Autonomous Transportation Systems

In recent times, autonomous vehicles such as UGV (Unmanned Ground Vehicle), UAVs (unmanned aerial vehicles), USV (Unmanned Surface Vehicle), etc., are gaining a lot of attractions. An overall picture of autonomous vehicles/UAVS based smart transportation system is shown in Fig. 19. For autonomous navigation, understanding the surroundings is the most crucial part. Initially, researchers have tried to integrate RGB cameras for autonomous navigation. But due to lack of depth information, using only RGB cameras is not enough to achieve fully autonomous navigation. In this regard, LiDAR (Light detection and ranging sensor) becomes very popular due to its ability to give depth information. LiDAR consists of multiple laser transmitter-receiver pair (known as channels). It creates a 3D representation of the surrounding by emitting and receiving laser pulses (~903nm). Based on the time difference between received and transmitted laser lights and speed of the laser light, it creates a 3-D representation of objects. This 3D representation, known as point cloud, contains thousands of points in the space, each having X, Y and Z coordinates with additional information such as distance, intensity, etc. The point cloud data is one of the most exhaustive sensor information that can be used for object detection and avoidance. Along with LiDAR, various sensors like stereo vision cameras, single-channel LiDAR, Radar, INS/GNSS are also used to complement LiDAR. A stereo vision camera is a type of camera with two or more image sensors. This allows the camera to simulate human binocular vision and therefore gives it the ability to perceive depth. Using image and depth information from stereo vision camera and also 3D data from LiDAR, a more detailed representation of the scene can be constructed. Along with these sensors, various navigation devices like INS/GNSS are also required for the global positioning of the objects. INS is a navigation device for measuring various physical parameters like position, linear velocity, angular velocity, linear acceleration, angular acceleration, etc. It consists of a global navigation satellite system (GNSS) receiver with various sensors like accelerometer, gyroscope, magnetometer, barometer, etc. GNSS is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. Common GNSS Systems are GPS, GLONASS, Galileo, Beidou and other regional systems. GNSS gives more accurate positioning by receiving signals from more number of satellites. The proposed problem description about three types of autonomous vehicles (UGV, UAV, and USV) are presented in the following subsections.

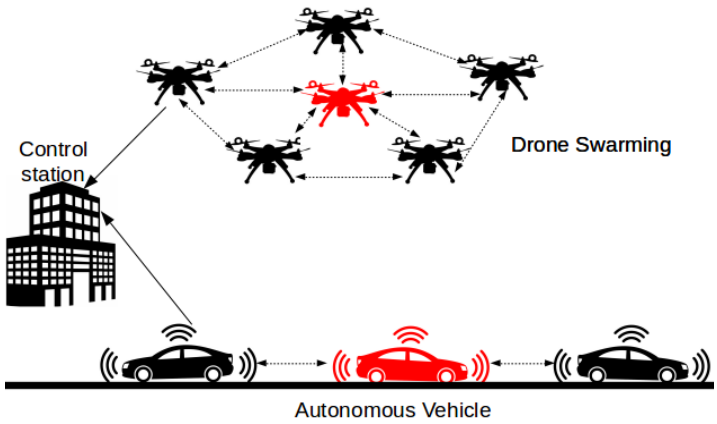


Figure 19: Unmanned ground vehicles/UAVS based smart transportation system

6.2.1 Unmanned Ground Vehicle (UGV)

An Unmanned Ground Vehicle (UGV) is a class of vehicle that operates in contact with the ground, without the direct presence of a human, on-board (Fig. 20). These are gaining popularity in applications where the environment of operation is hostile, inconvenient or dangerous to human life. A number of application domains like military operations and reconnaissance, industries for material movement, agriculture, and construction are incorporating these vehicles to improve performance, avoiding risk to human life.

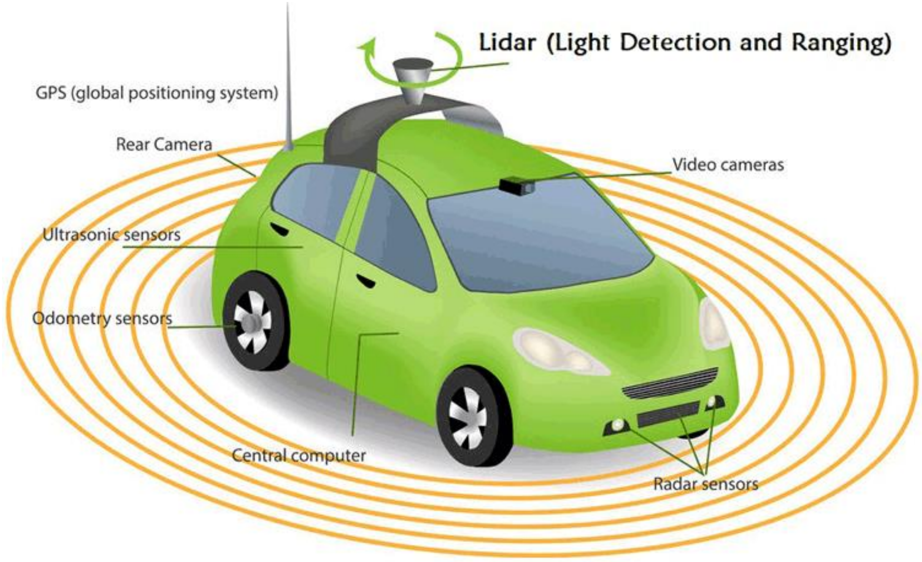


Figure 20: UGV Components

(Image Source: https://circuitdigest.com/article/what-is-lidar-and-how-does-lidar-works)

These vehicles are generally found to be operational in three architectures:

➢ ***Autonomous UGVs***: Self operated without any human intervention using sensors, navigation systems and computer algorithms to deal with real-time and dynamic situations in the vehicle circuit. The main challenge of these vehicles is implementing a fully autonomous computing and processing system, capable of making dynamic navigation decisions based on the environment of operation, in real-time, during vehicle transit.

➢ ***Semi-Autonomous UGVs***: Driver controlled vehicle with few aspects supporting auto-pilot mode and driver assist features. Drive-by-wire is an upcoming technology break-through that is piloted in research prototypes, globally. In this, the mechanical and hydraulic fixtures of the vehicle steering mechanism is replaced with sensors and a computer that provides sensitive and fast steering to the vehicle. Automated braking assistance is also provided in some vehicles, based on sensor based electronic computer that provides quick reaction time to the driver in trying situations.

➢ ***Remote Controlled/Tele-operated UGV***: Visual and sensor data is wirelessly transmitted from the vehicle to a remote operator who steers and controls the movement of the vehicle using commands. These are especially important in applications where the driver's life is at risk like military application surveillance and remote location surveys. Communication to the device forms a non-negotiable sub component in this type of architecture requiring reliable, low latency and high data communication channels.

Based on its application domain, UGVs will generally include the following system components:

➢ **Sensors and Data Acquisition Interface** – For a UGV, sensors form the data generators which lead to better decision making. A number of sensors can be integrated into a UGV platform for applications like detecting obstacles, identifying the location, speed, terrain, inclination, and other aspects required for vehicle transit. Sensors require a number of algorithms to be developed to provide predictive analysis and real time and dynamic decision support. Multi-sensor fusion will be required to derive collective value from all sensors and serve as a means to minimize false positives in the system.

- **Navigation and Control Interface** – This component is the decision engine which uses the sensor data to derive navigation and control information that can be used to move the vehicle in a specified trajectory. In addition to the sensor data, GIS information of the environment is also a requisite in some applications of UGV to gain an understanding of the environment. Identifying the path of transit, detecting the road and its lanes and maneuvering the vehicle along the road are some of the navigation decisions and algorithms that ought to be developed here. Moreover, control data is to be issued to the steering wheel system, the acceleration system and the braking system to ensure that the vehicle is performing the intended navigation, with continuous feedback and correction in real-time and a dynamic manner.
- **Vehicular Communication and System Security** – In situations where vehicles intend to communicate with each other, or with the backbone infrastructure or with users, vehicular communication becomes important. The challenges here are to ensure that communication happens with the least latency to ensure that vehicles traveling at high speeds are alerted in advance of road situations or impending danger. Along with vehicular communication what is also required is system security to ensure that data in communication within the vehicle and wirelessly transmitted should be secure to ensure that malicious users do not compromise the system security.
- **Main Processing** – A main processor will be required to integrate the sensor data, perform multi-sensor fusion, execute navigation and control requirements in the UGV. Data modelling can be undertaken for faster response using technologies like Machine Learning and Artificial Intelligence for improved system performance.
- **Power Supply** - The Power supply for the various sensors and systems mentioned above will have to be adequately provided for in a UGV system.
- **Mechanical Chassis Platform** - This Forms the frame of the vehicle where the body gets assembled. A number of mechanical aspects of the vehicle are built upon the chassis.

6.2.1.1 Global Ground Vehicle Autonomy Standards

Autonomy in vehicles is often categorized in six levels. The level system was developed by the Society of Automotive Engineers (SAE) and is defined in the standard SAE J3016, (see Fig. 21). Table 1 presents few products and manufacturer details related to UGV.

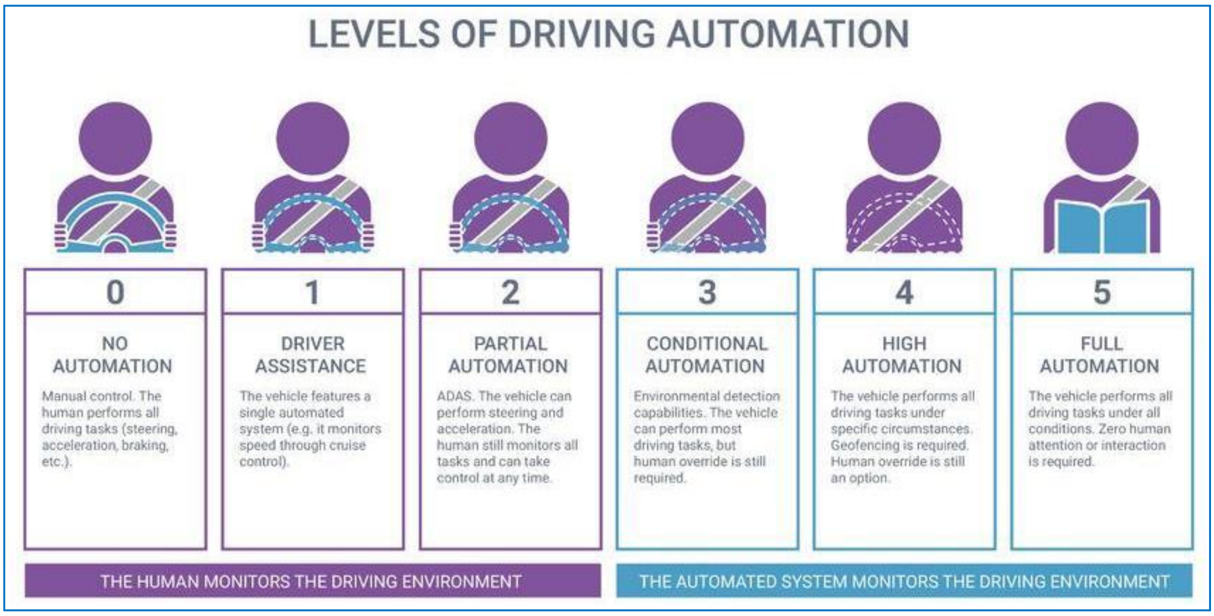


Figure 21: SAE Levels of Driving Automation

(*Image Source:* https://www.synopsys.com/automotive/autonomous-driving-levels.html)

As depicted in Fig. 21, Autonomy begins with driver assistance in level 1, which is available in most vehicles these days, as features. These could be alerts that provide useful information to the driver and also ease the driving experience like hill assist drive systems, power steering and ABS braking. Most vehicles today are exploring and performing research in partial automation where a few aspects of the vehicle are automated. Very few vehicles claim a level 4 of automation and nobody has reached full automation mentioned in level 5. A summary of the global scenario of autonomous vehicles is tabulated in the next section.

AUTOSAR (AUTomotive Open System ARchitecture):

Also, many of the current automobile manufacturers are adhering to the standardized software framework for intelligent mobility proposed by AUTOSAR. AUTOSAR (AUTomotive Open System ARchitecture) is a worldwide development partnership of vehicle manufacturers, suppliers, service providers and companies from the automotive electronics, semiconductor and software industry. The primary motivation of the AUTOSAR includes the following:

- to manage the software and E/E complexity associated with growth in functional scope
- to support the flexibility for product modification, upgrade and update
- to leverage the scalability of solutions within and across product lines
- to increase scalability and flexibility to integrate and transfer functions
- to improve quality and reliability of software and E/E systems

The AUTOSAR achieves this by standardizing the middleware which enables more flexibility in the integration of various components from different OEMs and future upgrades as shown in Fig. 22.

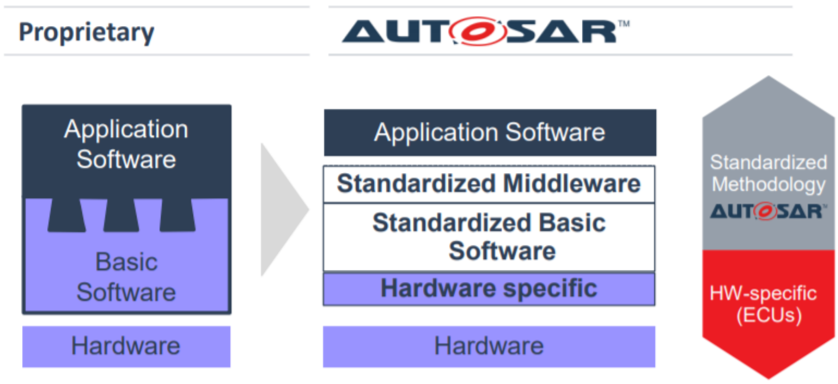


Figure 22: AUTOSAR architecture

(Image Source: https://www.autosar.org/fileadmin/ABOUT/AUTOSAR_EXP_Introduction.pdf)

Autonomous Vehicles Computing Consortium (AVCC):

Also, recently the Autonomous Vehicles Computing Consortium was established with a group of automotive and technology industry leaders coming together to help accelerate the delivery of safe and affordable autonomous vehicles at scale. The main objective is to enable a common computing architecture for the autonomous vehicles. Hence, we sincerely believe the development of a standard and reference architecture for autonomous vehicles considering the Indian context will significantly reduce the development time, costs and improves integration and upgrades across the OEM vendors and benefits various stake holders.

6.2.1.2 Global Scenario of Autonomous Vehicles

Table 1: UGV products and manufacturer details

S. No.	Vehicle Name	Manufacturer and Country	Autonomy Level	Remarks
1	Tesla	Tesla	Level 2	Tesla vehicles are "Level 2," a more advanced driver assistance system than most other vehicles on the road today.
	Autopilot	USA	(Partial Driving Automation)	
2	Cadillac	General Motors(GM)	Level 3	Super Cruise works a lot like Autopilot, with sensors and cameras and GPS guiding the car, but only on certain highways across the U.S. and Canada, where the computer knows the route.
	Super	USA	(Conditional	
	Cruise		Driving Automation)	
3	Audi	Audi	Level 3 (Conditional Driving Automation)	Audi (Volkswagen) announced that the next generation of the A8—their flagship sedan—would be the world's first production Level 3 vehicle. The 2019 Audi A8L arrives in commercial dealerships this Fall. It features Traffic Jam Pilot, which combines a lidar scanner with advanced sensor fusion and processing power (plus built-in redundancies should a component fail).
	A8L	(Volkswagen)		
		Germany		
4	Autonomous	Navya	Level 4	Navya's self-driving cars are considered to be at Level 4
	Shuttle	France	(High Driving Automation)	

	and			
	Autonomous			
	Cab			
5	Waymo	Alphabet USA	Level 4 (High Driving Automation)	Alphabet's Waymo recently unveiled a Level 4 self-driving taxi service in Arizona, where they had been testing driverless cars—without a safety driver in the seat.

The leaders in autonomous driving have achieved Level 4 technology, but only along predefined routes under specific circumstances (daytime, good weather). These companies are offering campus shuttles or employee buses only, and always with human safety drivers on board. Currently there are no companies that are able to offer a fully autonomous ride in any conditions, on any road, with no human overseer.

6.2.1.3 Proposed project objectives with respect to UGV

The overall objective of the proposed project in regard to UGV will be development of a UGV for number of applications like surveillance, reconnaissance, agriculture, construction, etc. This includes development of algorithms and software using ML/AI techniques and experimenting with dynamic decision algorithms and system components. Specifically, a real-time CPS realization of autonomous ground vehicles with the integration of multiple sensors will be performed. Also, involves calibration of sensors for quality data acquisition from the mobile environment and efficient transmission and processing of huge data generated from the on-board sensors. For the development and testing of the autonomous vehicles with proposed autonomous navigation and data acquisition frameworks, a living lab will be set up which specifically focuses on the Indian traffic and road conditions.

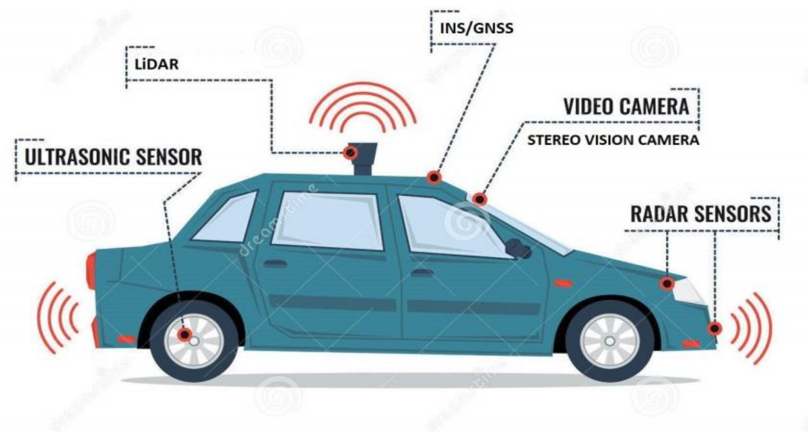


Figure 23: Multisensory perception system for autonomous car (https://medium.com/@armaanmerchant17/sensor-fusion-in-autonomous-vehicles-3e77a9e6a1fc)

For the navigation system for autonomous driving, the first step involves the processing of the collected data from various sensors as shown in Fig. 23 for obstacle detection and segmentation with minimal latency. Due to its substantial size, processing of this collected data directly is computationally cumbersome. So, we have to compress the data without losing the necessary information. This compressed data is then segmented into multiple clusters. These clusters, consisting of similar region characteristics (such as color for the camera, minimum distance or same intensity for LiDAR), are then classified into various objects like car, pedestrian, etc. Generally, the processing pipeline involves various steps such as ground removal, object detection and classification, speed tracking, etc. For real-time applications, all the above steps should be completed as fast as possible. With an efficient processing pipeline i.e., using faster and accurate obstacle detection and segmentation can improve the efficiency of the system. Various edge computing devices enabled with GPU's can also be very useful for fast real-time implementation of algorithms. Another challenge is to geo-reference the LiDAR point cloud data, which is represented in the local coordinate system. Generally, geo-referencing is used to associate a physical map or raster image with global locations in the field of Geographical Information System (GIS). By geo-referencing LiDAR's local data, global positioning of the objects and also the vehicle is possible. For this purpose, INS (Inertial Navigation System) can be very useful. The GNSS receiver can give precise locations of objects by receiving signals from different navigation systems like GPS, Beidou, GLONASS, etc. This geo-referenced data can also be shared with other vehicles and road-side units (RSUs) in the field of Autonomous Transportation System (ATS). In this regard, we also have to consider the challenge to predict human behavior. This will help us to navigate through more complex road traffic scenario. In Indian case, the traffic flow is very different from other countries. So, a thorough human behavioral analysis should be done. Overall, for a UGV, the project objectives can be summarized as follows:

- Development of standard operating procedures for quality data acquisition
- Establishment of a living lab for the research and development of Autonomous Vehicles. Also, a testbed facility for testing the Autonomous Navigation of vehicles will be developed
- **Sensor data compression**: The development of efficient compression techniques for sensor data is important due to its large size. Compression should be done such that all the necessary information is preserved.
- **Ground removal**: In the case of LiDAR data, a large number of points belong to the ground, which hinders proper object segmentation. Removing these points will decrease the size of the data and will be helpful for further steps.
- **Obstacle detection**: Computer vision algorithms need to be developed for multi-sensor data processing techniques for obstacle detection and segmentation in real-time. Under-segmentation and over-segmentation pose a great challenge for this task.
- **Obstacle classification**: Using AI/ML algorithms, the objects can be classified into real-life objects like cars, pedestrians, bikes, etc. State of the art deep learning algorithm will also play an important role for obstacle detection and classification.
- By solving the aforementioned challenges, we can create a multi-sensor system that will help us to achieve full autonomy. In Fig. 24, an autonomous navigation flow chart for autonomous vehicles/UAVs is shown.

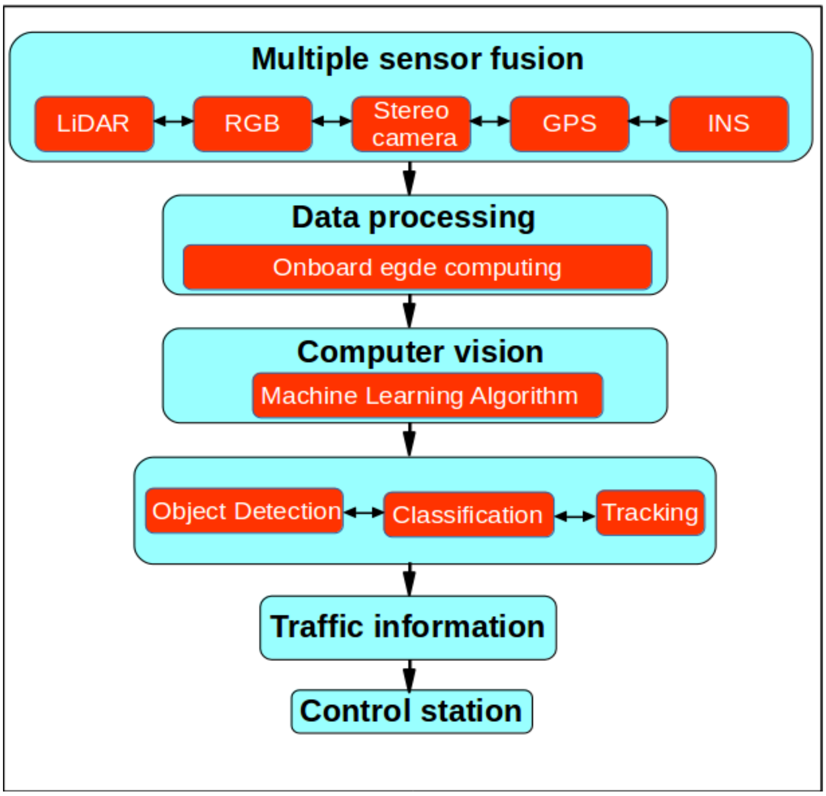


Figure 24: Autonomous navigation flow chart for autonomous vehicles/UAVs

- **Dynamic object detection and tracking**: This step involves the classification of the objects into static and dynamic and measurement of the speed of the moving vehicles using Deep Learning based algorithms. The challenge for this task is to correctly associate the objects in two consecutive frames.
- **Navigation and Control Interface** which include: Lane Detection & Lane Changing, Collision Prevention and Avoidance, Steering Control, Speed Control and Braking, Terrain and Inclination Control
- **Geo-referencing** the LiDAR point cloud using INS/GPS devices.
- **Development of low cost CMOS compatible inertial MEMS sensors:** In the meantime, we can also focus on developing low-cost CMOS compatible inertial MEMS sensors. Instead of high-cost commercial products, using homemade sensors will increase sustainability.
- **GPU Implementation**: All the processing steps on the sensor data must be completed within the time duration between two frames. The development of a parallel processing architecture utilizing GPUs will help in reducing the latency in obstacle detection. The challenge for this task is to integrate various libraries used for data processing with GPU.
- **Real-time implementation** of the developed frameworks using suitable edge computing device e.g. NVIDIA Jetson TX2, Intel NUC.
- **Security**: Enabling System Security in UGV systems to prevent hackers from gaining control of these vehicles Development of Test bed facility for testing the Autonomous Navigation of vehicles
- **Enhanced Security of ML-based ADAS:** The existing vulnerabilities in the ADAS based vehicles coupled with increasingly sophisticated attacks on the machine learning networks pose a serious threat in the operation and control of autonomous vehicles. This work aims to identify potential vulnerabilities and study their proliferation pattern and design novel and efficient defense mechanisms to mitigate the concomitant issues arising out of the proliferation.
- **Testing and demonstration** of the developed UGV at various system integration levels

➢ **Developing a standardized model** for human behavior analysis in Indian traffic scenario using input from multiple sensors
➢ Power Management
➢ **Main Processing board** which includes the application processor and required GPU integration for running algorithms for obstacle detection through multi-sensor fusion, navigation and control in real time, technologies like ML/AI, Image Processing etc.

6.2.1.4 System Architecture

The overall architecture of Unmanned ground vehicles (UGV) is shown in Fig. 25. The architecture can be broadly classified into Sensing, Perception, Planning and Actuation interfaces. Each of the interfaces are briefly described below:

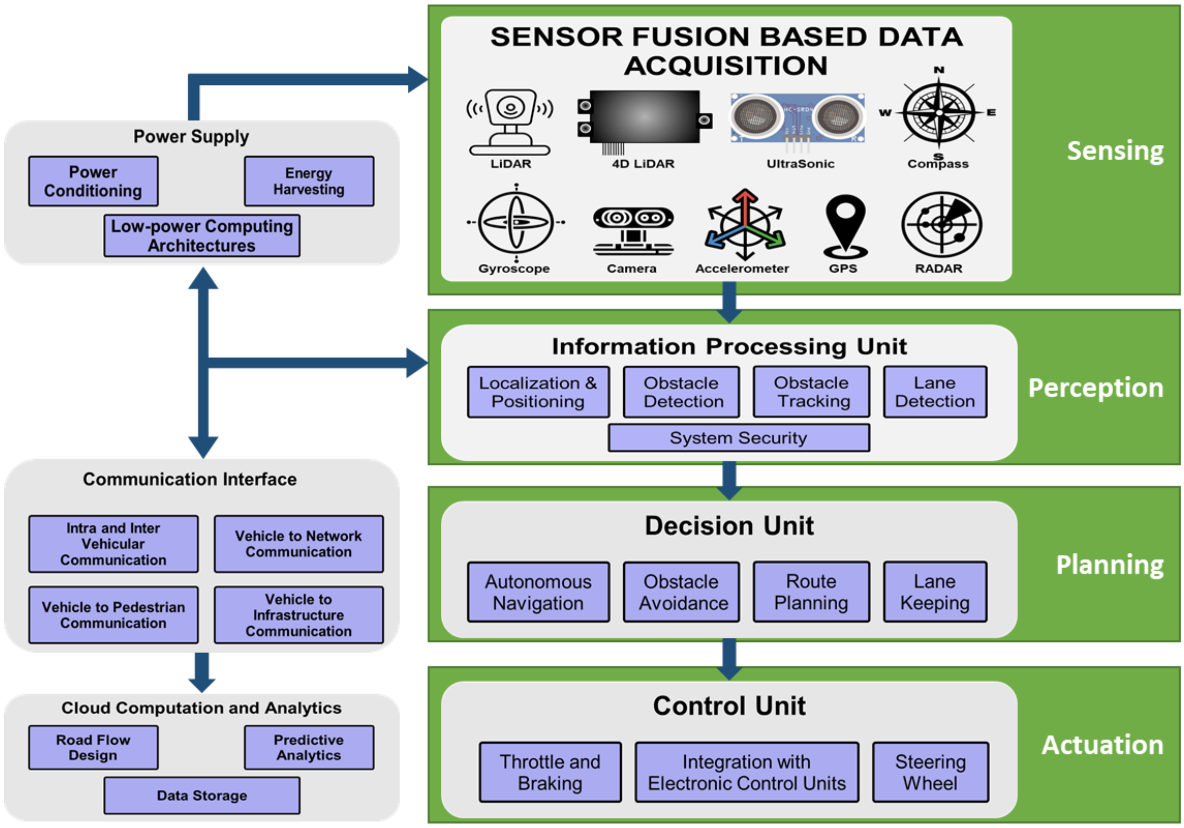


Figure 25: A holistic view of the system architecture of a UGV

➢ **Sensing:** The primary challenge of the UGV is to provide navigation in an autonomous manner, without human intervention. For this, a number of sensors like LIDAR, 4D LiDAR, Ultrasonic, Compass, gyroscope, camera, acceleration, inclination, GPS etc. are integrated in the system architecture as data generators. Using these sensors, it will be possible to detect obstacles in the path, know the direction, speed, heading, altitude, inclination and position of the vehicle which are important for navigation. These sensors will be sampled in real-time and require high speed interfaces to ensure that the vehicle has sufficient time to issue navigation commands to the navigation interface. However, in many scenarios each of the sensors, such as radars, cameras and other sensors used by the vehicle for self-driving purposes have their own limitations in terms of the information perceived about the surrounding environment. For example, whilst camera systems are ideal for identifying roads, reading signs and recognizing other vehicles, LiDAR applications are superior when it comes down to accurately calculating the position of the vehicle, and radars perform better at estimating speed. Hence, sensor fusion is the combination of these and other autonomous driving applications which, when smartly bundled and set up, give autonomous vehicles an all-encompassing and thorough 360-degree view of the environment. Also, the quality of data acquired plays a major role in accurate information extraction. Hence, in this, we also develop the standard operating procedures for quality data acquisition from multiple sensors integrated to the vehicle. **A simplified and standard architecture for the data acquisition from multiple sensors will also be developed which aids in faster development and deployment of the autonomous vehicles, especially in the Indian context.**

➢ **Perception:** The perception importantly deals with the extraction of important information about the surrounding environment using the sensor data aggregated. Such information includes the location and position of the vehicle with respect to the global coordinates, real-time obstacle detection and tracking, and lane identification. This information plays a key role in preventing the autonomous vehicles from colliding and also allows adhering to the traffic guidelines. However, the major challenge here is the amount of data generated from the sensors and to be processed. Typically, the autonomous vehicles operate under critical time and power constraints. Hence, the cloud computing is not always a feasible solution and edge computing architectures have to be designed. **This research focuses on the development of a standard and efficient edge computing architecture for perceiving information about the surrounding environment from the sensor data collected using AI/ML techniques.**

➢ **Planning:** After the necessary information from the surrounding environment is perceived, the navigation of the autonomous vehicle has to be planned in real-time which include obstacle avoidance, route and lane planning, etc. Also, necessary decisions have to be made on the motion, direction, speed and power available to the UGV based on the terrain and the path of travel. Similar to perception, the latency in planning plays a key role in achieving the desired operation of the autonomous vehicles. Hence, an important focus will be laid on the development of light-weight and accurate AI/ML frameworks for the planning interface.

➢ **Actuation Interface:** The decisions made as part of the Planning interface will have to be translated into physical actions which include throttle and braking control, steering wheel, and communication to various electronic control units integrated on-board the UGV.

➢ **Communications Interface:** The UGV comprises of various communicating entities such as intra-vehicle communication (communication between in-vehicle components such as electronic control units, infotainment, etc.), vehicle to vehicle (which includes transfer of the information from one vehicle to surrounding vehicles), vehicle to infrastructure (where the data will be communicated to the road side units, or traffic coordination units), vehicle to network (where the data will be stored on the cloud for computations, deriving predictive insights, etc.). Hence, each of the communication interfaces described above demand varied network requirements in terms of coverage and speed. The development of these interfaces require significant effort, and as part of this research we aim to develop a standard architecture for the different communication interfaces.

➢ **Power Supply:** With the future being the electrical vehicles, the power consumption required for computing plays a key role in determining the efficiency of the UGV. Hence, we aim to develop low-power computing framework for the proposed system architecture. The design of the battery based system with power conditioning requirements for various sub systems will be developed as part of the project activities. Wherever feasible, it would be explored whether power harvesting and generation can be applied. Solar power supply is a practical approach for this. However, this would be feasible only where the system is outdoor functional. Otherwise, the system will be powered from charging stations. Power control mechanisms will be employed in the system design to minimize the consumption, thereby prolonging the run duration of the vehicle.

- **System Security** is an important aspect which has to be addressed in the UGV to prevent hackers with malicious intent from taking control of the vehicle and cause damage to life and infrastructure. It is proposed to develop adequate mechanisms of security to ensure that the communication with the vehicle as well as the vehicle’s electronic equipment is tamper free and secure. Security will have to be viewed comprehensively in the entire UGV, including interfaces like sensors, navigation, communication etc., where communication happens with the main processor.
- We also aim at developing a standardized architecture for information flow across the various interfaces and propose a standard software and hardware co-design architecture which offers better flexibility to interface hardware from different vendors with minimal complexity. Such an architecture results in reduction of software developmental costs as the technologies upgrade in the future. Also, we aim to develop a standardized computing architecture (both edge and cloud) which can reduce the time and cost to develop the autonomous vehicles, especially considering the Indian context. Other aspects of the UGV would include system health monitoring, display devices and user assistance as per the device use casein the application domain.

6.2.1.5 Major Problems to be Addressed

Autonomous Vehicles for Indian Context: As part of this research, an important focus will be laid on understanding the challenges pertaining to realization of autonomous vehicles in the Indian context (roads and traffic conditions). Also, novel autonomous navigation frameworks will be developed for the Indian context. A standard architecture for the development and deployment of autonomous vehicles will be developed, especially for the Indian context. Also, the living lab will consider different land types which enable in the robust validation of data acquisition procedures and the developed autonomous navigation frameworks.

Latency in Sensor Responses: For autonomous vehicles, latency in decision making should be reduced to as low as possible, to ensure that the high speed nature of vehicles is controlled without danger to life. However different sensors respond with varied timing constraints. This poses a challenge in decision making since sensors form the data basis for autonomous vehicles.

Effects of Weather Conditions in Obstacle Detection: Obstacle detection forms an important aspect of autonomous vehicles. In typical urban settings, obstacles include urban structures, vehicles, curbs, road/street signage, bridges, poles, curbs, speed breakers etc. Urban structures are more likely to contain people, whether friendly or hostile. Items in this category include buildings, bus stops, sidewalks, and markets.

A number of sensors are used for detecting obstacles in autonomous vehicles. However, the sensors used to detect obstacles suffer from a number of practical challenges in their responses owing to weather conditions. A few of these which will be investigated include: cameras, RADAR, pedestrian recognition, and LiDAR:

Lane Detection: Lane detection involves identifying the various lanes in a street/road and navigating the vehicle to be within these lanes. This is generally identified by color sensing using a camera and Image processing techniques. There are standard algorithms and methodologies to achieve the same. However, the important challenges that are to be addressed include: lane detection under various lighting conditions and roads without lanes or unclear lanes:

Lane Changing: Lane changing at high speed transits requires other information like speed, heading, direction for the current vehicle and data concerning surrounding vehicles. These have to be done at high speed to ensure that the lane changing is safe in busy environments. City based lane changing is more challenging than highway transitions, where the traffic flow is more structured.

Security in Vehicular Communication: Prevention of malicious users/hackers from gaining access to the vehicular data/self-driving car vulnerabilities, thereby resulting in compromising road safety. The important aspects that are to be addressed include: Data protection, Cloud storage, Secure algorithms, Inter device communications, Security threats for the sensor operation.

Interference between autonomous vehicular sensors: In a highly congested road environment where multiple vehicles are playing together, interference between the sensory data being triggered has to be evaluated to ensure that the sensors do not cause hindrance in the commute.

Terrain Management: The positioning errors grow rapidly when terrains obscure the sky precluding GPS receivers from obtaining signals through a sufficient number of satellites. This is a genuine concern in the heart of the cities, where tall buildings create “urban canyons” in which GPS capabilities are severely limited. A sensor configuration appropriate for a flat environment may be inappropriate for steep hills, where sensors must look “up” or “down” slopes. Different terrain can require different sensor configurations, which may not be readily changeable. While sensors can be put on adjustable mounts to accommodate this problem, this adds complexity and cost

Ethics in Autonomous Vehicles: The ethics of the autonomous vehicles play a key role. These include problems pertaining to the data shared, legal and liability aspects. As part of this research, we focus on identifying these aspects which helps in better policy making.

6.2.1.6 Technology

Technology at work:

There are four major steps in the operation of an autonomous vehicle as depicted in Fig. 26:

Figure 26: Brief operation of self-driving cars work (https://medium.com/@armaanmerchant17/sensor-fusion-in-autonomous-vehicles-3e77a9e6a1fc)

Realization of an optimized computing architecture comprising of the following functional elements will be achieved

- Perception: Understanding the world which includes detection of road signs, lights, objects, vehicles, obstacles etc.
- Localization: Where we are, which direction are we heading, what is the speed of travel
- Path Planning: This includes the navigation from a source point to a destination, along the standard road. This also includes lane detection on the road and the mechanism required for the same
- Control: Vehicle control to incorporate steering control for lane switching, speed control, etc.

Perception:

The autonomous vehicle uses a large number of sensors to understand its environment, to locate and move. While each sensor is unique and provides a specific capability and accuracy, sensor perception deals with understanding the environment around the vehicle. This is achieved by integrating the data from a number of these sensors into a 3d interface to depict the environment.

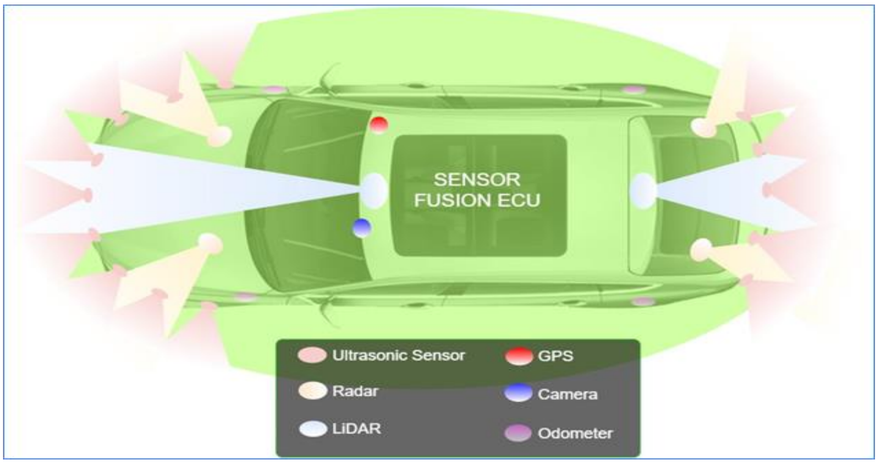


Figure 27: Use of different sensors in the motor vehicle (https://medium.com/@armaanmerchant17/sensor-fusion-in-autonomous-vehicles-3e77a9e6a1fc)

Sensor fusion, as depicted in Fig 27, is a crucial step for autonomous vehicles. Each type of sensor has its own strengths and weaknesses in terms of range, detection capabilities, and reliability. A host of technologies is required to provide the redundancy needed to sense the environment, safely. A combination of such sensors together, such as camera and radar result in more data and greater detail thus improving accuracy of the perception block. This is called sensor fusion.

Sensor Fusion requires algorithms to be developed that can use the data from different sensors in an optimal manner, by assigning weights based on the nature of the sensors and the environmental conditions. These algorithms need to respond to real time conditions and should be dynamic in nature. ML/AI techniques can also be used here to learn the best fit sensor combinations, given a specific problem of perception.

The following sensors are popularly integrated for driver assistance systems:

- Camera (Image Sensor)
- RADAR (Radio Detection and Ranging)
- LiDAR (Light Detection and Ranging)
- Global Positioning System (GPS)
- Ultrasonic Sensing and Odometers
- Odometers

Working together, they provide the car, visuals of its surroundings and help it detect the speed and distance of nearby objects, as well as their three-dimensional shape. Every autonomous driving system is built on a whole suite of software and an array of sensors. LiDAR, radar, and ultrasonic sensors all work together to create a living map of the world that a self-driving car can navigate. Additionally, Machine learning techniques help in improving the system level accuracy and help in developing faster algorithms and reliable systems. Most companies in the race to full autonomy are relying on the same basic technological foundations of LiDAR + RADAR + cameras + ultrasonic, with a few notable exceptions.

A summary of sensors required for the perception block is tabulated below.

Table 2: Summary of sensors required for perception

S.No.	Sensor Name	How They work	Areas of Improvement
1	Camera(Image Sensor)	Video cameras are commonly used in autonomous vehicles to observe and interpret various objects in the road. They contain color information which is useful for objects detection and classification.	Weather conditions such as rain, fog, or snow might make it difficult for cameras to notice hazards in the path.
2	RADAR	Radar (Radio Detection and Ranging) sensors are critical to autonomous driving's general function: they send out radio waves that detect objects and calculate their distance and speed in real time in relation to the vehicle.	There is scope of improvement in object (pedestrian, car etc.) recognition
3	LiDAR	LiDAR provides precise 3D representation of the surrounding and gives a 360 degree horizontal field of view	The data can get corrupted by snow or fog. The LiDAR and other sensor like camera fusion can give a better results for object detection and tracking.

Localization:

Localization refers to identifying the physical position of an object in space. This is particularly important for autonomous vehicles where the locality becomes important to identify where the object is and the direction in which it is heading. A number of sensing methods are available to identify the location with varying degrees of accuracy. However, concerning autonomous vehicles and especially from the perspective of navigation, the global positioning system is very important.

Sensors:

- Inertial Measurement Unit (IMU) is a sensor capable of defining the movement of the vehicle along the yaw, pitch, roll axis. This sensor calculates acceleration along the X, Y, Z axes, orientation, inclination, and altitude. This method gives a lot of information about the location and is more precise to devices in flight. However, for ground vehicles, it may be an overkill.
- Global Positioning System (GPS) or NAVSTAR (refer Fig. 28) are the US system for positioning. In Europe, we talk about Galileo; in Russia, GLONASS. The term Global Navigation Satellite System (GNSS) is a very common satellite positioning system today that can use many of these subsystems to increase accuracy.

Figure 28: Global Positioning System (GPS)

Global positioning system (GPS) is used to locate the position of a GPS receiver (x, y, z coordinates) using four or more geostationary satellites. These satellites maintain their position relative to earth. A GPS receiver on earth deciphers the actual location within meters' accuracy. However, the so-called "differential GPS" can pinpoint a location within centimeter accuracy which is necessary for navigation of autonomous vehicles. GPS based navigation applications are greatly used to accurately predict the vehicle location with respect to a map which is known as localization.

There are many different techniques to help an autonomous vehicle locate itself.

- Odometry — This first technique, odometry, uses a starting position and a wheel displacement calculation to estimate a position at a time t. This technique is generally very inaccurate and leads to an accumulation of errors due to measurement inaccuracies, wheel slip etc.

- Kalman filter — this technique to estimate the state of the vehicles around us. We can also implement this to define the state of our own vehicle.
- Particle Filter — The Bayesian filters can also have a variant called particle filters. This technique compares the observations of our sensors with the environmental map. We then create particles around areas where the observations are similar to the map.
- SLAM — A very popular technique if we also want to estimate the map exists. It is called SLAM (Simultaneous Localization and Mapping). In this technique, we estimate our position but also the position of landmarks. A traffic light can be a landmark.

Path Planning

Path planning deals with identifying the path from a source point to a destination, where a vehicle is intended to travel. The challenge associated with autonomous vehicles and path planning is to be able to navigate from source to the destination in a manner that is safe and reliable, owing to the road being a common entity, used by both autonomous and non-autonomous users.

Path planning is one of the most important parts of an autonomous vehicle. It deals with, searching a feasible path, taking into consideration the geometry of the vehicle and its surroundings, the kinematic constraints and others that may affect the feasible paths. Some of the activities involved in path planning are depicted in Fig. 29.

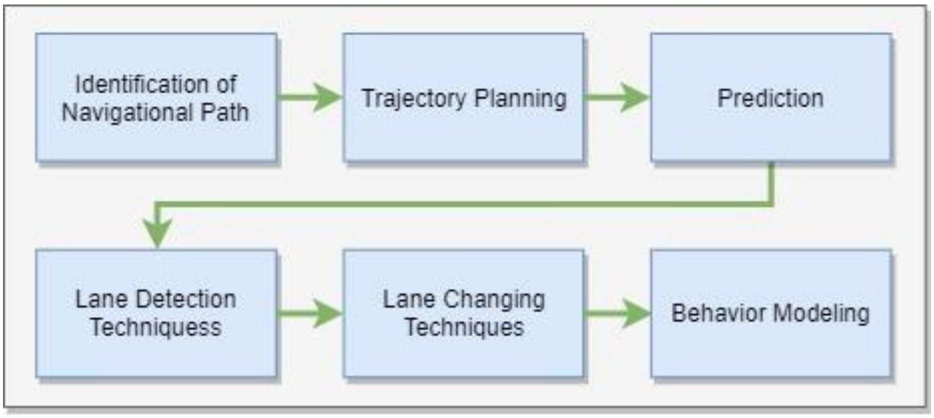


Figure 29: Activities comprising Path Planning

Path planning begins with the identification of the various paths between source and destination and choosing the best path, given various constraints like traffic information, vehicle information, road information etc. Thereafter, the trajectory for the vehicle is planned along the chosen path.

There are generally 2 methods for trajectory planning: Static Planning and Dynamic Planning. In the first method, the entire road network for a specified area is geo-mapped onto a GIS system, where all routes, lanes of a road, the intended directions of travel are incorporated and geo-fenced. Thereafter, vehicles whose location information (known using the localization techniques discussed above) and the vehicle dimensions are known, are aligned into the corresponding lane of the road, in the identified transit path. The vehicle thereafter traverses along the required path and the geo-fence into which it is required to travel. Google's Waymo uses this method and has geo fenced the road network in a pilot region where it is able to run its vehicles along predefined paths.

The other method computes the features of the road in a dynamic manner, once the transit path/route to the destination is identified and chosen using navigation applications. Computer Vision and Image Processing techniques are used to detect the lanes in realtime in which the vehicle is required to travel. Tesla uses this method to compute the path for its vehicles to travel.

The problem of lane detection using computer vision and real-time algorithms involves 2 parts: detecting the lane on the road and finding the area of the region encompassed between the lanes. This is also called Region of Interest (RoI). The technologies used to detect lanes includes Image processing techniques like Mutation from RGB to HSV to detect the lines clearly in which Hue provides good information for lane detection. Algorithms for lane lines detection include Canny edge detection (edge detection of the lanes), Hough transformation (area of the lanes) and Sobel filter methods (edge detection). Two methods to detect the region of interest are: Triangular approximation method – Stretch the lanes till they intersect. The area within this region is the RoI and Skyline Method – A horizon line is drawn where the skyline meets the earth and the area within this forms the RoI.

Lane changing requires a trajectory and a tracking controller. Therefore, path planning is only half of the story, controller design is of the same importance. A vision based lane keeping based on nested PID algorithm suggests a fuzzy control method as one method for lane changing. Similarly, a model based lane change controller was developed by Du while a lane keeper/changer control algorithm with low ripple for highway driving is presented by Kang. There are methods taking into account the driver comfort such as the torque based lane change assist presented in.

Control

This is the last step. An autonomous car uses the Perception module to know its environment, the Localization module to know its position in this environment and the Planning module to make decisions and generate trajectories. The Control module is now in charge of moving the vehicle by generating an angle for the steering wheel and acceleration.

The Control step consists of following the trajectory generated as faithfully as possible. A path is a sequence of waypoints each containing a position (x; y), an angle (yaw) and a speed (v).

A Control algorithm is called a controller. The purpose of a controller is to generate instructions for the vehicle such as steering wheel angle or acceleration level taking into account the actual constraints (road, wind, wheel slip, etc.) and the trajectory generated.

A large number of controllers exist to move a robot / vehicle. They are more or less complex depending on the problem that we want to solve.

PID — Proportional Integral Derivative

The simplest of all is called Proportional Integral Derivative or PID. The PID controller is an algorithm that calculates a value (for example a steering wheel angle) from an error calculation. The error is the difference between the trajectory that we must adopt and the one we actually adopt. The PID controller is the simplest and most common in the world. It has the advantage of being implemented quickly and operating in simple situations. In the case of a stand-alone car, a PID controller can be used to calculate the angle and another to calculate the acceleration. Lateral and longitudinal controls are difficult to combine. Moreover, it is impossible to model the physics of the vehicle. When we drive, we naturally adjust our manoeuvres according to the size, mass and dynamics of the vehicle. A PID controller cannot do it.

- *MPC — Model Predictive Control:* Other controllers are also known to integrate the physics of the vehicle (mass, size, …). They are more difficult to implement but more effective. These regulators can take into account the forces that apply to the vehicle, the characteristics of the vehicle etc. A car has three actuators: a steering wheel, an accelerator pedal and a brake pedal. The objective of an MPC is to play on these actuators by varying the angle of the steering wheel, the pressure on the accelerator pedal or on the brake pedal. The MPC controller is very powerful but very difficult to implement. An MPC controller can be very powerful and allow a vehicle to reach faster speeds while still being safe.
- *Drive by wire:* A technology known as "x-by-wire", also called drive by wire or simply "by-wire". A car with this type of system mainly on electronics, to control a wide range of vehicle operations, including, braking, acceleration, and steering. Conventional cars mainly use hydraulic and mechanical technology to conduct these basic vehicle operations, and although the systems are powerful, they can be overly complex, inefficient and conducive to wear and tear over the years. Drive-by-wire technology could also be integrated with driverless car technology, which would allow vehicles to be operated remotely or by a computer. Current driverless car projects use electromechanical actuators to control steering, braking, and acceleration, which could be simplified by connecting directly to drive -by-wire technology
- *Anti-lock Braking System (ABS):* ABS is part of an overall stability system, commonly known as electronic stability control, which monitors wheels' under heavy braking. Each wheel has a sensor attached to it. If the intelligent sensors detect that a wheel is about to lock up and stop moving, the system will release the brake. The release is only for a moment. ABS then continuously and repeatedly applies optimum braking

pressure to each wheel, meaning the system will brake just enough to not lock the wheels. When ABS is active you may feel pulsation through the brake pedal as you're pressing it. The anti-lock system helps the driver remain in control of the vehicle rather than bringing the car to a stop. It reduces the risk of skidding even when undertaking excessive evasive maneuvers.

- *Adaptive Cruise Control (ACC):* A radar sensor is usually at the core of the adaptive cruise control (ACC). Installed at the front of the vehicle, the system permanently monitors the road ahead. As long as the road ahead is clear, ACC maintains the speed set by the driver. If the system spots a slower vehicle within its detection range, it gently reduces speed by releasing the accelerator or actively engaging the brake control system. If the vehicle ahead speeds up or changes lanes, the ACC automatically accelerates to the driver's desired speed.

6.2.2 Autonomous Navigation for UAVs

TiHAN focuses on technology development for different category of drones (nano, micro, small, light and large) for different applications. In Nano/Micro category drones, Bio-Inspired drones like Quad-wing UAV (Dragon fly based) and Flapping Wing Micro Aerial Vehicles (Aerial Birds based), Nano drone swarms, which are used for various applications including Defense Applications: Reconnaissance, stealth operations etc., Space Exploration: Insect based UAVs are more suitable for exploration of Mars, Jupiter and Titan planets that have low gravity atmospheres, etc. In Small category drones, TiHAN is focusing on technology development for integration of high end sensors like Hyperspectral cameras, Multi-spectral cameras, Lidars, thermal imagers, etc. on to UAVs which are useful for applications like agriculture, land surveillance, healthcare, etc. In Medium/Large category drones, TiHAN is focusing on developing solutions for next generation urban air mobility – air cargos, air taxis, air metros, air ambulances etc. As a means of solving traffic congestion in the downtown of large city, the interest in urban air mobility (UAM) using electric vertical take-off landing personal aerial vehicle (eVTOL PAV) is increasing.

Autonomous aerial systems are becoming popular these days because of the lowered price lightweight consumer drones resulting from technological advances in this field. Such aircraft paves the way for innovations across a range of industries and application areas, for example, delivery of products, passenger drones, drone swarming, etc. Their capabilities, such as small spatial footprint and easy integration with state-of-the-art control, IoT, navigation, and guidance systems, makes them ideal for autonomous missions. Autonomous transport drones (Fig. 30) have been projected to play a significant role in enhancing mobility and improving traffic efficiency.

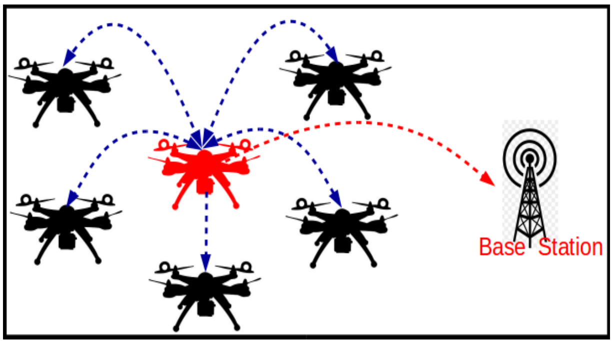


Figure 30: Multiple UAVs connected to each other and to base station

In this context, the objective of the current project is to develop an autonomous navigation system for a drone for various applications in urban and rural environments, including special causes such as rescue operations and emergency relief. The realization of such an advanced drone-based flight platform necessitates the integration of a variety of subsystems that include sensors and IoT, communications, computer vision and artificial intelligence (Fig. 31).

Figure 31: Various research areas in the field of UAV automation

For autonomous navigation, the UAV should be able to sense its surroundings. Following are the various challenges faced in this field and strategy that will be adhered to address the challenges:

6.2.2.1 Urban Air Mobility (UAM)

In aviation and transport, Urban Air Mobility (UAM) refers to urban transportation systems that use air travel. These transportation systems are developed in response to traffic congestion. Urban air mobility is a subset of a broader Advanced Air Mobility (AAM) concept that includes other use cases than intracity passenger transport. NASA describes Advanced Air Mobility as including small drones, electric aircraft, and automated air traffic management among other technologies to perform a wide variety of missions including cargo and logistics. Urban air mobility leverages the sky to better link people by bringing the safety, convenience, and joy of flight, to city inhabitants to cities and regions, giving them more possibilities to connect. To do so, it takes a holistic approach to urban air mobility, seamlessly integrating a variety of critical components. While we have only known taxis on the street up to now, (passenger) drones are tapping into the sky as a new mode of transport step by step. This could relieve the strain on many chronically overburdened infrastructures such as those in cities with a rapidly growing population. Cities such as Dubai, Singapore, Los Angeles, and Dallas have already been experimenting with Urban Air Mobility projects for some time. Unmanned Aircraft System Traffic Management (UTM) is a" traffic management" ecosystem for uncontrolled operations that is separate from, but complementary to, the FAA's Air Traffic Management (ATM) system. UTM development will ultimately identify services, roles and responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements for enabling the management of low-altitude uncontrolled drone operations. Path-planning is an important part of the UTM system. It allows drones to fly safe and it gives a suitable and shortest possible path to fly the drone from starting point to endpoint. For this, we have to give waypoints and then the algorithm sees the optimal path for that drone and gives us. During path-planning algorithms have to take care of the geo-fence area, terrain, weather conditions, dense of the drone at that area so it can give an optimal path to all drones. Generally, it can detect an obstacle and during planning avoid them. But in each drone's sense and avoid should be equipped for real-time collision avoidance. Its main purpose is to give an optimal path to the drone with minimum energy consumption and When the emergency happened then it will give a new path to the drone cause of weather, rogue drone, etc. it can be 2D and 3D configuration. The UAM based PAV is shown in Fig. 32. Experimental and numerical studies are carried out in TiHAN at IITH. The results show that chosen propeller is able to generate sufficient thrust force at different rpms.

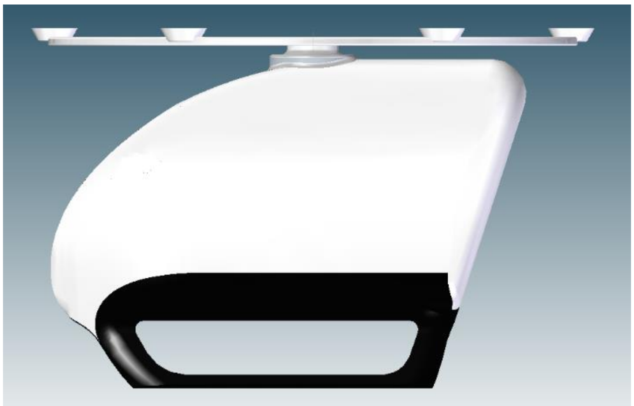


Figure 32: (a) UAM based passenger aerial vehicle

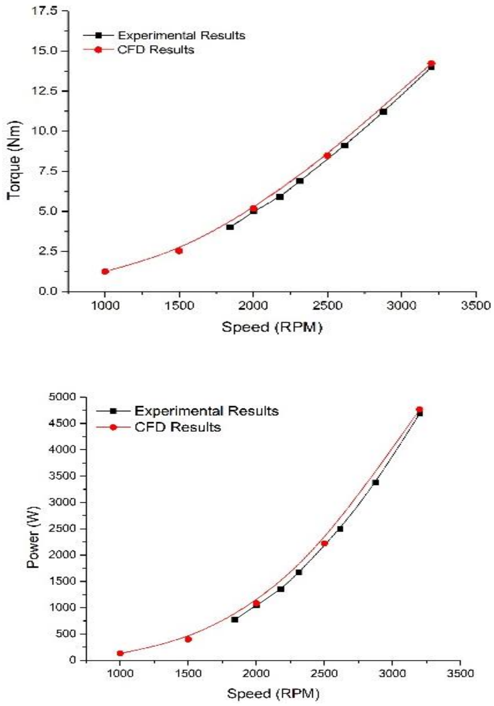


Figure 32: (b) Fig. 11. Propeller torque and power vs angular velocity of eVTOL vehicle.

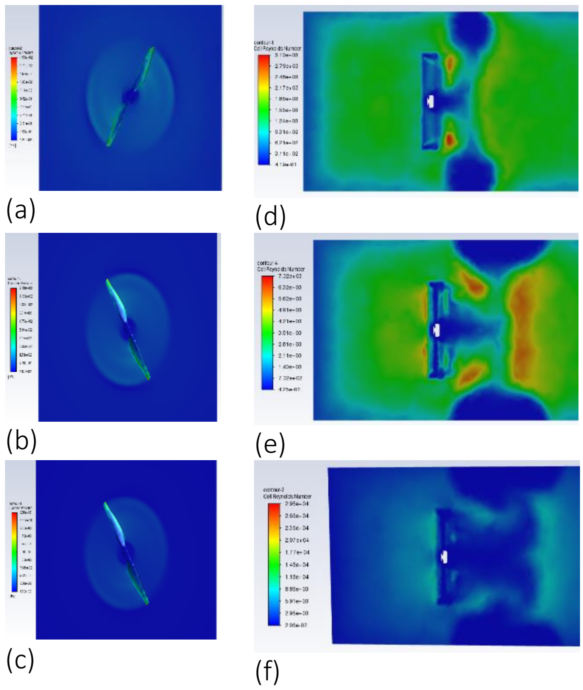


Figure 32: (c). Dynamic pressure at (a) 1000 rpm (b) 2000 rpm and (c) 3200 rpm; *Re* at (d) 1000 rpm (e) 2000 rpm and (f) 3200 rpm.

6.2.2.2 Bioinspired Micro Aerial Vehicles (MAVs)

Technology Innovation Hub on Autonomous Navigations (TiHAN) at IITH would like to showcase the theme on UAVs under different categories catering to various applications. In Nano/Micro category drones, Bio-Inspired drones like Quad-wing UAV (Dragon fly based) and Flapping Wing Micro Aerial Vehicles (Aerial Birds based) (Fig. 33), Nano drone swarms, which are used for various applications including Defense Applications: Reconnaissance, stealth operations etc., Space Exploration: Insect based UAVs are more suitable for exploration of Mars, Jupiter and Titan planets that have low gravity atmospheres, etc. In Small category drones, TiHAN is focusing on technology development for integration of high end sensors like Hyperspectral cameras, Multi-spectral cameras, Lidars, thermal imagers, etc. on to UAVs which are useful for applications like agriculture, land surveillance, healthcare, etc. The thrust force measurements of quad wing UAV and comparable propeller are shown in Fig. 33 (c-d).

Fig 33 : (a) Quad-wing UAV in free flight (b) Autonomous UAV in free flight

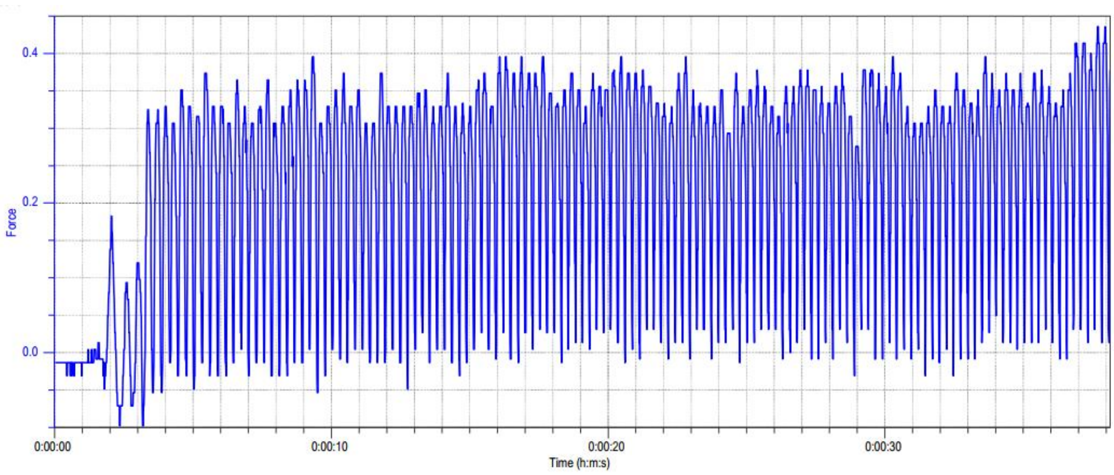


Figure. 33 (c) Time History of quad wing UAV using force sensor

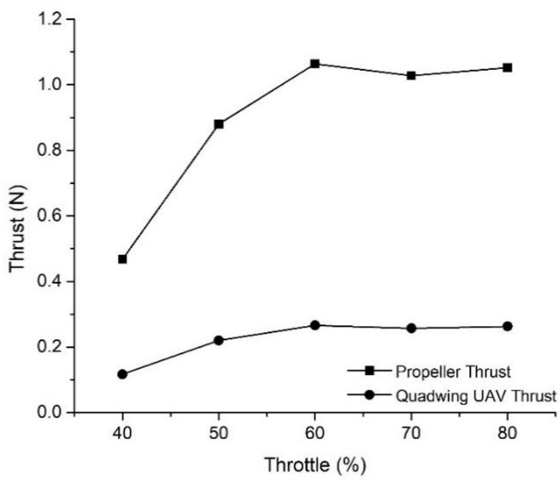


Figure 33: (d) Quad wing UAV thrust force measurement.

6.2.2.3 Additive Manufacturing for Fabrication of Components for Vehicles

Often UAV systems would require repair, replacement viz. propellers, and frame, camera mount since UAV will have various payload conditions of propellers, frame, camera mounts and antenna holder. To come across these limitations 3D printing the parts help in replacing, repairing, new material and designing new parts for existing systems and new set ups. Polyjet 3D printing allows users to achieve light weight and strength by use of different resins material, at different ratios and mix into one part. Proposed objectives include:

1. 3D printing of UAV (propellers, frame, etc.) components
2. Reduction of overall weight of UAV by use of light weight material and High strength to weight material.
3. UAV components integration while printing itself

Performance of UAV can be improved in different ways: use of light weight material and High strength to weight material. In 3D printing it will allow designers to fabricate different types of structure (honeycomb), area filling, material selection which eventually can reduce weight of objects and also create functionally gradient objects. Which results in high strength to weight material. Proposed method uses polyjet (Fig. 34) 3D printing techniques to fabricate different structures of UAV. This technique allows the user to mix different types of resins material and print the model.

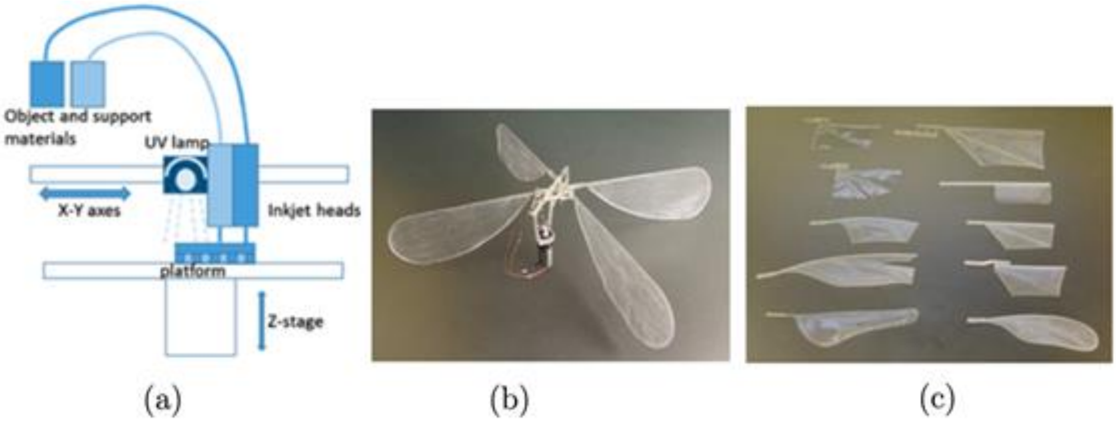


Figure 34: Schematic of polyjet 3D printing processes (b) 3D-printed elements of flapping-hovering insect (c) a variety of wing shapes for experimentation (Artificial Life, MIT).

6.2.2.4 Radio wave Propagation Aspects of UAV

Maxwell's hypothesis was a game changer in the area of communication technology. Until the Hertz's experimental validation for Maxwell's hypothesis it was assumed that the electromagnetic energy can be transported from the transmitter to receiver thorough guided medium only. Hertz proved that the electromagnetic energy can travel in free space with a speed of light. This is the basis for today's wireless propagation of data/information from source to destination.

The study of radio wave propagation in different scenarios like indoor and outdoor propagation with different environmental conditions is a fascinating subject for the communication engineers. To meet high data rate with low loss in the transmission path the accurate predictions of these radio wave propagation models are highly essential. The radio wave propagation in free space can be predicted using analytical models, statistical and deterministic modelling. Analytical models are very simple and quick, whereas the statistical models are highly suitable to analyze the highly complex scenarios. On the other side, the deterministic propagation models, based on Geometrical Optics and diffraction theory (Uniform Theory of Diffraction), provide physical understanding of the problem by considering the different ray paths and by superimposing their individual contributions at a given location. The waves in free space exhibits different behavior depending upon the type obstacle it encounters in their path, which may lead to reflection, diffraction and refraction (see Fig. 35) which is analogous to light theory (which is an electromagnetic wave), by incorporating the appropriate form (pre-existing models) the signal strength at a given location can be determined. The main advantage of these deterministic models is they provide physical insights of the problem. A survey paper on air-to-ground propagation has summarized the limitations and future directions. A radio wave propagation in UHF band over a mixed environment was discussed in   using Geometrical Optics and Uniform Theory of Diffraction.

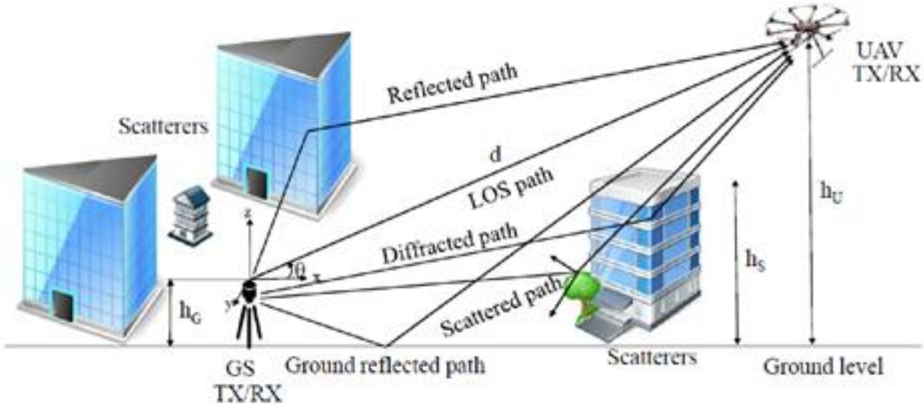


Figure 35: Air-to-ground propagation scenario with UAV.

Radio wave Propagation Scenarios:

- **Urban area:** in urban location, there will be large number of static and mobile communication platforms use common frequency bands for communication/surveillance purpose. Due to high density of users and multiple obstacles(buildings) in the signal path the signal strength may fall in shorter distance (Fig. 36-37).
- **Vegetation:** the path loss models can be computed easily, and there will be no big obstacle in the signal path. Hence there is direct ray from the transmitter to the receiver and there is a possibility for additional ray due to ground reflection.
- **Hill terrains:** in this scenario, if the transmitter and the receiver are on either sides then there is no possibility for the line of sight communication between them. The wave launched due to transmitter under goes diffraction at the hill edge/wedge and as a result there is a possibility of a diffracted wave to travel in the direction of receiver.
- Additional crucial parameters that influence the performance of the radio wave propagation model:
- **Environmental conditions:** during heavy rains the signal attenuation will be increased due to the absorption of the water molecule. During the foggy conditions the medium characteristics will be varied and the signal attenuation will be increased.
- **Antenna:** is a crucial element for the free space wave propagation analysis. The orientation and polarization will influence the transmission and reception characteristics of the antenna.

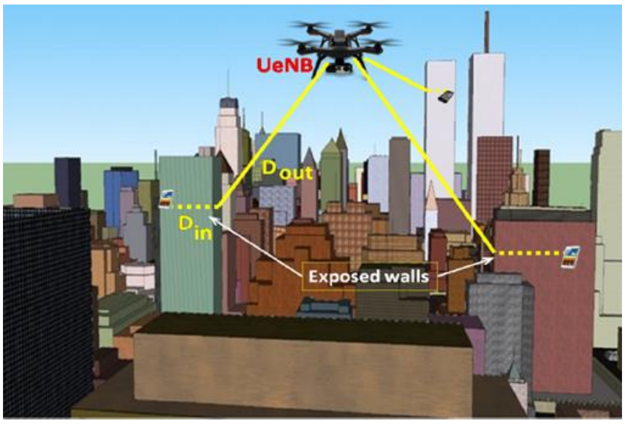


Figure 36: Urban Airborne communication scenario (doi: 10.1117/12.2519164)

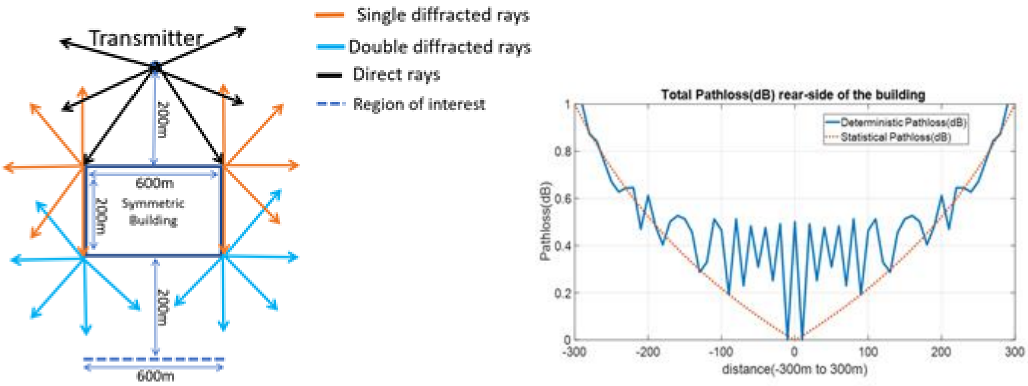


Figure 37: (a) Rectangular building scenario, (b) Symmetric building deterministic results verified with statistical results

The proposed objectives include:

- Path loss models for UAVs in urban scenario
- Two-way Non-Line of sight channel propagation model using deterministic approach
- Sub-surface radio wave propagation model for precision agriculture and water bodies.
- Scalable to plan 5G radio networks to meet the explosive growth in Urban scenario.
- Prediction of optimal location for base stations to enhance the coverage in specified industrial/commercial areas.

6.2.2.5 Intruder Detection Monitoring

TIH of IITH also want to initiate development of UAVs for intruder detection, supply of essential goods etc. shown in Fig. 38. UAV required for the above list of applications need special care in design considering the parameters like noiseless flight, small size, robust to rough environmental conditions, minimum payload, long range connectivity issues etc. Computer vision plays a crucial role with appropriate deep learning models for the applications like intruder and activity detection across problematic border regions where human involvement is at risk.

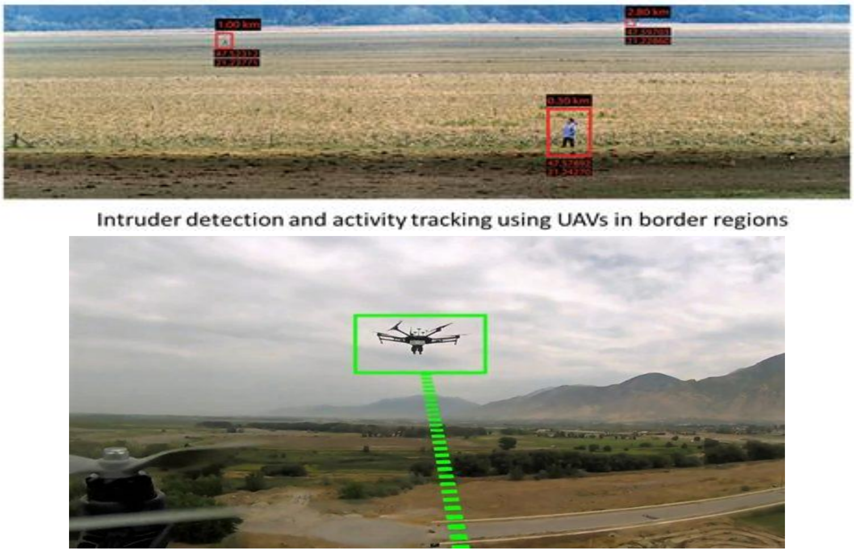


Figure 38: Drone intrusion detection

The recognition activity of drone will be handled by the computer vision techniques which includes human recognition, suspicious activity recognition, drone detection etc. There are plenty of applications of such recognition system such as intruder detection, delivery of goods, etc. Thus, the state-of-the-art object detection techniques (mainly human recognition) will be deployed along with the drone. Moreover, new light-weight and highly precise techniques will be also investigated for such tasks in border cases.

The UAVs for intruder detection activities have many design requirements as mentioned before: (1) noise potentially arising from the outside rotors, (2) small size of the whole system as the target should not easily detect it, (3) should withstand high temperature, wind, rain, and fly in dark without illumination, (4) weight of the payload should be considerably small as the UAV have to travel a long distance, (5) the connectivity of the components in the drone to the base should be strong so that even if the UAV travels to a long distance still it is possible to communicate with the UAV in a seamless manner, etc.

The hardware components chosen for various functionalities of the UAV basically affect the design requirements mentioned before, for example, choosing lightweight rotors may reduce the noise and the weight of the UAV, however, the UAV should also travel a long distance for certain applications. These conflicting design requirements lead to a multi objective problem where we need to study the tradeoff choosing one hardware component over another towards satisfying the design requirements. In this project, we propose to study all these design alternatives using a unified framework. The proposed strategic objectives include:

- Sensor calibration for reducing noise due to mobility distortions
- Development of standard operating procedures for operation in extreme weather conditions
- Novel frameworks for transmission of huge data generated.
- Autonomous surveillance module in low light/night conditions in cross border regions.
- Novel AI driven software system for low light image enhancement.
- Computer vision models to identify the suspicious objects/activities even in bad lighting conditions.

6.2.3 Indigenous Autonomous Surface Vehicles

ASVs (Fig. 39) are used for several defense applications, such as mine countermeasures, anti-submarine and maritime security, among others. ASVs have a key role to play in major scientific research areas – Bathymetric survey, ocean biological phenomena, migration and changes in major ecosystems, ocean activities research, multi-vehicle cooperation (cooperative work among aerial, ground, water surface or underwater vehicles), as experimental platforms for the purpose of testing hull designs, communication and sensor equipment, propulsion and operating systems, as well as control schemes Environmental missions ,Environmental monitoring, samplings, and assessment.

Figure 39: Autonomous Surface Vehicle

Research on environmental monitoring uses ASV for oceanic survey applications such as mapping/cleaning of oil spills, weather/storm forecasting, and water sampling search techniques for environmental monitoring. ASVs aid in environmental research which helps in prediction and management of disaster (like tsunami, hurricane, eruption of submarine volcano) and emergency response, pollution measurements and clean-up. Ocean Resource Exploration is another major application area for ASV - Oil, gas and mine explorations, offshore platform/pipeline construction and maintenance.

ASV is a crew-less autonomous navigation platform with long range and endurance. This can be configured with multiple sensor technologies/ equipment to fulfil the customer requirements. As Indian Regional Navigation Satellite System (IRNSS) have become more effective and affordable, advanced guidance, navigation and control systems based on IRNSS are proposed to be designed and developed for more capable, affordable, indigenous ASV platforms. The project is proposed to develop an indigenous Autonomous surface vehicles including development of subsystems like hull and auxiliary structural elements, propulsion mechanism and power system, GNC system, communication systems, Data collection equipment and Ground station. Sensors like Echosounders, Speed log, Side scan sonar and mmWave radar will be integrated.

6.2.3.1 Major Problems to be addressed

Unmanned surface vehicles (USVs) are extensively used for collecting ocean data, scientific research, mapping, commercial, and maritime security. Consistent growth in all the aforementioned sectors has certainly propelled the demand for unmanned surface vehicles and it is expected that the demand will grow with brisk pace in coming years.

USVs witnessed rapid growth in their application in the military and defense sectors. These vehicles provide unmatched surveillance towards the maritime borders and often used for preventive actions in case of emergency. The rapid adoption of such autonomous vehicles in military and defense application has certainly encouraged the growth of USVs market.

Bathymetric surveys being part of hydrographic measurements, which aims at measuring the seabed topography require adequate positioning, hence the use of unmanned boats in hydrography has become very popular.

Unmanned surface vehicles (USVs) come very handy for the management of coastal environment. USVs are an important and highly accessible tool for operating in shallow and near shore waters. The maneuverability and bathymetric survey capabilities of USVs are tested through sea trials. The results show that USVs have the potential to be an integrative platform for surveying shallow water zones (rivers, estuaries, and coasts), and this potential can be enhanced by installing appropriate transducers and sensor modules. The advances in sensing technologies and microelectronics will lead to the miniaturization of sensors and devices resulting in the proliferation of USVs in the field of coastal management.

There are grave challenges for real-world applications of ASVs such as accurate autonomous navigation, system endurance for long-term missions and operation under extreme weather conditions. Obstacle avoidance (both above and underwater) is also pointed as a technological challenge. The lack of laws and regulations for the use of ASV is yet another non-technological challenge which may get sorted out with the emergence of cost-effective technologies and the subsequent production in huge quantities. In this proposal the aim is to develop a crewless Autonomous Surface Vehicle which can perform tasks in a variety of cluttered environments without any human intervention, and is expected to exhibit highly nonlinear dynamics. Major features include:

- Development of a real-time CPS system with multiple sensors mounted on to the autonomous surface vehicle.
- Calibration of the sensors mounted on the vehicle
- New techniques for edge processing of the huge amount of data generated will be explored to meet the real-time constraints.
- Development of standard operating procedures for quality data acquisition from multiple on-board sensors.
- Autonomous control & way point navigation using GPS/IRNSS
- Redundant power supply - Dual powered (High density LiFePO4 battery & solar panels)
- Long endurance operation of up to 5Hrs continuously. Scalable depending on need.
- Maneuverability
- Modular design
- Autonomous Navigation, Collision avoidance and Communication suite
- Can be easily customized to the site & customer needs.
- Variable payloads like bathymetry sensors (pressure, temperature, wind, meteorological etc.), Bottom profiler, Depth sensor, SONARS (navigational, side scan, reconnaissance), LIDAR, Surveillance and collision avoidance (Thermal Imaging camera, PTZ CCTV wide angle camera, millimeter radar etc.)
- Hybrid propulsion system
- Conformity to Naval Standard

6.2.3.2 Technology

The technology involved in the development of an ASV is challenging. Expertise in multiple domains need to be integrated for bringing out a workable design (Fig. 40). The basic building blocks consists of Hull and structural elements, Propulsion and Power system, Guidance, Navigation and Control (GNC) System, Communication, Sensor system, Emergency response system and Control Console.

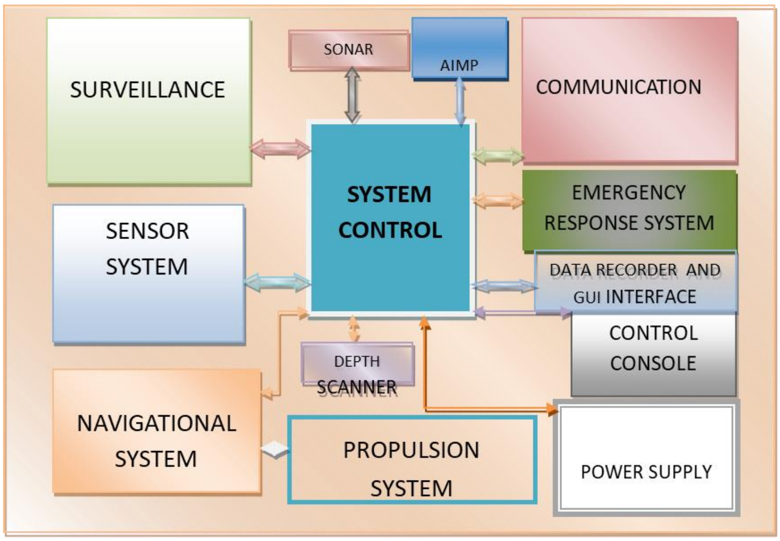


Figure 40: Functional Blocks of ASV

Guidance, Navigation and Control (GNC) System

Guidance, navigation and control (abbreviated GNC) system is to control the movement of vehicles, especially, marine craft in this context (Fig. 41). In many cases these functions can be performed by trained humans. However, for an autonomous vehicle/vessel, set of sensors along with an autopilot computer can substitute the human intervention required to control the vessel.

Autopilot Controller

The autopilot computer is the heart of the system, processing navigation data from the IMU, GPS, instrument system and outputs smooth control signal to the rudder and throttle/thruster drives. Physically an autopilot module can be a single board computer or a real-time microcontroller module running specific autopilot algorithm taking input from GPS, IMU and rudder/thruster feedbacks. Advanced AUTOPILOT systems can store multiple predefined trajectories and failsafe routes and points, realizing autonomous cruising with minimal operator intervention.

Failsafe Control

A failsafe controller is used for redundancy in case the primary communication or AUTOPILOT fails. The failsafe controller is equipped with an auxiliary communication channel and it activates the position transmission and aids in recovery of the USV. The failsafe controller also takes input from the health monitoring system and relays it to the control station via auxiliary communication channel. Failsafe controller can also guide the autopilot system to pre-programmed failsafe stations in case of communication failure.

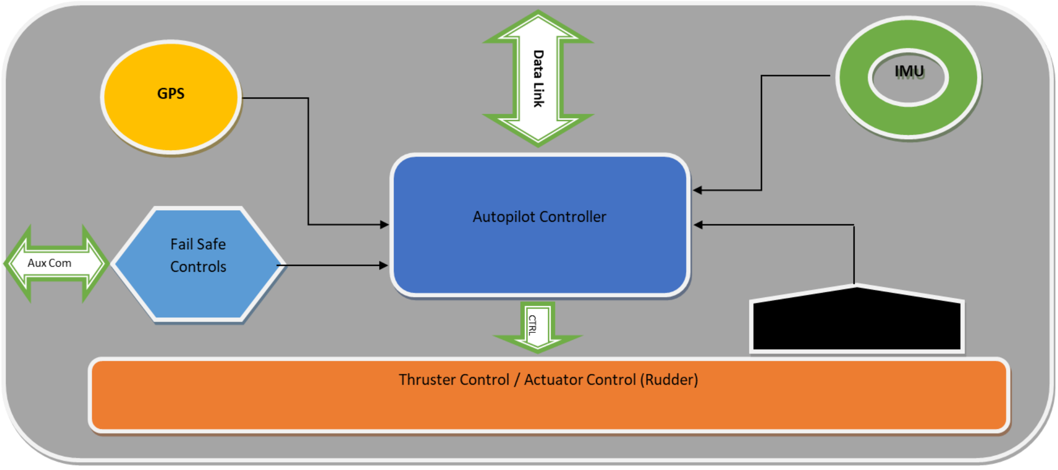


Figure 41: GNC System

Thruster Control / Actuator Control (Rudder)

Thruster control unit receives inputs from the autopilot module and activates corresponding physical actions such as direction change, speed change etc. The physical realization of this block is done using Electronic Speed Controllers (ESC), Throttle by wire units and Rudder control drives. All these units receive electrical signals from autopilot module and works accordingly.

Feedback Electronics

The feedback electronics transmits a signal proportional to the rudder angle, throttle status or thruster speed depending upon the configuration. It is mounted close to the probed device and is mechanically connected to the system using a transmission link. Physically this can be realized using Rudder Feedback Unit (RFU), rotary encoders and tachometers.

Global Positioning System (GPS)

The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities including navigation to military, civil and commercial users around the world.

Inertial Measurement Unit (IMU)

An inertial measurement unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and orientation of the body, using a combination of accelerometers, gyroscopes, and magnetometers. IMUs are typically used to maneuver vehicles (an attitude and heading reference system), including unmanned vehicles (UAVs) and Unmanned surface vehicles. IMU modules will give the positional awareness of the vehicle to the autopilot system for feedback control.

Collision avoidance

Sixty percent of casualties at sea are caused by collisions contributed by obstacles such as lobster traps, buoys, fishing nets, submerged rocks, other maritime traffic, new constructions, variable water levels, and sea debris. This leads to the importance for the capability of USVs to avoid collisions with any objects present along the planned path. In addition, a collision avoidance module can also enhance the autonomy of USVs to avoid approaching objects by conducting autonomous path re-planning.

Communication system

Autonomous surface vehicle is equipped with three levels of communication link for redundancy and emergency response. These include MIMO, UHF and Emergency Position Indicating Radio Beacon based technologies. The communication links are to be designed considering various aspects such as range, data rate, marine performance and recovery of the vessel in case of eventualities.

Sensor System

IASV payloads include components that the ASV will carry in addition to what is necessary to operate and navigate the vessel. Payloads will interface with the ASV and help carry out lethal or non-lethal missions. Non-payload sensors are necessary for basic operation of the ASV, and may include water sensors, temperature, pressure, wind direction, chemical, meteorological sensors.

Emergency Response System (ERS)

ERS of IASV consists of 3 modules namely a VHF communication link, a health monitoring system and a SOS system. VHF communication link will activate only on critical occasions and data will transfer to the operator through this medium. The operator can take control of the system by sending commands through this link. Secondly the health monitoring system always monitor the health parameters of all the units which are interfaced to system controller and it will initiate the corrective actions in the case of any failure in the IASV system. The SOS system will drive the system to a predefined location so that the IASV will automatically drive to that direction in the case of any critical failures. This will always check the power back up and produce beacon signals during critical failure situations.

Power System

First stage of the project is planned as an electric system till the GNC part is completed, then diesel engine is used as the main power of the IASV.An individual power supply system with the battery pack should be designed to guarantee the stability. This battery is used for starting, and supplies power to those existing facilities such as the system control and surveillance system on the USV. The Li-ion battery pack is used to feed all other loads with the power supply system, and it can be charged on need basis.

Navigational Data Recorder and GUI Interface

Basically there are two modes of operation for IASV, first is auto mode, in which the path is preloaded and IASV has to maintain the track. This method is preferred for long range sailing. Second mode is controlled by a user within the communication range. In both cases we need to store the data locally. There may be different type of sensors interfaced with ASV. If it is in mode 1 operation, it is not possible to send data immediately to the shore. In such cases, all data will be stored locally and can be retrieved when connected to the GUI interface. The GUI interface is capable of analyzing the data from each sensor and display/ print accordingly. In mode 2 operation, data will be sent to shore directly and at the same time a backup will be created in the storage. This system consists of a Navigational Data Recorder (NDR) with a NAND flash disk of high capacity for the storing of the data from different sensor and a microcontroller and FPGA architecture for handling the data received from different channels at different rates.

Vehicle design

The main part of the vehicle body is the hull (Fig. 42). The vehicle body is designed as a mono-hull structure. It is designed such that they have a larger L/B (Length to width ratio) as in figure and that the hull is symmetric about x-axis, to ensure stability.

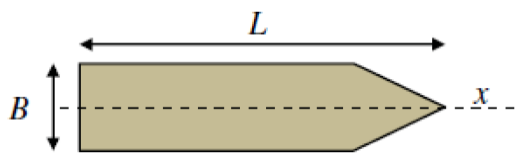


Figure 42: Mono hull structure aspect ratio

The mono hull is a vessel designed to operate in open waters and therefore it will have enough stability to guarantee the safety of the equipment. As it is important to balance the vessel in order to have good behavior at relatively high Froude numbers it was chosen a semi-planning hull type, which possesses a little of the planning hull characteristics and a common displacement hull, balancing the most important requirements. This type of hull form has a flat area with a certain degree of inclination located at the keel, which provides enough lifting capability to reduce wave resistance.

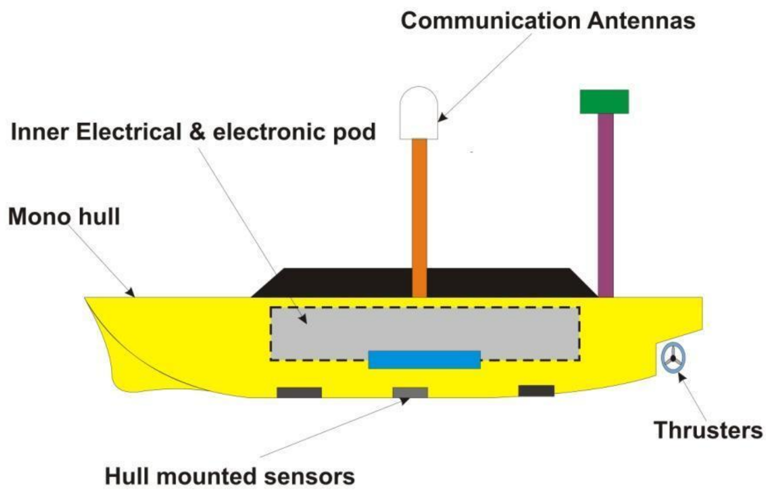


Figure 43: Layout of proposed ASV

The hull will have a built in water sealed chamber for placement of electronic capsule components, the control computer, the battery back, electrical relays, switches and actuator controls. Two solar panels will also be located at the top flat area of the hull (Fig. 43). The outer hull will also have special sensor mounting bays to integrate various oceanographic, telemetry and navigational sensors at the front end, sides and bottom ends. The ASV assembly is expected to have a gross weight of 350Kg.

6.2.4 Applications of Autonomous Vehicles for Environmental, Infrastructure Monitoring

6.2.4.1 Water and Air Quality Assessment

Water and air pollution is one of the increasing concerns in developing countries like India. Both drinking and usage of different water bodies like rivers, ponds, artificial water reservoirs are polluted due to explosive urbanization, industrialization and pesticides of agriculture and other connected fields. Continuous monitoring of distributed water bodies installing the pollutant sensors in the distributed water bodies is essential for better quality of water. Scalability of such wide area monitoring systems with traditional wireless sensor networks is challenging due to power aspects of the nodes, cost, maintenance etc. Proposed TIH wants to develop a UAV based autonomous and scalable water and air quality monitoring systems for distributed water bodies. Also, TIH will work closely with the **Govt. of Telangana for monitoring the Musi river bed** for algae growth and mosquito spread using UAVs. Below is the example for the above application (Fig. 44).

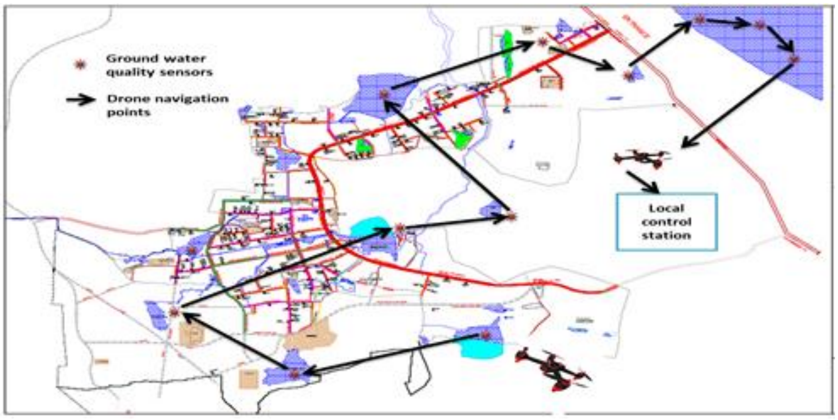


Figure 44: Data acquisition of distributed water bodies in an example geographical region.

We propose to arrive at a distributed water quality monitoring system for any given geographical area. Water bodies distributed in the given area are marked blue in color. Each water body is monitored by one or more sensors and a short range communication module like Wi-Fi. UAV with autonomous navigation can traverse through a predefined point of sensors shown in Fig. 62. Ground sensors equipped with communication modules can offload data to UAV whenever it is in its radio range. Drone after navigating through all defined points can offload sensor data, images/video to local ground stations. Computer vision based add-on applications like debris, wastage, chemical foam, unwanted plants can be classified at remote backend servers on the drone collected data.

The research also focuses on value add-on applications which have immediate societal impact in the same area. To mention a few; Detection of Chemical foam in water bodies due to industrial waste, Eutrophication effects, plastic & other waste in water. UAVs with a knowledge of the defined path of water bodies can collect images at periodic intervals and arrive at classification using AI and computer vision techniques.
The drone will hover over the desired area and capture the images. The image will be processed to localize the waste in the water body. The drone may be also equipped with grasping robotic hands which can automatically pick the waste from the water body and drop it at the designated place. Some of such application scenarios are described in Figs. 45 and 46. The proposed objectives include:

- Development of distributed UAVs based water body and air quality monitoring infrastructure
- Development of standard operating procedures for quality data acquisition using UAVs with multiple on-board sensors for environmental monitoring.
- Visibility detection with computer vision frameworks using images acquired from the UAVs.

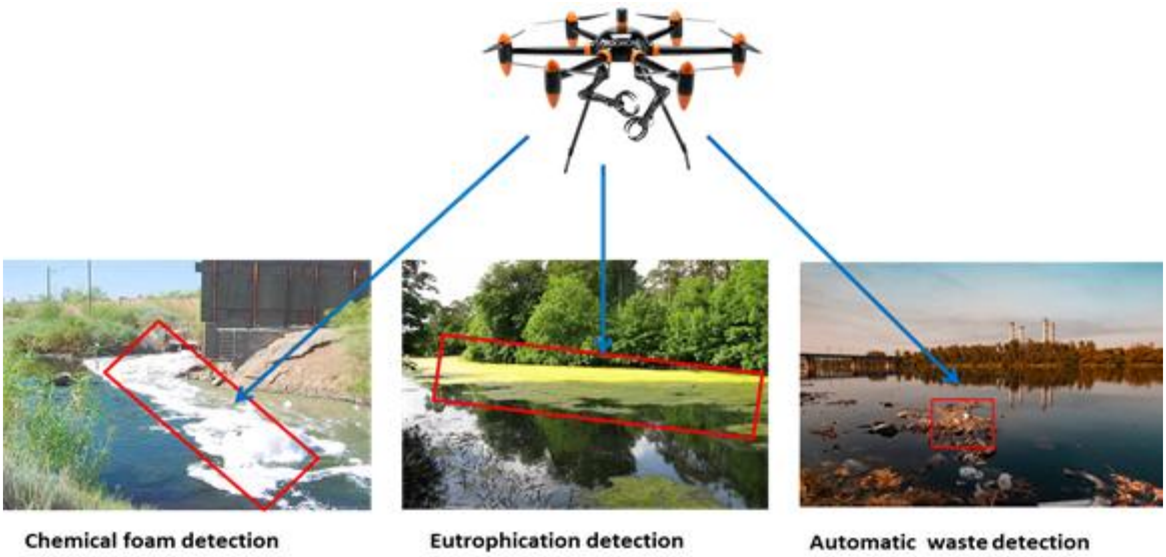


Figure 45: UAV based Water quality assessment applications

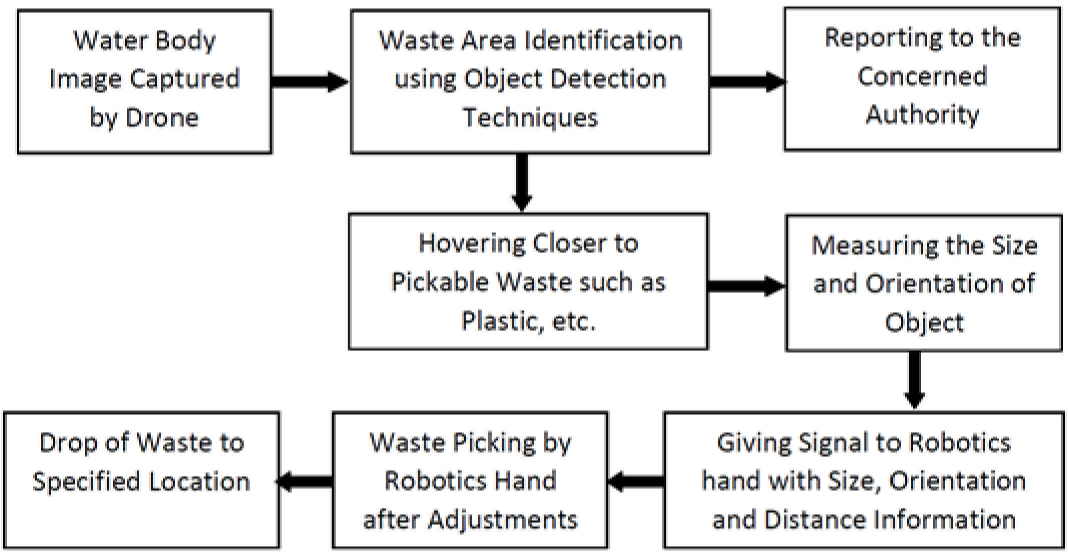


Figure 46: The flowchart for waste management in water bodies using Drone and Computer Vision Techniques.

6.2.4.2 UAV Based Soil Erosion Detection and Mitigation

The use of UAVs for the agricultural domain, in particular for monitoring soil erosion has both commercial benefits and environmental benefits. The use of UAVs for monitoring soil erosion has been published in literature in numerous articles in the past decade. The Food and Agriculture Organization of the United Nations has documented in this report the successful use of drones in Myanmar for detecting soil erosion to reduce agricultural risks.

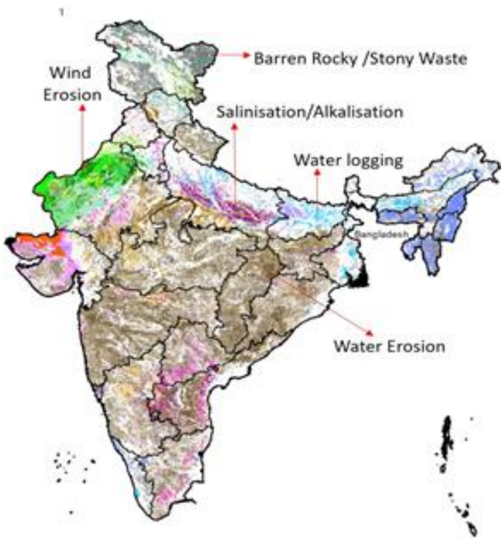


Figure 47: Land Degradation Map of India during the year 2015-2016 obtained using Linear Image Self Scanning System (LISS-3). Land degradation is temporary or permanent degeneration of productivity of land due to physical, chemical or biological factors.

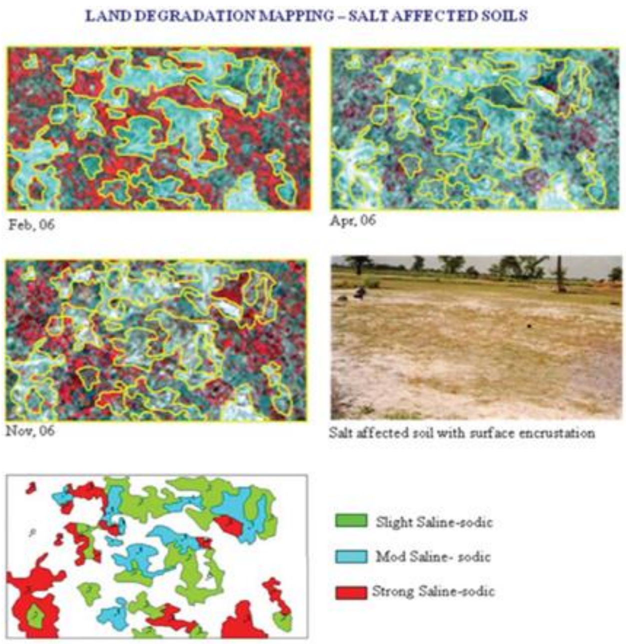


Figure 48. A salt - affected soil map obtained using geospatial technology such as remote sensing, GIS, and GPS for the study of land degradation mapping. The sensor used is Linear Image Self Scanning System (LISS-3) in the satellite and the data has been collected from multiple seasons.

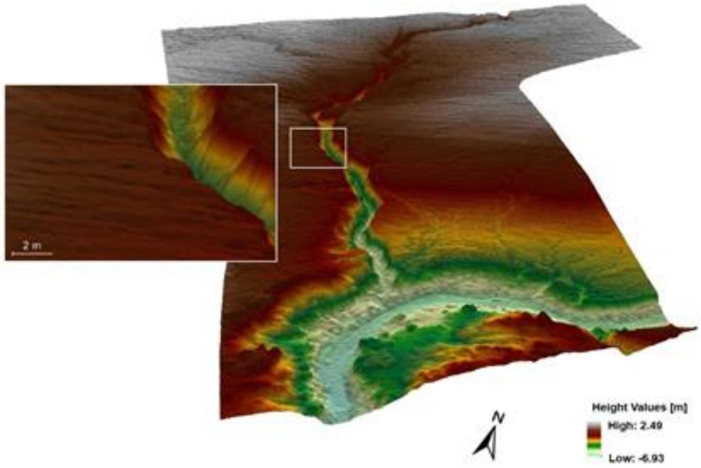


Figure 49: Digital Terrain Models obtained using UAVs to identify gully sites in a region in Morocco.

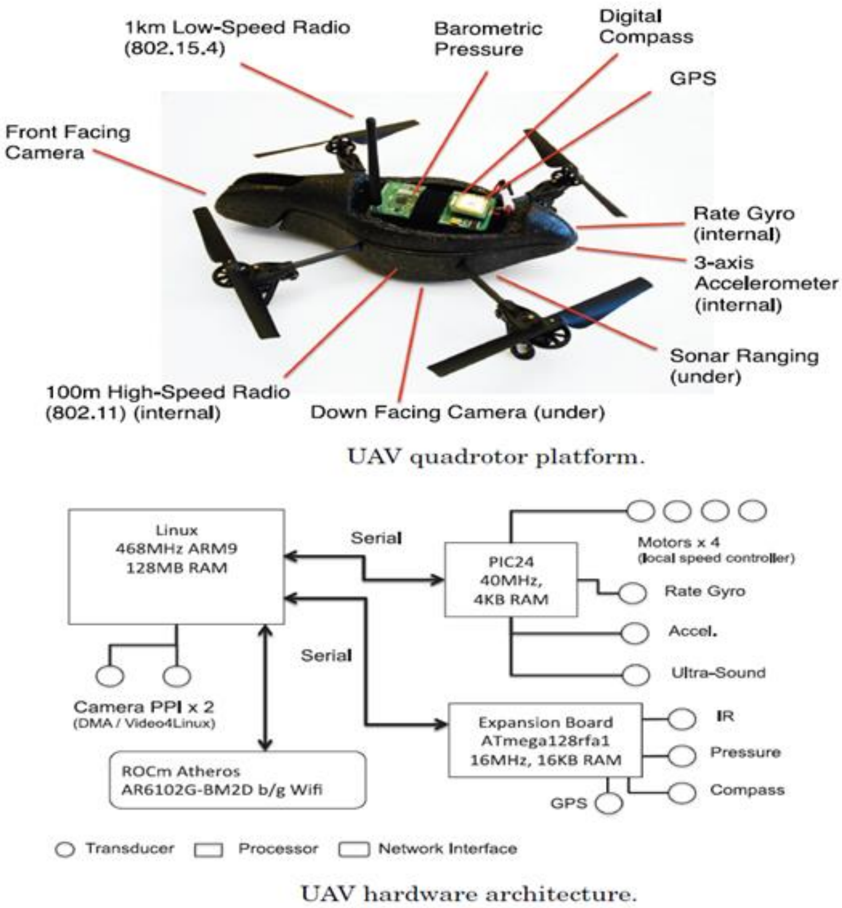


Figure 50: An example of the hardware components presented for a study of resource constrained hardware/software co-design mapping.

The Fig. 47 shows the land degradation is a synoptic view of soil properties across India from the National Remote Sensing Center, India Space Research Organization. These maps can be obtained from online queries from the Bhuvan portal. The output from our UAVs should be able to deliver such digital mapping with the geographical maps of various regions within India.

Further, the E-book published by the National Remote Sensing Agency, shows how we can identify whether the soil is degraded or not (that is salt affected soil regions with the soil mapping). The same report has also shown the detailed methodology on how we arrive at the land degradation picture, the soil mapping methodology.

The approach we propose in this application is to build a UAV prototype to navigate through geographical regions automatically and use artificial intelligence and computer vision techniques to automatically find the land degradation regions (Fig. 48-49). Our main contribution is also to design the UAV such that it caters to the requirements of the specific application, that is, to digitally map the images we get and to automatically identify the degraded land regions (Fig. 50). The use of Small-Aerial Format Photographs (SAFP) in drones (in Morocco) for mapping soil erosion shows the applicability of drones for repeated data acquisition. As there is repeated data acquisition, it is important to know the feasibility of using drones over such a large geographical map, especially in India. It has been shown that there is a possibility for minimizing the data collection latency and hence we can circumvent the problem of limited power supply of the drones with a predefined hovering time.

6.2.4.3 Power Line Inspection

Electrical power transmission lines are an important part of the Indian power infrastructure. Every year the power line failures account for huge maintenance costs for the distribution companies (Fig. 51). Typically, power line failures occur due to strand breakages, pole damages, foreign matter presence on the transmission lines, and corona leakages. These failures lead to significant outages and thus leading to revenue losses. However, one can reduce or control these losses by conducting frequent power line audits which involve significant human capacity and time. Also, this manual audit process requires huge investment and is also error prone. Recently, UAVs have proved to be a valuable technology for inspection of infrastructure. Especially, in the case of power line inspection, UAVs significantly reduce the business costs and time to anomaly detection.

UAVs provide a number of advantages for transmission line inspection:

- UAVs greatly reduce human labor and costs by automating inspections, saving 30 – 50% of the cost and time.
- Cell towers' condition and orientation can be assessed without the no need for workers to ascend to height. This reduces the life threat and towers remain functional during inspection.
- Drones enable collecting the needed data for identifying and mitigating risks in power distribution in advance
- Ultra-violet, Thermal and LiDAR can be used to aid in inspecting and monitoring the corridor for power lines and towers
- Inspections are done from a safe distance avoiding hazardous conditions, while increasing efficiency due to data accuracy and reliability with real-time images
- Higher-resolution visual inspections are possible as compared to ground-based inspections

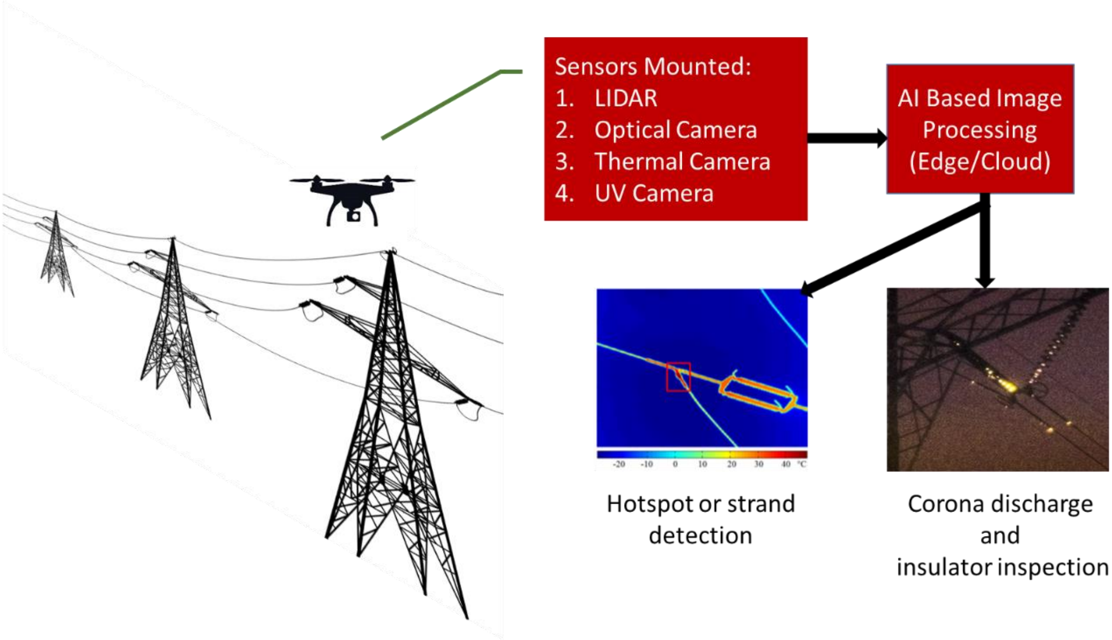


Figure 51: An example scenario of UAV based transmission line inspection.

The use of UAVs provides a flexible approach to acquire high-resolution airborne data on power lines. During recent years, the technological advances related to UAV components and battery technologies have been rapid, which have improved the feasibility of UAV-based data acquisition for power line inspection. Different UAV platforms have been applied to power line surveys. Generally, fixed-wing UAVs need to fly higher and faster and they are suitable for vegetation monitoring and rough inspection of long power lines, while multi-rotor UAVs can be used to acquire detailed pictures by hovering in the air close to the objects. However, for realizing a real-time CPS system using UAVs to monitor the power lines requires the following aspects to be addressed and are the main focus of this research:

- Development of standard operating procedures for quality data acquisition using UAVs with multiple on-board sensors in power line inspection.
- The sensors mounted on the UAV requires calibration which involves significant complexity
- The communication and transmission of the huge amount of data requires novel edge processing architectures and communication mechanisms.

There are various applications related to transmission lines where UAVs can play an important role:

Power line detection: Using computer vision techniques on UAV images detection of power line (conductor wire and other components) is carried out. Few interesting applications are detection of power line from images, 3D modeling of power line, detection of poles and their cross arms using oblique color images taken from a UAV.

Real time monitoring: Real time inspection of power line using UAV data is another important application. The visual data are used to detect vegetation and buildings close to power lines and calculate the distance between them and the conductors. For example, identification of power lines is based on a line detection approach, laser altimetry data are used to measure heights above the ground, and stereoscopic analysis is used to calculate distances between objects.

Detecting bad conductivity and hot spots: The joints have higher temperature than other parts of the towers and can thus be detected as hot spots in the thermal images. Temperature differences between joints are used to detect faults. Thus, the thermal image data are used to detect bad conductivity and hotspots in the power lines, transformers and electrical substations.

Vegetation control: Laser scanner data from a UAV can be used for vegetation controlling at high-voltage transmission lines. Using a laser scanner data, a 3D model, of power line is generated, which helps to calculate the distances between the vegetation and conductors. In addition, the problems to be solved in this project are given as follows:

6.2.4.4 Development of a power line crawling robot

Designing the power circuit of the robot: The robots used by utilities in USA, Canada, Japan use battery energy storage which increases the weight and needs to be charged after a short distance. This project will take power from the electromagnetic power of the transmission lines where the line is the primary of the current transformer and power for the robot can be extracted from the secondary. The CT will be clamp type and will be free to move along the line. The difficulties in extracting power is this method will be in opening the CT clamps while overcoming the obstacles. The strong electromagnetic field produced by the line current will try to oppose any change in magnetic circuit. Another difficulty will be in protecting the power circuit in case of any power system fault or current surge. Different types of CT core including air core, will be tested in these conditions. Optimum of size of a capacitor will be used after the rectifier in the secondary side of the CT to remove the effects of current transients in the primary. A basic schematic of the power circuit is given in Fig. 52:

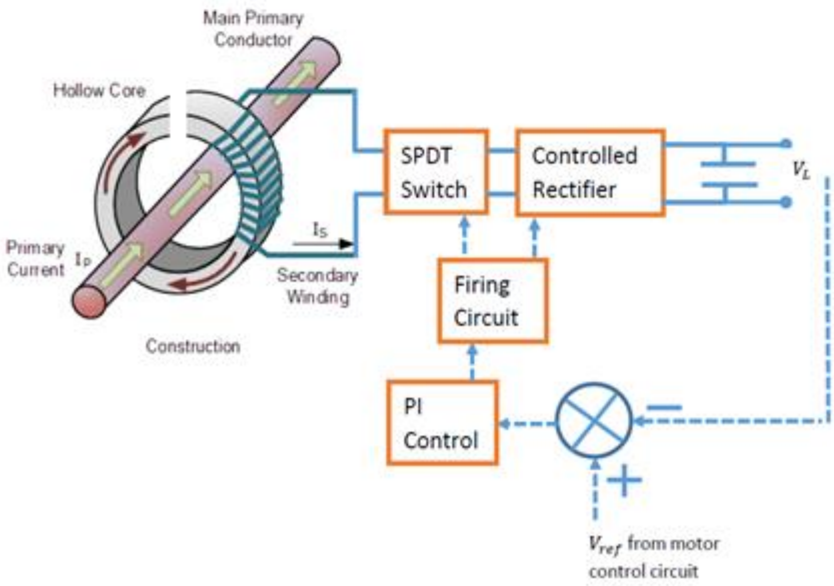


Figure 52: Schematic of the power circuit of the robot.

The SPDT switch ensures that a parallel resistance is connected across the CT secondary when current drawn by the controlled rectifier is zero at any instant e.g. during thyristor turn on and off transients. The proportional and integral control ensures that reference voltage is maintained across the motor input terminals.

Designing the robot: The robot will have to crawl over the transmission line conductors. It has to overcome different obstacles on the line and near the tower. Depending on the type of the insulator and bend on the transmission line path, there will be different obstacles near each tower. Also, there will be several in the line obstacles like Cable spacers, suspension clamps etc. Also, the robot should be able to crawl for single conductor lines as well as bundle conductor lines. The robot has to be manually mounted on two high-tension wires or a single wire. Once mounted, the wheels present in the robot would latch on the two wires. As the wheels are rotated, the robot could be made to move forward or backward on the transmission line. Mechanically avoiding the obstacles would be studied and implemented. Mechanical obstacle avoidance may be complemented with intelligent electronically controlled obstacle avoidance.

Inspecting the transmission line: The robot will carry a camera and different sensors to inspect the transmission line. Defects in the line will be inspected using HD camera, different sensors and electrical measurements. If there is any defect in the line conductor, insulator, tower etc., information of the location and the photos will be sent to a remote PC.

6.2.4.5 Oil and Gas Pipeline Inspection

The need and challenges for regular pipeline inspection are multifold. Typically, pipes used for oil & gas operations are required to adhere to strict quality standards checks before they are deployed in the field by the industry. These checks include verifying the effectiveness of the materials used against corrosion, pressure loads, wide range of temperatures and other physical damages expected during transportation, deployment and operational life-time of these pipelines. Additionally, these structures are used to transport hazardous and dangerous gases and liquids, which if allowed to escape can seriously endanger lives and the environment. To put things into perspective, a 1% leak in a 20-inch pipeline can lead to a loss of 450,000 barrels a year and can irrevocably damage an area of up to 10 square kilometers. It is therefore essential that proper care be taken to ensure the reliability and quality of the pipelines in the field. Traditionally, several intrusive and non-intrusive techniques have been utilized that include manual inspection, acoustic resonance, ultrasound scanning, flow analysis, MFL etc. The use of UAVs for pipeline inspection is a non-intrusive method not only for inspecting the pipeline itself but also to monitor the environmental conditions along the distribution network. UAVs enable coverage of large areas with varying terrains and can reach areas inaccessible by a human. There are several other benefits including cost-effectiveness, diverse applications, reduced scanning time, operational safety and environment friendliness.

The maintenance is a quintessential part of oil and natural gas industries. In this regard, GAIL has established dedicated National and Regional Gas Management Centres (NRGMCs) which monitor and control the pipelines across the country. The NRGMCs monitor overall installation, holistic maintenance and ensure their continuous and periodic assessment. Thus, a substantial portion of the revenue is allocated for maintenance activities at every level including at regional and at national levels.

The need for a detailed structural assessment can be assessed from the statistics. Statistics gathered by EGIG (European Gas Incident Data Group) over 40 years from 1970 to 2010 indicate 0.35 incidents per year per 1000 km. The incidents are recorded for unintentional release of gas due to failure in NG pipelines. This underscores a need for a detailed quantitative assessment of the structural health at every level of GMCs. Accordingly, the objectives include:

1. **Development of a real-time CPS system based RoV for gas pipeline inspection:** A real-time CPS system with multiple sensors mounted on to the RoV will be developed. For quality data acquisition from the sensors mounted, calibration is an important aspect which involves significant complexity. Also, new techniques for edge processing and communication of the huge amount of data generated will be explored to meet the real-time constraints.

2. **Comprehensive Quantitative Assessment of the surface flaws (spalls) severity:** Spalls are surface flaws which arise when a portion of material breaks off from the structure. By augmenting in-situ information of these flaws from a RoV, it is envisaged to get a comprehensive knowledge of conditions of the surface flaws. The information from the RoV in the form of 2D images are employed to construct a 3D CAD model which incorporates the flaw morphology details. The CAD is constructed by employing algorithms from image-processing techniques. The 3D CAD model, thus, constructed renders conveniently for FEA in commercial software. Subsequently, the FEA results can be used to assess the severity of the flaws using established theories in Solid Mechanics. This comprehensive information on the flaws acts as a guide for judicious planning of subsequent actions. The outline is schematically represented in Fig. 53. Indirectly, this comprehensive quantitative assessment of structural health will help in leading to optimization of resources including, among other things, judicious scheduling of maintenance and repair.
3. **Integration into a seamless analysis module:** A module incorporating seamless integration of surface flaws image data from RoVs, image processing algorithm for conversion to 3D CAD model and the subsequent FE analysis, is envisaged.

4. **Pipeline Surveillance**: A UAV equipped with a visual or infrared camera can be used to perform regular patrolling duties. UAV platforms equipped with such devices can be configured at take-off, navigate and patrol a segment of pipeline, identify and capture images or videos of areas of interest at predefined timings and return to their base station with little or no human intervention.

5. **Physical damage and corrosion detection:** Images captured from a high-resolution camera onboard a drone can be processed on board to identify loss of protective coating, joint failures, buckling & bending, dents and gouges on a pipeline surface.

6. **Pipeline leak detection**: To identify gas leaks, drones can be configured to carry a payload of on-board gas sensors. Air samples on top of the pipelines can be analyzed to measure the concentration of various gases and to detect a potential leak. Drones carrying specialized hyperspectral or infrared cameras can identify the nature of leaks by measuring the absorption of background radiation at multiple-wavelengths and uses techniques such as Fourier transform infrared spectroscopy (FTIR) to identify the nature of the leak.

Deliverables:

A system consisting of a ROV equipped with camera, an algorithm to convert 2D image to 3D CAD models

incorporating flaw morphology and FEA giving a comprehensive quantitative assessment of the severity of the flaws. Also, we propose to develop standard operating procedures for acquiring high quality data from the ROV with multiple sensors for pipeline inspection applications.

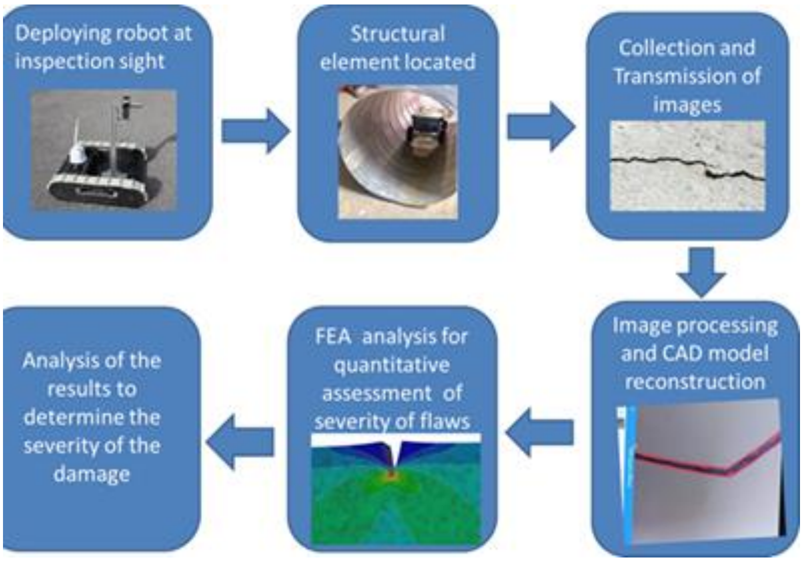


Figure 53: An outline of the details for execution of the proposal

6.2.4.6 Structural Health Inspection

Commonly known as Structural Health Assessment (SHA) or SHM, this concept is widely applied to various forms of infrastructures, especially as countries all over the world enter into an even greater period of construction of various infrastructures ranging from bridges to skyscrapers. Especially so when damages to structures are concerned, it is important to note that there are stages of increasing difficulty that require the knowledge of previous stages, namely:

- Detecting the existence of the damage on the structure
- Locating the damage
- Identifying the types of damage
- Quantifying the severity of the damage

The following are the objectives of this research:

- Development of standard operating procedures for quality data acquisition using UAVs with multiple on-board sensors in structural health monitoring.
- Identification of structure(s)
- Development and installation of sensors - The sensors include accelerometers, strain gauges, displacement transducers, level sensing stations, anemometers, temperature sensors and dynamic weight-in-motion sensors. They measure everything from tarmac temperature and strains in structural
- Integration of Data acquisition systems
- Development of autonomous navigation frameworks for quality data acquisition and obstacle avoidance
-

6.2.4.7 Application to Railway Track Inspection

Railway track detection and gauge measurement are considered as crucial aspects of railway inspection systems. Traditionally, monitoring was done manually with extensive human labor. Nowadays, the trend is to use computer vision-based systems capable of automatic information extraction. In recent years, various prototypes of vision based inspection system have been proposed, most have a camera mounted on carts or trains. Employing drones for such monitoring systems provides a cost effective and accurate means for monitoring tracks.

Railway station inspection: One of the applications is to inspect train station for maintenance. Unmanned aerial vehicles are flying over the train stations and platforms to collect photos and videos of the infrastructure objects. With the help of the drones, the maintenance of the train stations can be improved (Fig. 54)**.**

*Figure 54: Railway track inspection with UAV [*https://www.geospatialworld.net/news/indian-railways-deploy-drones-projectmonitoring/ (accessed Jan. 15, 2020)*].*

Track maintenance: Another important application is track detection and inspection. Unmanned aerial vehicles, equipped with a heat-sensitive 4K camera, help to identify the damages of the tracks. Network drones are considered as a good option for track maintenance. The advantage of UAV is that the flights do not require to close the railways for train traffic.

Track-side vegetation management: The presence of track-side vegetation of a height exceeding that of the rail and/or in the ballast section may result in damage to track and locomotive components or increased risk of derailment. UAVs are being used effectively for selective vegetation monitoring which, in turn, facilitates proactive control within the right of way in order to achieve the following: maintain sight line visibility at road and pedestrian crossings; reduce physical hazards to train crews and track maintenance personnel who must work in these areas; reduce fire hazard potential; remove woody vegetation and brush that is interfering with the normal functioning of equipment used to detect rock falls and slides.

6.3 Agriculture

6.3.1Introduction

The quality, quantity, and security of the food is a global challenge that needs to be addressed in the view of the growing population. Agriculture being the backbone of the Indian economy has witnessed significant advancement over the years, but still is in a nascent stage in terms of technology adoption. The agricultural industry must use the available resources to the maximum extent possible in order to cope with the population growth. Hence, precision agriculture (PA) can play a significant role in reaching this goal. PA is one of the crucial areas of interest where both the developed and developing nations are increasingly focusing to develop different breeds of crops that are stress-tolerant, disease-resistant, and also provide high yields with optimized inputs. PA often utilizes digital techniques (remote sensing, sensors, etc.) to optimize inputs (water, fertilizer, herbicides, insecticides, etc.) while minimizing environmental impacts. The traditional techniques used for crop improvement are the bottleneck as the methods used are manual, destructive, time-consuming, and hence require more workforce. The concept of "Agriculture 4.0", recently developed to enhance agriculture, emphasizes the utilization of digital information, and creates actionable intelligence and meaningful added value from such data to deliver impact on the ground. In agriculture, many developed countries are already benefiting from remote-sensing imaging techniques for monitoring the health and security of the crop. Therefore, the over-reaching aim of the project is to develop the tools and methodologies in order to enable the cost-effective high throughput and standardized phenotyping services to assist crop-improvement programs. The scope of project will include support to develop and validate the robust methodology to capture the main agronomic features of the crops using the images generated by various sensors (RGB, Multispectral, Hyperspectral, Thermal, LiDAR, etc.) carried by the suitable unmanned autonomous vehicle (UAV). This will involve access to the field trials and generation of ground truth observations for the traits of interests. In India, the use of drones for agriculture has just begun, nevertheless, being hindered by evolving country regulations and lacking expertise and capacities to handle the required operations. Once these obstacles are crossed, UAVs utilization in agriculture can contribute to achieving the country's goal to improve production, efficiency, in the agricultural sector. Fig. 55 shows a typical processing architecture when utilizing drones for agricultural applications using various sensors.

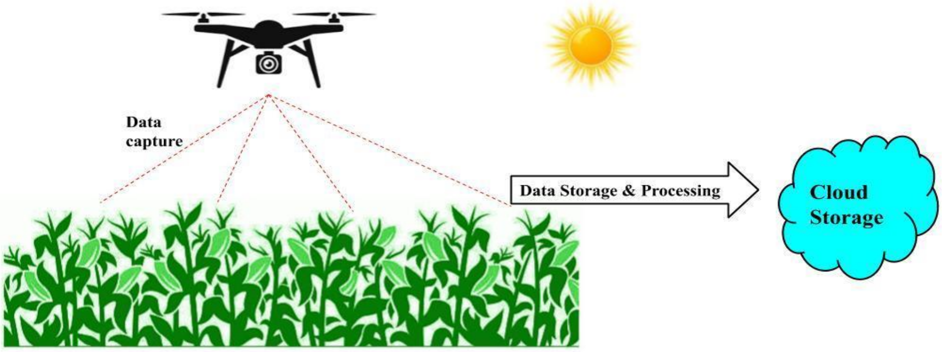


Figure 55: Data Capture from UAV in the Agriculture field

6.3.2 Technology

In this we plan on realizing a real-time CPS system for agricultural applications using UAVs, with multiple sensors (both for autonomous navigation and imaging) integrated to the mobile environment. Hence, the sensors need proper calibration for quality data acquisition. Also, importantly, the sensors mounted on the UAV used for agricultural purposes such as hyper-spectral camera, LiDAR, etc., generate huge amount of data and requires novel and efficient edge processing and transmission techniques for meeting the real-time latency requirements. In addition to the above, following are the technological objectives that will be addressed as part of this project.

6.3.2.1 Need for Standardization

Establishing ground rules before flying drones over fields can help efficient image capture and analysis. The quality image acquisition from UAV is challenging as they depend on many technical (e.g. altitude, speed, flight plan, camera set-up, etc.) and environmental parameters (e.g. wind speed, solar radiation). Following are the challenges faced while acquiring images from UAV which need to be resolved in a standardized way:

- Technical set-up (flight plan [height, speed, overlap], cameras set-up)
- Accounting for environmental variables (light, wind speed)

For example, the number of images captured varies with the speed of UAV which affects the further process (i.e., construction of orthomosaic). The UAV flight altitude affects the spatial resolution of the image. Raising flight altitude allows covering larger areas than a low altitude survey but results in poor spatial resolution of the image. At very low altitude, and with the high speed of UAV, the image quality degrades because the propellers induce speed along with wind speed, hence, the crop gets distorted, which results in poor picture quality. The altitude of UAV also depends on the type of crop and crop stage or DAS (Days After Sowing). Similarly, UAV flight plan depends on the number of overlaps required. Flying with the perfect amount of overlap can produce quality images while using batteries most efficiently. There are two overlaps: Frontal and Side overlap. Frontal overlap tells how fast the drone will be taking pictures throughout the flight, Whereas, side overlap will distinguish the number of transects a flight will need over the area of interest. Increasing the value of side overlap will have more effect on battery life. To obtain the range of parameters for better image quality, various spatio-temporal datasets has to be collected across the environmental conditions. Based on image quality metrics considered, optimal range of parameters are obtained for a better picture quality which helps in evaluating crop phenotypic traits which contribute to crop improvement programs. Therefore, these technical and environmental parameters will have to be evaluated in the standardized way to optimize protocols for the picture image acquisition.

6.3.2.2 Processing of UAV Images

Once the standardization procedure is set for quality image capture from Drones, the flight data is captured and the processing of such huge amount of data generated from multiple sensors - like RGB, Multispectral, Hyperspectral as given in Table 3 in real-time comprises of the following challenges which lay the foundation for our proposed research activities.

- **Data quality analysis** - The data collected during the flight on the site should be verified for quality in terms of its usefulness before processing. This is required because the images captured depend on technical setup (speed, height, the overlap of UAV, aperture, shutter speed of camera) and environmental conditions (wind speed and solar radiation) which affect the spatial resolution of the image. Also, this analysis helps us in developing standard operating procedures for different applications. The quality analysis is done after some time of data collection. It should be done in real time on the UAV itself while capturing the images.

Pre-Processing - Currently, commercially available softwares like Pix4D, Agisoft Photoscan are used to construct DSM, DEM model and aerial view of the field (orthomosaic) . Whereas QGIS, ArcGIS are popularly used for creating shapefile which is useful for the segmentation of individual plots. DSM and DEM is used to estimate the plant height. This process is manual and is time-consuming, and hence, there is a need for automation of this process for real-time application. Spectral Indices (NDVI, NDRE, etc.) from multispectral, hyperspectral are used to estimate the vegetation content, weed detection, early stress detection, disease, and pathogen detection, nutrient analysis, etc.., as

- shown in Fig. 56. Also, AI and ML algorithms are used to extract the features of the plants. The images are trained to learn the features and this helps in stress, weed, disease detection. Ground truth is collected manually and the output obtained is validated to check the accuracy of the algorithm. This whole process takes at least one day to get the final desired output. Hence, automation is required for processing of UAV images with less human intervention.

Table 3: Flight data from different sensors for a single flight path

Name of Sensor	Flight time (minutes)	Speed of UAV (km/h)	Altitude of UAV (m)	No.of Images Captured

RGB	10 - 12	5	10	200 - 240
Multispectral (5 bands)	10 - 12	5	10	2000 - 2500 (for 5 bands)
Hyperspectral	10 - 12	3.6	20	25 - 30 data cubes

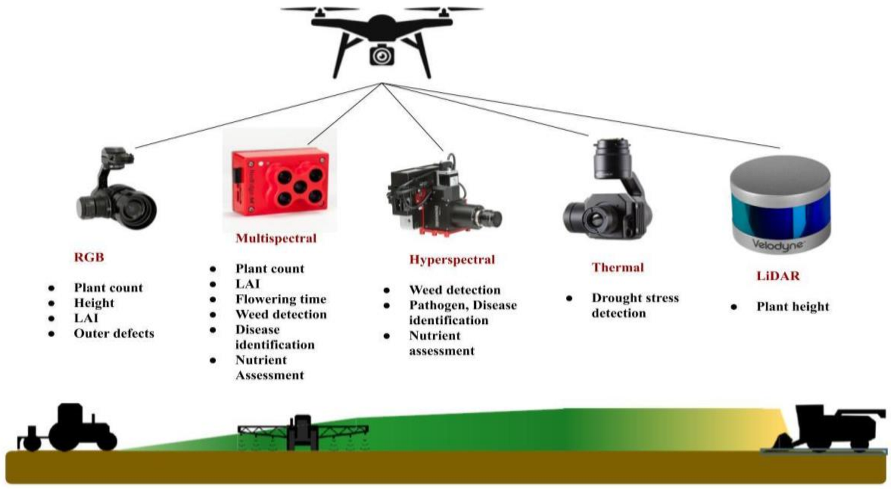


Figure 56: Sensors integrated with UAV and their application in Agriculture

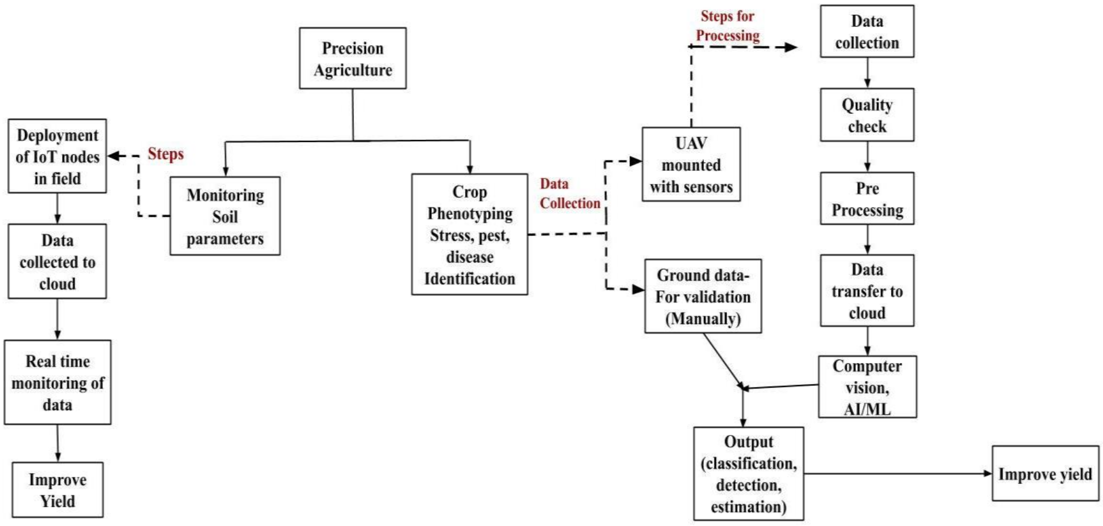


Figure 57: Flowchart to obtain objectives of precision agriculture

➢ The intervention of sensors and wireless networks has transformed cliched agricultural practices. Internet of Things (IoT) has penetrated various verticals, with agriculture being one of them. The application of IoT in agriculture is primarily focused on field parameter monitoring and automation, which aims to help farmers increase crop yield. Long-range and low-power devices, convenient installation, and cost-efficiency are the primary factors to be considered for deploying an IoT network in real-time. In this project, we also aim to propose a low-power long-range IoT network for monitoring of soil parameters (moisture content, temperature, humidity, etc.) in the field. With continuous monitoring of evapo-transpiration in plants, one can optimize the flow of water and try to improve yield. The flow chart for the processing is shown in Fig. 57.

6.3.2.3 Need for Edge computing:

The challenge for airborne agriculture is to produce useful information quickly and locally from the enormous data generated so that decisions and actions are taken at the same time. Due to the presence of multiple imaging sensors on-board, a huge amount of data is captured during every flight (Table 3). The time taken for analysis using software such as Pix4D, AgiSoft Photoscan, or uploading it to a cloud server for overnight processing of AI, ML algorithms not only costs money but also eats away the valuable time and information. For example; the picture quality depends on environmental conditions. The quality should be analyzed on the spot because a slight delay may change the environment drastically and may not be feasible to capture data which further affect the estimation of traits and yield. So, there is a need for real-time quality analysis while capturing images. Also, Crop health includes stress level, pest, disease detection, and nutrient deficiency. Monitoring of crop health is essential for better quality, quantity, and yield. The health of crops might be decayed in cases where a failure condition exists that demands immediate action. A slight delay can result in a loss of tens of thousands of dollars in terms of yield. Most of the agricultural fields in India and around the world are located in rural areas where the connectivity to the network is less. Hence, it is difficult to upload the data to the cloud and processing gets delayed which may further affect the crop and its yield. Therefore, there is a need for edge computing devices enabling AI, so that the captured data can be processed and decisions

can be taken in less time. Nowadays, Edge computing is used for real-time object recognition and tracking, Face recognition, Logo detection, etc. Edge computing combined with AI can address this problem and can benefit breeders and farmers. Various edge computing technologies such as Multi-access edge computing (MEC), Fog computing, Cloudlets, Microdata centers and Cloud of Things (CoT) are developed to process the data at a faster pace. The benefit of edge computing is the ability to process and store data faster, enabling more efficient real-time applications that are critical to agronomists. Companies such as NVIDIA recognized the need for the processing of this huge data, and has developed edge computing platforms which have AI computation capabilities inbuilt. The company's latest Jetson Xavier NX module is smaller than a credit card and can be built into drones. The AI algorithms require large amounts of processing power, which is why most of them run via cloud services. The growth of AI chipsets that can handle processing at the edge will allow for better real-time responses within applications that need instant computing.
The authors in described a framework based on IoT and have been deployed and validated in vineyards. Here the soil and weather parameters are monitored as this affects the health of the crop. The developed architecture is Cloud-centric, with an edge computation node being harnessed to collect data from the distributed sensor network. Recently Slant Range has tied up with Microsoft to develop powerful and scalable

aerial measurement and data solutions for the global agriculture market. The combination of spectral imaging technology alongside Microsoft Azure Internet of Things (IoT) Edge will enable agriculture firms to collect, manage and analyze data from large networks of sensors that can be used anywhere in the world, including in the most remote farming areas.
Hence, UAVs mounted with sensors is the future of the Agriculture sector. The challenges faced with the processing of data are discussed. The recent development in edge computing can address these challenges and help the farmers to take the decisions required for crop improvement. The benefits of edge computing along with AI can change the future of PA and can help breeders to develop the disease and stress-tolerant crops with high yield addressing the global challenge.

6.3.2.4 Semi-Autonomous Navigation Algorithms for UAVs and UGV in farming

The crop and health monitoring sensors proposed to be developed require the measurements from different parts of the farm land. Using a ground robot carrying the sensors can speed up the task of taking the measurements, and with appropriate on-board processing, recommend the required actions like pesticide or fertilizer application etc. The ground robots can be used to take the necessary actions, if they are equipped with appropriate mechanisms. UAVs complement the tasks of ground robots through over the canopy imaging, quick surveys, bulk spraying etc.

The navigation of these robots is constrained by the limited spaces between the rows of the plants and other obstacles present in the field. Fully autonomous navigation requires multiple high accuracy sensors and complex algorithms while the manual remote operation requires a well-trained operator. We aim to develop control algorithms for UAVs, and UGVs which demarcate the tasks for autonomous navigation and human operator so that, the navigation becomes more intuitive for the operator, freeing his/her mind for more effective operation for the task at hand like imaging, pesticide applications, weed removal etc. Proposed objectives include:

1. Design of autonomous navigation algorithms for UAVs, UGVs, and ROVs under typical conditions of agricultural land with low-cost sensors e.g. for moving UGVs on loose soil, operate UAVs in slow wind conditions.
2. Demarcate the autonomous tasks and tasks requiring human intervention.
3. Explore different possible user interfaces for human intervention and feedback.
4. Integrate remote operation by human operator with the autonomous navigation algorithms and device conflict resolution techniques.
5. Optimization of algorithm, field study and prototype development.
6. Development of training/ simulation software.
7. Patenting, technology transfer / startup for commercialization.

6.3.2.5 Few-shot and self-supervised learning for remote sensing of Agriculture:

Deep Learning methods are data-hungry, which gives promising results under the availability of sufficiently large labeled data. However, in the remote sensing field, data annotation for labeled data is difficult and very expensive. Also, sometimes it may be possible to encounter unseen classes in the images. Some techniques such as data augmentation (DA), transfer learning (TL), and unsupervised/semi-supervised learning have been proposed to overcome this problem to some extent. Few-shot and self-supervised learning-based techniques can effectively solve the problem of limited labeled data availability of remote sensing with UAVs. A few-shot classification aims to make a classifier learn to recognize unseen classes during training with limited labeled examples, which aims to build accurate ML/DL models with less training data, and less resource costs (time, space, and computational). In self-supervised learning (SSL), the main aim is to make use of large volumes of unlabeled data along with few labeled data. In SSL, labels are generated from the unlabelled data, using the structure or characteristics of the data itself, and then train on this unsupervised data in a supervised manner. The objective is to develop few-shot and self-supervised learning techniques for the analysis of remotely sensed imaging data with UAVs for agricultural applications.

6.3.2.6 Leveraging the UAV-based technology for crop residue: an important resource for the crop-livestock farming community

Livestock animals are an important part of the agriculture-based farming community in India. Grazing has long been the principal source of feed to these domestic animals that has now drastically declined due to changes in land use, land degradation, and population pressure. Currently, feed supply and demand scenarios show that crop residues (CR; leftover crop biomass in fields after grain harvest) such as straws, stover, and haulms contributes to 50–70% of the feed resources in smallholder crop-livestock mixed farming systems. The challenge for crop improvement teams is now not only to increase the quantity of crop biomass but also to enhance the quality of crop residue. Present reports show that crop residues are generally poor in their nutritive value with low nitrogen (crude protein content <4%) and digestible organic matter (less than 50%). Large variation has been reported for crop residue quality traits, and this leads to major increases in milk or meat productivity. Formal and informal trading happens for crop residues and starts being graded for quality with a price premium paid to the highest quality crop residue. Market studies in India have identified significant differences

Crop improvement for crop residue (CR) quantity and quality is seriously constrained by easy and quick phenotyping methods. Measuring stover yield in the field is mostly manual, laborious, and time-consuming. Nevertheless, CR quality assessment is still more cumbersome than stover yield which ultimately determines livestock performance trials which are unsuitable for routine feed and fodder quality analysis. Previous studies have shown a wide range of potential in vitro traits (in vitro digestibility, Nitrogen content) were investigated in sorghum stover and groundnut haulms related to livestock performance measurements and found consistent relationships with in vivo measurements. Conventional laboratory analysis cannot efficiently cope with the large set of sample entries from multidimensional crop-improvement programs. Therefore, we identify these as major thrust areas where advanced technology like UAV-based phenotyping can boost the multi-dimensional crop improvement for crop residue quantity and quality programs for crop-livestock smallholder farming community. While there have been a number of initiatives to use UAV-based imaging to generate plot-based indices of breeding plots, time and resources have been often inefficiently used in trying to develop homemade solutions that were either improper because lacking that different skill set, or impossible to scale up. UAV-based imaging is still far from being common practice in breeding programs, despite their great potential benefits. Part of the reason is indeed in the difference in the skill set needed to use such techniques.

Therefore, the main objective is to develop;

1. UAV-based image analysis for crop residue yield in terms of plant height and canopy coverage in sorghum and groundnut varieties.
2. Exploiting UAV-based images for crop residue quality in terms of color (Nitrogen content and digestible stover yield).

Testing the cost efficiency of the multispectral and hyperspectral cameras for AI-based stover quality assessment.

6.3.2.7 Hyperspectral Remote Sensing with UAVs for Agriculture:

Monitoring the agronomic crops in terms of nutrients, diseases, pest attacks, water-stress, and overall plant health is very important in successful agriculture. In traditional agriculture, this was done by the visual examination of crops from the ground, which were faulty. Sometimes the visual symptoms will be noticeable even to the experienced observers only after the conditions due to stress are well-advanced.

The rich spectral information provided by hyperspectral sensors in hundreds of narrow spectral bands has potential to precisely study these changes, and early detection of stress related issues. Due to high spatial, spectral and temporal resolutions UAV-based hyperspectral imaging (HSI) can be successfully employed in precision agriculture.

Drought Stress Analysis:

Water is a key agronomic input, which affects the health and growth of the crop, and hence production.

Early detection of water-related issues in field crops will help to identify the irrigation requirements of the crop. Around 70% of the freshwater worldwide is used for agriculture. Due to the decrease in rainfall in the past decade, the farmers are forced to utilize groundwater for irrigation requirements. Hence efficient utilization of water resources is crucial farming like identifying the precise areas in the field which require water and irrigation scheduling etc. Also, in crop phenotyping agriculture scientists are working to develop new cultivars which are resilient to water stress and produce high yields. But, the major bottleneck in phenotyping is to assess thousands of cultivars under field conditions. Till now the imaging techniques, mostly RGB and partly Multispectral cameras have been explored to partially address the traits related to drought. However, the phenotyping for abiotic stress such as early detection of drought stress can be explored more precisely through the rich spectral information provided by hyperspectral imaging. Hence, the drought stress analysis is very important in successful agriculture.

Nutrient Stress Analysis:

Nitrogen and phosphorus are considered to be very important plant macronutrients and proper management of them is a prerequisite for successful agriculture. Nitrogen plays a vital role in health, growth, and yield of the crop as it is a major component of chlorophyll- which is used in photosynthesis, a major component of amino and nucleic acids, the building blocks of proteins. Phosphorus (P) is another essential nutrient which determines plants' growth and productivity. Phosphorus stress in plants generally shows no obvious visual symptoms other than stunting of the leaves. Hence, the nutrient stress analysis is important in crop phenotyping. The abiotic stress due to nutrient deficiency in plants can be precisely studied and can be identified in advance using hyperspectral imaging techniques. Also, with UAV-based hyperspectral sensing it is possible to identify specific areas of the field that are nutrient-poor, which enables the precise application of fertilizers.

The key objectives are as follows:

1. Early detection of canopy water stress and nutrient stress (nitrogen and phosphorus) using UAV-based HSI.
2. Progressive water stress and water intake profile analysis of different genotypes.
3. Developing irrigation scheduling algorithms for precise water management by taking weather forecast information also into account.
4. Biomass and yield estimation analysis due to abiotic stress.
5. Development of ML/DL-based algorithms.

Disease/Pest Identification:
Pests, fungi, pathogens, etc. cause serious damage to agronomic crops and yield losses. Early detection of crop diseases in the fields will allow the agriculturists for immediate treatment of the affected areas, and also prevents the disease from spreading to neighboring fields. In general, healthy plants interact differently for electromagnetic radiation than infected plants that lose pigmentation. Hyperspectral imaging has the potential to detect crop diseases, pests by identifying the changes in canopy reflectance caused due to infestations well ahead of the visual symptoms. Lee et al. in showed suitability of V-NIR reflectance for detecting pathogen propagation and chlorophyll degradation, Bauriegel et al. in studied the early detection of Fusarium infections in 400 nm - 1000nm range. In the early detection of sugar beet diseases, and in Franke et al. detection of the leaf rust disease caused by the fungal pathogen were studied using HSI. Based on the previous studies, hyperspectral imaging has potential in early identification of disease/pest attacks in agronomic crops. Also, HSI can be used in mapping fields with diagnostic symptoms for plant disease management. UAV-based HSI can automate this process, in mapping fields with diagnostic symptoms, and will be helpful in crop disease management.

6.3.2.8 Secure Learning and Communications for Autonomous Navigation and Data Acquisition Systems in Farming

The first objective to be addressed is the development of a proprietary wireless communication system, which is tailor-made for automatic navigation. This system should not only be able to communicate control messages required for navigation (which are typically low data-rate), but also provide a mechanism for relatively high-rate data transfer (if required by the application). For example, in the case of crop monitoring, the communication system should provide the bandwidth to transfer the images of the crops to a central server periodically. When this data transfer is not required, it should be able to use the bandwidth to further improve the reliability of the control message transfer. The proposal aims to design such a communication protocol, focusing on the network, medium-access control and physical layer aspects.

Secondly, autonomous navigation requires the collection of data from various nodes through wireless links, in order to take either centralized or distributed decisions. The success of algorithms aimed towards achieving autonomous navigation heavily relies on the fact that the communication is optimized to achieve better performance with respect to the goals set by the application and there is no threat to security in terms of attacks i.e., the algorithm and communication protocol should be robust to attacks. The attack can lead to incorrect estimation of the parameters and may lead to failure of the entire system. As mentioned earlier, a famous example is the December 2011 attack by the Iranian forces on a US drone using a GPS spoofing attack where the GPS coordinates were spoofed, and incorrect coordinates were transmitted. In the context of autonomous navigation, it was demonstrated by the authors in that by GPS spoofing attacks, it is possible to force an UAV to follow a trajectory dictated by the "spoofer." An overview of the various possible attacks on VANETs such as GPS spoofing attacks, man-in middle attacks, deauthentication attacks and Sybil attacks can be found. The authors in present a complete threat analysis of popular commercial UAVs. All the existing approaches either study a particular attack, and its impact or make a simplified assumption on the system model, which are far away from the real-world scenario. On the other hand, in a typical navigation system, the nodes/entities are moving bringing more challenges in estimating the parameters and hence are more susceptible for attacks. The existing models fail to take into account the mobility of the nodes/entity while analyzing attacks. The proposal aims to provide a "clean slate" design by developing distributed, communication efficient ways to mitigate general attacks for a fixed type of estimation. The performance of the proposed algorithms will be analyzed and compared with the state-of-the art methods. Further, a theoretical analysis of how good an estimate can be under cyber-attacks will be investigated. This will lead to a fundamental contribution to estimation theory under attacks in a communication constrained distributed network. The impact of the proposed estimation methods on the actual performance of autonomous navigation systems will be studied. Finally, a real implementation of the algorithm will be carried out to demonstrate the proof-of-concept in a network of ground vehicles/drones. All the developed components will be integrated to demonstrate an autonomous vehicle/drone system with proprietary communication protocol using which a controller can take distributed action will be demonstrated.

As mentioned, delivering fresh status updates in a network necessitates a joint design of the system. Towards this goal, we must first identify suitable metrics for freshness of information. The recently introduced metric called the age of information has limitations in that it does not account for the statistics of the sensed information. Further, the safety critical applications such as autonomous driving require hard constraints on freshness of information. This calls for development of novel network architectures and scheduling algorithms, as the existing networks are designed under average-case constraints. Moreover, distributed learning algorithms, which can potentially minimize the exchange of learning data, will be designed. Proposed objectives include:

1. Development of a proprietary communication standard with a minimum set of features required for a wide spectrum of autonomous navigation and data acquisition systems, including precision agriculture and precision manufacturing. In addition to the communication operation, the system will include specifications for sensing, computation, control and data transfer operations.
2. Development of efficient distributed learning/control algorithms for autonomous navigation and precision agriculture applications that are robust to attacks, taking into account the communication constraints.
3. Development of algorithms that ensure that fresh and reliable information is delivered for decision-making in autonomous navigation.
4. Prototype development of a communication system with the proposed standard in Software Defined Radios (SDRs).
5. Integration with other units of the autonomous navigation and data acquisition systems developed by other research groups at TIH.

6.3.2.9 Speech Technologies for Autonomous Navigation

The speech technologies like speech recognition, speech synthesis and speaker verification are needed for autonomous navigation. The study of existing speech technologies and also requirements for autonomous navigation will be carried out first. A framework for the use of speech technologies in autonomous navigation will be proposed. Development of speech technologies as per the requirement of specific application domain of autonomous navigation will be taken up. The testing of prototype speech technologies in the identified application domain will be carried out next. After this, patenting of speech technology enabled autonomous navigation platforms will be carried out. The patented technology will be transferred for production in a startup or any other company working in the domain. Accordingly, the objectives are

1. Development of a framework for adopting speech technologies for autonomous navigation domain.
2. Development of low footprint speech recognition, speech synthesis and speaker verification technologies.
3. Optimizing speech technologies for an identified autonomous navigation application.
4. Field study and prototype development of speech based autonomous navigation systems for the identified application.
5. Patenting, technology transfer / startup for commercialization.

6.3.2.10 Development of Farmer Assistance System:

A methodology for data acquisition system for wide area precision agriculture applications with autonomous UAV navigation, computer vision techniques, and design automation methodologies is proposed targeting existing problems in agriculture. Frameworks for automated systems to collect ground sensor data extraction, plant disease recognition, nutrition data and provide valuable expert suggestions to farmers in a timely fashion.

Methodology:

Different subsystems of the methodology are shown in Fig. 58. A holistic view of the methodology is shown which has both local and remote server link based backend processing engines. Different hardware and software modules co-exist in the system design are briefly explained as below.

Imaging Sensor:

Two types of images are required for the complete system implementation of the proposed plant disease classification application. Development of the application starts with creation of the image data set for training the disease classification models. This dataset can be a mix of existing image sets from known research communities for well-defined diseases and new set of images for newer plant diseases identified. Newer image requirements can be met with a database creation of leafs and plants in that particular area.

In view of the above requirements, a drone based multi-spectral image sensing system is planned to realize for very specific diseases that are local in nature but have significant effect on crop production. Images required for the hand-held device are captured from a low cost image sensor. Low resolution noisy data Image of the Mango and plants of the paddy fields are the unprocessed raw data set which forms a primary input vector to the hand-held system. Image sensor requirements for the disease classification algorithm for a local light-weight algorithm will be finalized after deciding upon the field requirements like plant height and any application specific requirements.

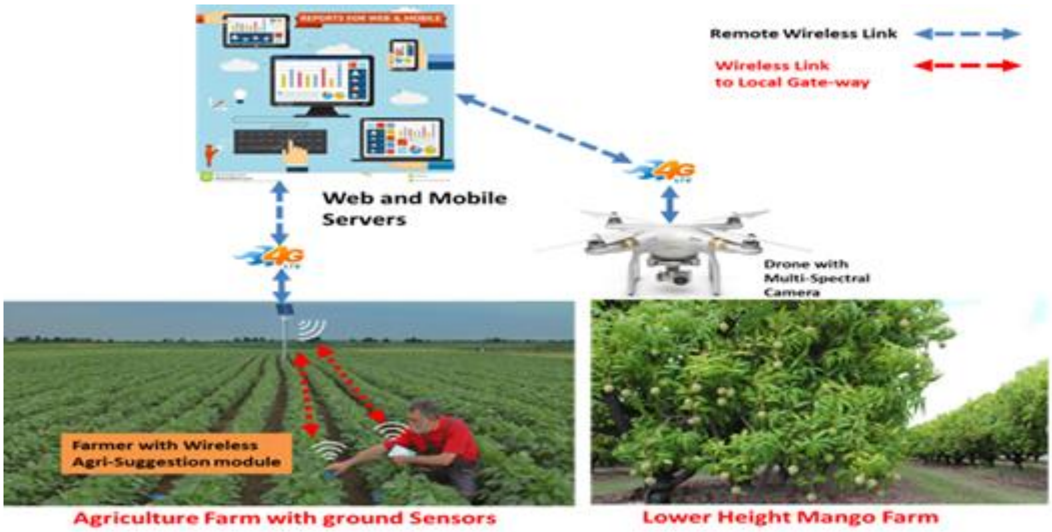


Figure 58: A system architecture for plant disease recognition using a hand-held device and server connection.

Local Processing Engine:

Image sensor is integrated onto an embedded platform which can take input and forward the data to the next processing module. Hand held device is an integration of image sensor and a processing engine based on a System on Chip (SoC) with DSP and graphics processors for image processing to be carried out as part of the disease classification. Ground sensor nodes with Wi-Fi/ZigBee/Bluetooth can communicate to the local gateway. Local gateway acting as aggregator from “N” nodes, relay the data through a UAV or directly link using 4G modules.

The mapping of the application software on the given architecture can be optimally designed using design space exploration techniques from Embedded Systems. The importance of the hardware/software design techniques lies not only in the efficient functioning of the detection of images but also on the optimal cost of the end system to be designed.

User Interface Unit:

Farmers are in the loop for the proposed application. Easy interface assuming that a farmer with minimal background knowledge should operate is the primary requirement of this User interface program. Any light-weight application software like Android can be custom made to meet the requirements of the application.

Back-End Processing Engine and Remote Server Module:

Hand-held devices have constraints like computation resources, adaptability to new diseases, size, power consumption and cost. We will use hybrid approaches of analytical models and simulation techniques to do a detailed trade-off study of the various design metrics such as performance, power, and cost. Handheld devices will have a seamless switching between on board classification or a remote backend computer vision algorithm when the on board computing engine cannot arrive at an accurate classification. Remote engines can be upgraded with the new diseases time to time using new image databases and deep learning models. Remote processing engines can also extend the processing to other crops depending on the future requirements of the agriculture industry. Remote engines can also be linked with data analytics and yield prediction algorithms for futuristic applications.

Computer Vision Processing Unit for Disease Recognition:

The computer vision approaches will be adapted in this project to analyze the crop data sent by Farmers. Basically, a two-step process will be used to solve this problem.

In the first step, the infected area will be localized/detected using object detection techniques. The state-of-the-art and recently developed techniques such as Region proposal based Convolutional Neural Network (R-CNN), Fast R-CNN, Faster R-CNN, You Only Look Once (YOLO), Single-Shot-Detector (SSD), etc. for object detection will be used. These models will be trained and tested for the proposed problem over large-scale dataset of crop-diseases and the best model will be used for crop infected area detection. Moreover, new such methods for the proposed problem might be also investigated.

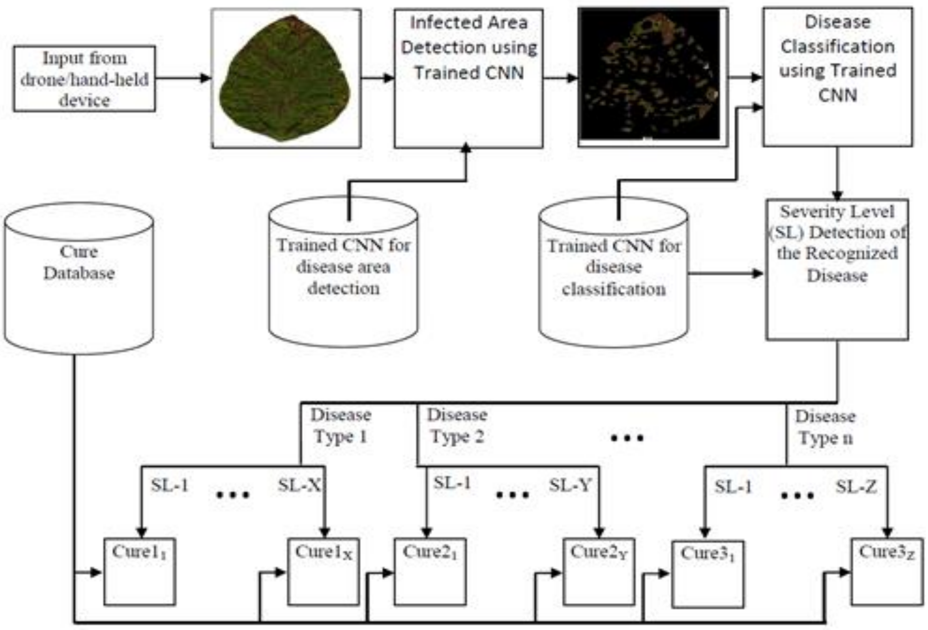


Figure 59. The expert system design for Farmer assistance using Computer Vision techniques for crop disease recognition and recommendation.

In the second step, the identified infected regions will be used for the disease classification with severity level. The CNNs such as Residual Network (ResNet), Squeeze and Excitation Network (SENet), Dense Skip Connection based Network (DenseNet), GoogleNet, etc. will be used for the classification. These models will be trained/fine-tuned over the large-scale image patches of crop diseases and tested to find the suitable model. Moreover, new such models might be also investigated for the crop disease classification. The severity level will be identified from the confidence/class scores or another sub-classification network can be trained for the severity level classification. The workflow of detection, classification and severity level computation is illustrated in Fig. 59.

Expert System Development to Respond to the Farmers Query:

An expert system will be also developed as shown in Fig. 46 which will take the input from Farmers, process using computer vision processing units, and send the recommendation to farmers based on the type of disease as well as stage/severity level and disease knowledge-base.

Modeling/Simulation Techniques for Hardware/Software Co-design:

The complexity of the design of the precision agriculture system stems from both the hardware/software: The hardware is the system-on-chip architecture, imaging sensor, communication components, computer vision algorithms for the detection of plant diseases. The major design challenge is the performance and the power constraints of the system, that is, the farmer using the system should be able to use the device for a long time when the device is charged; the algorithms in the system should also perform efficiently so that the farmer instantly notices the output of the diagnosis of the plants. The proposed objectives include:

- The expected deliverables for precision agriculture are autonomous scalable data acquisition framework for agriculture.
- Power efficient autonomous navigation algorithms to span the agriculture field for possible disease identification
- Computer Vision model for identification of Mango fruit in tree with ripe level
- Computer Vision model for identification of diseased region in paddy field as well exact disease
- It will also include the advisory model for precision agriculture to help the farmers for the precise pesticide /water usage and nutrient suggestions. This is planned to achieve with mobile App based communication between farmers and developed expert systems hosted at server.
- Developed Precision agriculture frameworks will be encouraged to use by research institutes like ICRISAT, ICAR, Swaminathan research foundation and Sri Venkateswara Agriculture college etc.
- nVipani Pvt. Ltd., Terradrone Pvt. Ltd., Efftronics Pvt Ltd., Marut Drones Pvt. Ltd. and Analog Devices Pvt. Ltd. has shown the interest to contribute towards the success of this project by identifying the user group, providing the support and commercializing the developed product.

6.3.2.11 Intelligent Robotic Systems for Human Assistance:

The current proposal involves development of different modules involved in robotic systems which can navigate autonomously in the specified environment. Importantly, we plan to realize a real-time CPS system using the intelligent robotic systems to be used in various applications such as agriculture, healthcare, human assistance, etc. With the robot being mobile entity, the on-board sensors that will be integrated require proper calibration for quality data acquisition and the huge amount of data generated requires edge processing to meet the latency demands. Also, the robotic system should be able to converse with farmers/patients/elderly in their native language and carry out limited electro mechanical activities. The idea is to develop independent modules as automatic speech recognition (ASR) interfaced to Chabot, text to speech synthesis (TTS), computer vision, artificial intelligence (AI), necessary computer networking and security. Though the proposed application targets agriculture, health care and ageing population, it can easily be extended to other areas as well. Mainly the proposed work can be broadly categorized as hardware and the software stack. The idea is to maintain a common hardware and make the necessary changes to the software stack to meet different objectives. This type of architecture enables to rapidly build different applications with easy customizations.

The general architectural block diagram of a navigating robot is as shown in Fig. 60. Though the architecture shown is applicable in general to any navigating robot, it should be noted that the same working principle equally holds good for navigating robot as well. It can be observed that the architecture is a feedback control system. The input to the robot system is the task description. For example, the task description can be asking the robot to navigate from one point in a planar space to another point or it could be as simple as pick and place an object from one place to another. The output of the system is the task delivered by the robot. The actual output response of the robot is measured by the sensors and fed as input to the information processing unit (IPU). For example, the actual movement of a robot in terms of Cartesian coordinates or joint movements can be measured by sensors. There are many types of sensors embedded within robotic systems to measure different types of sensors. The visual camera, microphone, pressure sensor, gyro sensor and many more that can measure different parameters. The IPU can be a simple computing device like a microcontroller unit or could be a complex machine like a cloud server. However, there may be a difference between the actual and the desired output response of the robotic system. Such a difference is called an error, and this error is fed back to the controller. Based on the controlling algorithms, the controller takes the remedial action by giving actuation signal to the actuators embedded in the robotic system. The actuators can be simple DC motors, pneumatic or hydraulic valves that steer the robot to desired position or move the hands of the robot to specific locations. Broadly speaking the decision taken by the IPU can be preprogrammed or it can be taken in a dynamic fashion. However, the dynamic decision requires intelligent algorithms and mostly such decisions are handled through the Artificial Intelligence (AI) module in the IPU.

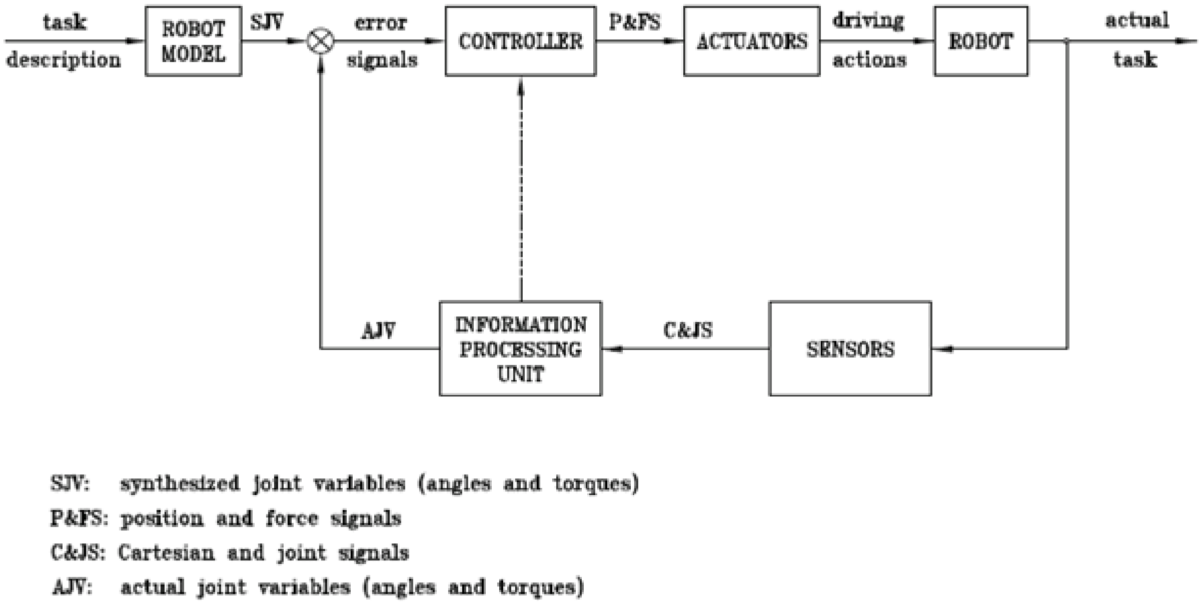


Figure 60: General Architectural Block Diagram of a Robotic System

*(*Ref: Fundamentals of Robotic Mechanical Systems - Theory, Methods, and Algorithms | Jorge Angeles | Springer." https://www.springer.com/gp/book/9780387224589*)*

Hardware and Software Architecture

A typical hardware and software architecture of robotic systems is shown in Fig. 61. It can be noticed that the present day architecture is more of a distributed structure, where the computations and control operations at multiple levels. Broadly the architecture can be divided as a local area and cloud area of operations. The local area consists of multiple layers and all the layers are housed in robotic systems. However, the cloud area is connected through the cyber-physical system to a remote server. The less complex tasks that involve lower numbers of computations mainly run on the robotic system. For example, most of the hard real-time applications such as gathering data from sensors or controlling the actuators and many such operations happen in the local area. Also, depending on the complexity of tasks some of the computationally intensive tasks can also be part of the local area. One of the main reasons for scheduling such less complex jobs in the local area is because the robots operate using battery packs. The battery packs need to be charged frequently and the lasting time depends on the battery capacity and the power consumption mainly depends on the nature of tasks that run in the scheduled time.

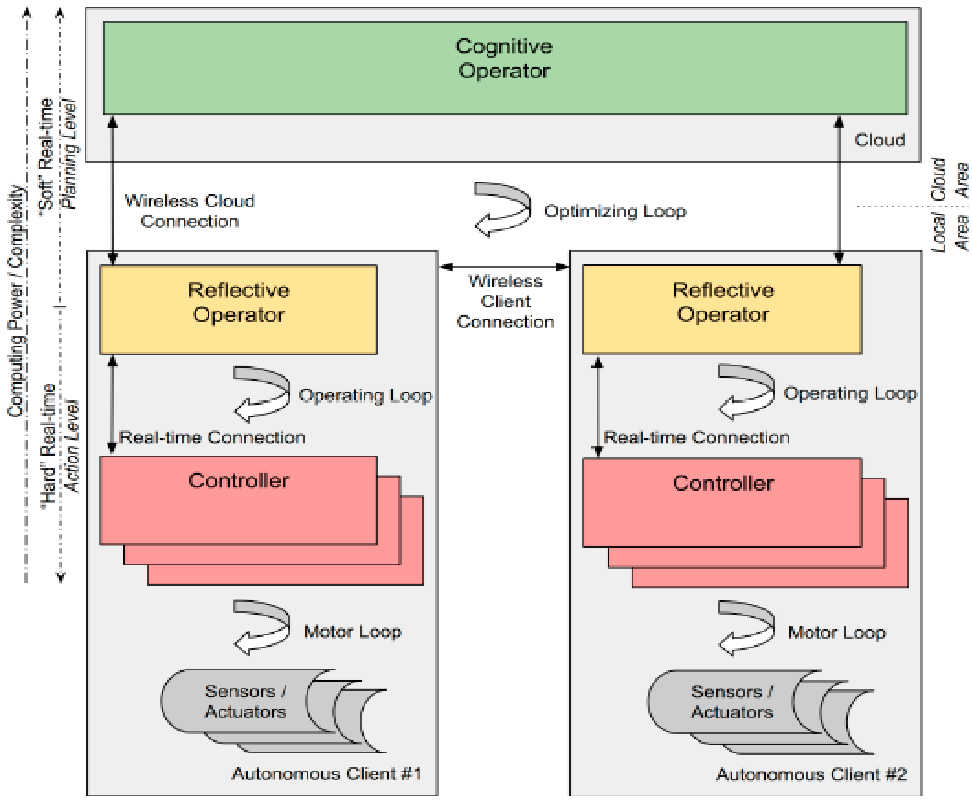


Figure 61: Conceptual Model of Hardware and Software Robotic System Architecture (Ref: Jahn U, Wolff C, Schulz P. Concepts of a modular system architecture for distributed robotic systems. Computers. 2019 Mar;8(1):25*)*

Local Area

The controller module directly operates on the sensors and actuators. There can be many such sets of sensors and actuators. The reflective operator is an autonomous software layer that can act independently. The reflective operator interacts with the controller through an operating loop. This layer interacts with both the controller and the cloud server. However, the reflective operator mainly runs on the local area.

Cloud Area

The complex tasks which involve computationally intensive applications mainly run on cloud servers. The advantage of using the cloud server as a component in the architecture is twofold. One of the reasons being that the cloud server offers tremendous computing power and many parallel computations can happen on Graphics Processing Units (GPUs) and hence complex applications as audio and visual information can be efficiently processed. Therefore, the speech based applications as voicebot that involve Automatic Speech Recognition (ASR), Spoken Language Understanding (SLU), Machine Translation, and Text to Speech Synthesis (TTS) modules will usually run on the cloud server. Similarly, the computer vision based applications as Face Recognition and Object Recognition mainly runs on the remote cloud server. Broadly such applications can be categorized as Human Computer Interaction (HCI). Strategically it is appropriate to deploy such complex applications in cloud servers; else the battery operated robotic system may drain the power.

The complete autonomous robotic system is a complex system that has many dedicated single board computers (SBCs) like Arduino and Raspberry Pi. Further such a complex system has many software modules that need to operate at different levels. Therefore, it is logical to have a layered approach of development. This helps to modularize the systems, easy to extend the features, and reuse the modules in different products. Due to complexity of the system, usually they are handled through an operating system (OS). Both general purpose operating systems (GPOS) and Real Time Operating Systems (RTOS) can be used independently or in combination. Robot Operating System (ROS) is an OS that is preferable on a robot. The ROS is flexible enough to get added as a layer on top of GPOS or an RTOS.

The above framework represents a general architecture for an autonomous robot. Depending on the specification the number of layers can vary and they can be named differently. However, the fundamental philosophy of an autonomous robot hardware and software architecture remains similar.

Autonomous Navigation

Based on the navigation, the robots can be broadly classified into Bi-pedal and wheel based robots. In a Bi-pedal scenario robot moves similar to Humans using two legs. However, it is the most challenging task to balance on two legs and walk as fluently as Humans. Alternatively, the current proposal focuses on a wheel based robot. The challenges are relatively less compared to Bi-pedal navigation. Meanwhile the ease of movement is highly limited in case of wheel based robots compared to Humans. The mechanical motion of robot is limited with the assumptions that the deployed scenario is a flat surface within a single floor and the movement is restricted to the confinement of a house boundary.

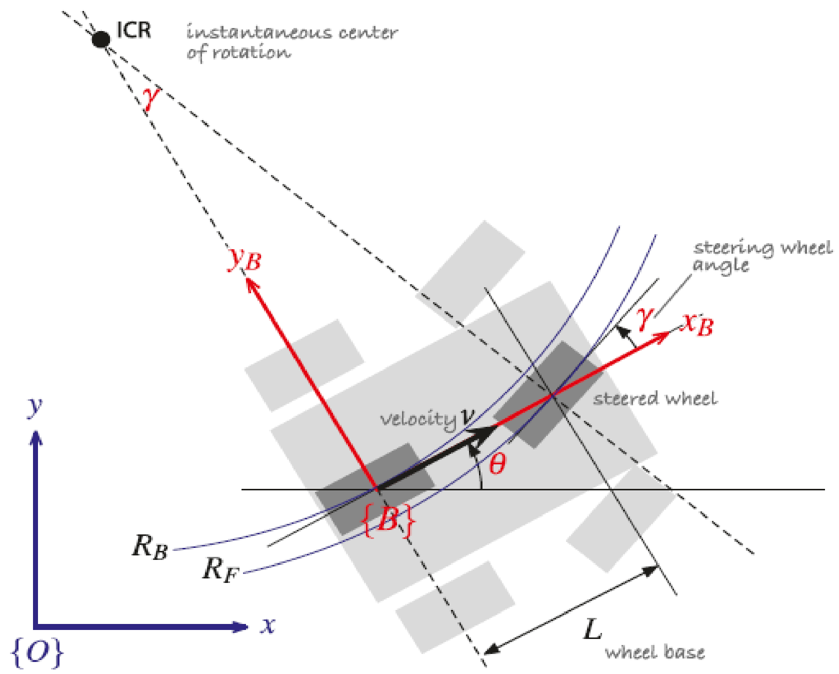


Figure 62: Bicycle Model of a Car

(Ref: P. Corke, *Robotics, Vision and Control: Fundamental Algorithms In MATLAB® Second, Completely Revised, Extended And Updated Edition*. Springer, 2017).

A typical wheel based robot has four wheels and is driven similar to a car as shown in Fig. 62. The complex phenomenon can be simplified using a simplified Bicycle car model representation. The car is

shown in light grey, and the bicycle approximation is in dark grey representation. The vehicle's body frame is shown in red and the coordinate frame in blue color. The steering wheel angle is γ and the velocity of the back wheel in the x-direction v. The two wheel axes are extended as dashed lines and intersect at the Instantaneous Center of Rotation (ICR) and the distance from the ICR to the back and front wheels is RB and RF, respectively. The model is referred to as a kinematic model as the model only refers to the velocities. The turn rate or the yaw rate of the model can be measured by a gyro sensor embedded in the robot. Based on the feedback received from such sensors the actuators (motors) are adjusted to drive the robot in the right path.

Autonomous Navigation Algorithms:

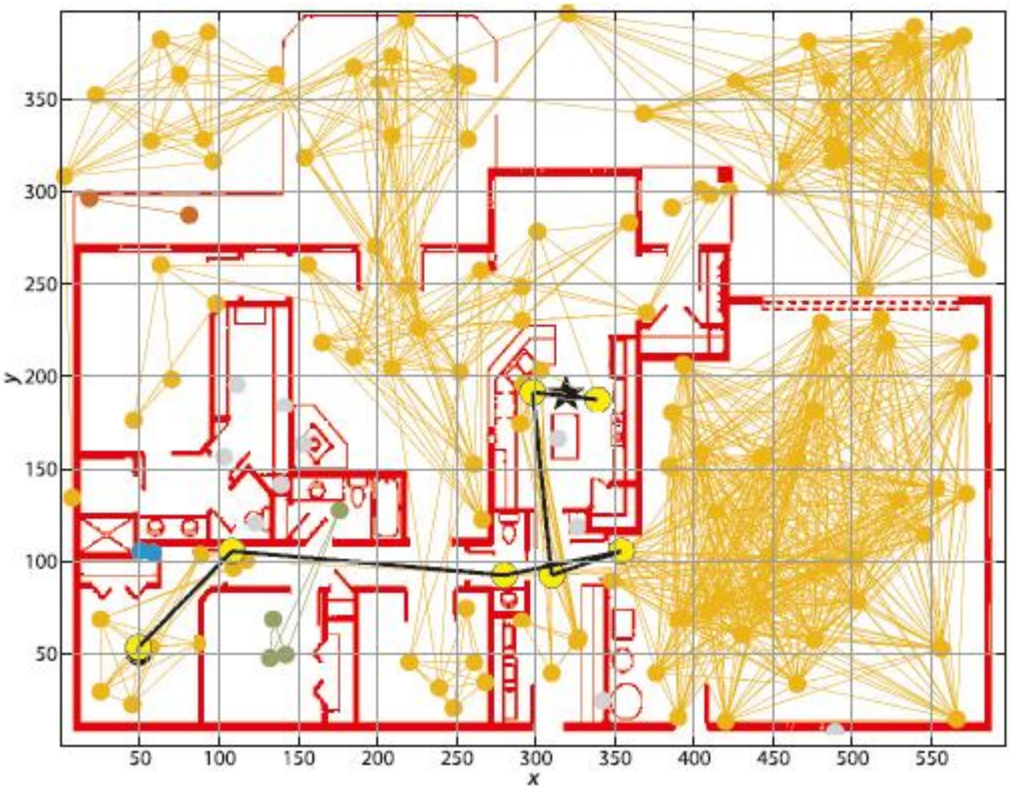


Figure 63: Probabilistic Road Map (PRM)

(P. Corke, *Robotics, Vision and Control: Fundamental Algorithms In MATLAB® Second, Completely Revised, Extended And Updated Edition*. Springer, 2017).

There are many algorithms that are suitable for autonomous navigation. One of the basic algorithms is called a Bug. There are many variants of this basic algorithm, and this class is based on reactive based approach. The autonomous vacuum cleaners extensively make use of such algorithms. The navigation is random and it is reactive based on the obstacles present in the path. The Fig. 63 shows the Probabilistic Roadmap (PRM) algorithm has two phases, namely, the planning phase and the query phase. A random number of initial points called nodes are selected as shown in Fig. 63, for instance in the example taken 150 such nodes are chosen. The paths are established between the adjacent nodes without crossing any obstructions in the given house. All the possible paths are established in the planning phase, while the query phase such paths are optimally traced to move from destination to source point as shown in the Fig. 38. Apart, there are other algorithms like simultaneous localization

and mapping (SLAM) and visual SLAM called VSLAM in the literature that are popular for autonomous navigation. Few well established methods will be explored for autonomous navigational purposes.

The complexity of the kinematic and dynamic structure of robot robots makes conventional analytical approaches to control increasingly unsuitable for such systems. Learning techniques offer a possible way to aid controller design if insufficient analytical knowledge is available, and learning approaches seem mandatory when robot systems are supposed to become completely autonomous. While recent research in neural networks and statistical learning has focused mostly on learning from finite data sets without stringent constraints on computational efficiency, learning for robots requires a different setting, characterized by the need for real-time learning performance from an essentially infinite stream of incrementally arriving data. Even high-dimensional learning problems of this kind can successfully be dealt with by techniques from nonparametric regression and locally weighted learning. As an example, we describe the application of one of the most advanced of such algorithms, Locally Weighted Projection Regression (LWPR), to the on-line learning of three problems in robot motor control: the learning of inverse dynamics models for model-based control, the learning of inverse kinematics of redundant manipulators, and the learning of oculomotor reflexes. All These examples demonstrate fast, i.e., within seconds or minutes, learning convergence with highly accurate final performance. The real-time learning for complex motor systems like robots is possible with appropriately tailored algorithms, such that increasingly autonomous robots with massive learning abilities should be achievable in the near future.

Time-varying external disturbances cause instability of robots or even tip robots over. In this work, a trapezoidal fuzzy least squares support vector regression- (TF-LSSVR-) based control system is proposed to learn the external disturbances and increase the zero-moment-point (ZMP) stability margin of robots. First, the robot states and the corresponding control torques of the joints for training the controller are collected by implementing simulation experiments. Secondly, a TF-LSSVR with a time-related trapezoidal fuzzy membership function (TFMF) is proposed to train the controller using the simulated data. Thirdly, the parameters of the proposed TF-LSSVR are updated using a cubature Kalman filter (CKF). Simulation results are provided. The above methods may be effective in learning and adapting occasional external disturbances and ensuring the stability margin of the robot.

To compare the performance between the two conditions, the devised questionnaire consisted of three parts: The GODSPEED test, questions based on the UTAUT model, and some additional questions (MISC) measuring the performance of the interaction module. A multivariate variant of the Mann-Whitney U test was chosen for these questionnaires to ensure the validity of the result. The continuous assumption of the data is only considered for trend analysis to support investigating the direction of changes as the multivariate tests do not explicitly provide information about trends. Furthermore, post-hoc analysis on each individual question was performed using the Wilcoxon rank-sum test on two independent samples. A Fisher's exact test was conducted to compare the decisions during the first and the second part, reported along with the percentage of the decisions made. The percentage is relevant to report since binary data often need a larger sample size to give a significant result, and therefore the percentage can indicate a pattern in the result.

The purpose of the algorithm introduced above is to enable us to predict the behavior of a given manipulator under given initial conditions, applied torques, and applied loads. The ability of predicting this behavior is important for several reasons: for example, in design, we want to know whether with a given selection of motors, the manipulator will be able to perform a certain typical task in a given time frame; in devising feedback control schemes, where stability is a major concern, the control engineer cannot risk a valuable piece of equipment by exposing it to untested control strategies. Hence, a facility capable of predicting the behavior of a robotic manipulator, or of a system at large, for that matter, becomes imperative. The procedure whereby the motion of the manipulator is determined from initial conditions and applied torques and loads is known as simulation. Since we start with a second-order n-dimensional system of ODE in the joint variables of the manipulator, we have to integrate this system in order to determine the time-histories of all joint variables, which are grouped in a vector. With current software available, this task has become routine work, the user being freed from the quite demanding task of writing code for integrating systems of ODE. The implementation of the simulation-related algorithms available in commercial software packages.

Voice Bot

Voice Bot module helps people converse with robot. Mainly the Voice Bot module consists of speech recognition, machine translation, text to speech synthesis sub-modules. All the sub-modules will be integrated to form Voice Bot.

Automatic Speech Recognition (ASR)

The goal of speech recognition is to generate the optimal word sequence subject to linguistic constraints. The sentence is composed of linguistic units such as words, syllables and phonemes. The acoustic evidence provided by the acoustic models of such units is combined with the rules of constructing valid and meaningful sentences in the language to hypothesize the sentence (Fig. 64).

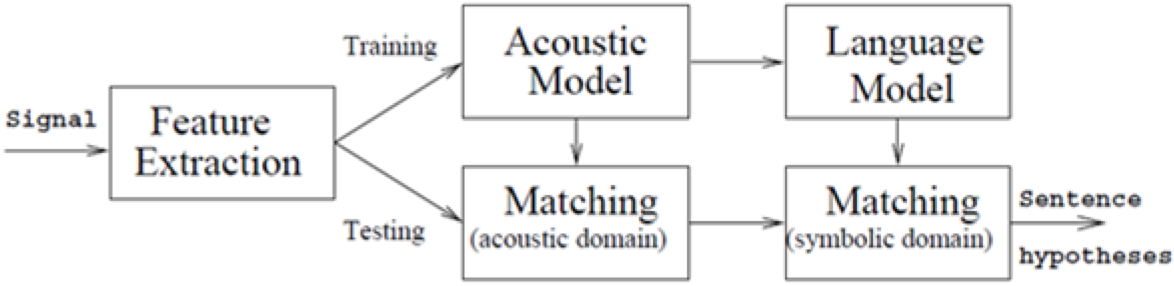


Figure 64: Block Diagram of an ASR System

Speech recognition systems are nowadays becoming the front-end for Human Computer interface in place of GUIs. Most current speech recognition systems use GMM-HMM based models. The major advancement occurred in the field of ASR four decades ago with the introduction of Expectation-Maximization (EM) algorithm for training HMMs. With the EM algorithm, speech recognition systems are developed using GMMs, which helps to represent the relationship between HMM states and the acoustic input. GMMs have a number of advantages that make them suitable for modeling the probability distributions over vectors of input features that are associated with each state of an HMM. During the last few years, advances in both machine learning algorithms and computer hardware capabilities for parallel programming have led to more efficient methods for training deep neural networks (DNNs) that contain many layers of non-linear hidden units and a very large output layer. Using DNNs the variabilities in acoustic features are well modeled and were able to achieve better Speech recognition accuracy. Using these new learning methods, several different research groups have justified that DNNs can outperform GMMs at acoustic modeling for speech recognition on a variety of datasets including large datasets with large vocabularies.

The speech conversation from the user with robot can be broadly classified into two, namely; free conversation and voice commands. Free conversation is a very large vocabulary and is relatively challenging to handle. Also, a large speech database to the order of 10000 to 20000 hours of data is needed to build such an ASR. Rather, the ASR is limited to a single word or a sentence that contains

few words. The speech interaction is limited to voice commands from the user and a limited feedback from the robot to the user in the form of TTS. Mostly the speech inputs are limited to spoken queries from the users in an Indian language similar to the one handled in Agricultural Commodity project. The current proposal is limited to handle such spoken queries in Hindi language. Further, in the given scenario a limited number of people interact with the robot. Therefore, it is possible to adapt the ASR system through possible adaptation techniques that are less complex in nature. Also, wake up spoken terms or keywords are necessary to seek the attention of robot. Such modules can run on the local area of robot and need to be less complex algorithms.

Machine Translation

Machine Translation or Speech Synthesis refers to the artificial production of human speech (Fig. 65). The main aim of Text to Speech synthesis system is to convert text to naturally sounding speech. The front end of the system does the job of text analysis and generates possible pronunciations for each word, while the backend generates the speech waveform. The main requirement of TTS is speech with proper punctuation, intonation (prosody), Speaking rate with the same speaker style transfer to the synthesized language. The main approaches for TTS are concatenative, parametric, and Neural. A typical model of TTS is shown in the block diagram, consists of the front end to process grapheme to phoneme conversion followed by a statistical model to learn phoneme to acoustic mapping and finally signal processing waveform generator to convert acoustic feature to an audio signal.

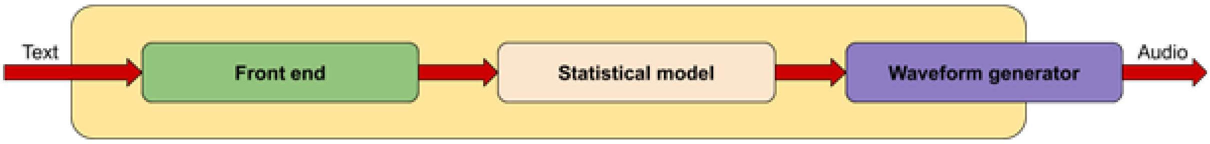


Figure 65: Block diagram of a Text to Speech Synthesis system

Deep learning models like the Deep Neural Network (DNN) have yielded significant results in speech synthesis. In advanced neural vocoder, both front end and statistical models are merged and learned using a single neural network and waveform generator with another neural network. Apart from DNN, many advanced neural network methods like WaveNet, SampleRNN, Tacotron, Deep Voice have been recently introduced. The main principle of all the above methods is modelling the raw waveform of the speech signal to get the best speech synthesis quality.

Sound Source Localization

Hearing is the ability to perceive an acoustic signal and together with vision, touch, taste and smell one of the five human senses. The most developed senses of hearing have animals which are using acoustic signals for communication, prey’s localization or area orientation such as in case of Bats and dolphins. Sound source localization (SSL) has been important in localization objects. Sometimes you need to know coordinates by an object. For We can find a cordless phone when it rings based solely on sound source location. But you have only sound waves. For this case you can use an algorithm to solve the localization problem.

The oldest and the easiest technique for SSL can be described like two microphones which are measuring sound waves. Two and more microphones are called microphone arrays. Using an algorithm and microphone array one can determine the angle or coordinate of the sound source. There are several methods for solving the problem. Basically the problem is solved using two different methods i.e., Time Difference of Arrival (TDOA) and BEAMFORMING. The methods assume that the distance between microphones array and sound source is bigger than distance between two sensors in the microphone array.

In the Automatic Speaker Verification task, a speech utterance from an unknown speaker is analyzed and compared with speech models of known speakers. The unknown speaker is identified as the speaker whose model best matches the input utterance. Speaker verification is the process of verifying the claimed identity of a speaker based on the speech signal from the speaker (voiceprint). There are two types of speaker verification systems: Text-Independent Speaker Verification (TI-SV) and Text-Dependent Speaker Verification (TD-SV). TD-SV requires the speaker saying exactly the enrolled or given password. Text independent Speaker Verification is a process of verifying the identity without constraint on the speech content. Compared to TD-SV, it is more convenient because the user can speak freely to the system without adhering to any constraint text. The i-vector system has been one of the most popular techniques for speaker verification and is known to provide state-of-the-art performance. Fig. 66 shows i-vector technique based ASV. In an i-vector-based ASV system, Universal Background Model (UBM) and i-vector extractors are trained using UBM (background) data and development data respectively. After the models are trained, i-vectors are extracted for the enrollment and authentication utterances and compared to find similarity scores using Cosine Distance. Channel and session compensation parameters are trained on i-vectors from the development set and used to compensate the enrollment and authentication i-vectors.

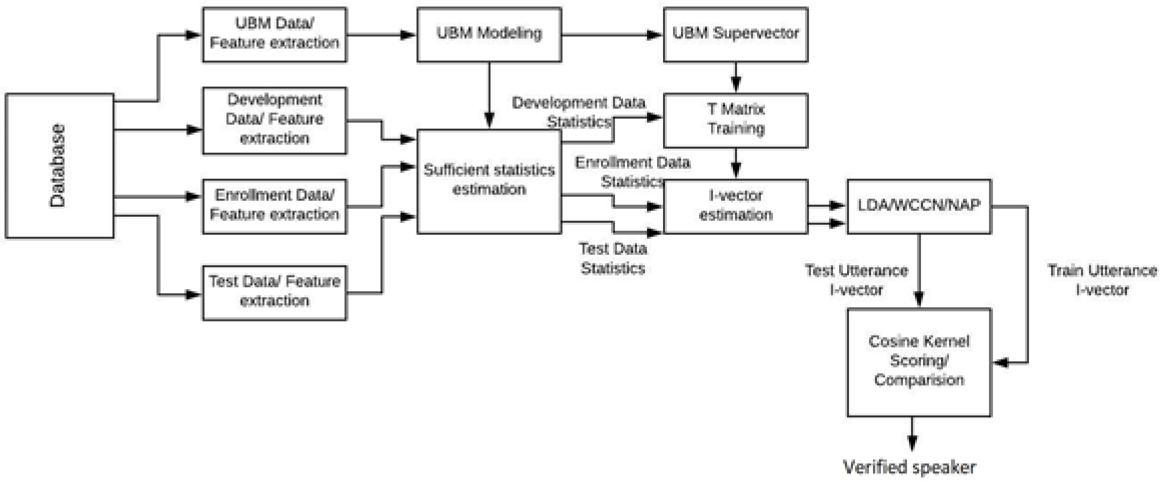


Figure 66: i-Vector based Speaker Verification System

Building a Speaker Verification System (TI-SV):

Steps involved for building an i-vector based system.

- Train UBM with a large amount of background data pooled for a large number of speakers and spanned over different texts.
- Train T matrix (since the data is less in amount, the same background data may be used to train UBM and T matrix).
- Train channel compensation models, LDA and WCCN, on i-vectors. (on development data preferably).

At enrollment, the speaker utterance is converted into compact for i-vector representation using i-vector extraction and channel/session compensated using the trained compensation model parameters. (preferably three utterances, and thus three i-vectors). At authentication, the subject’s utterance is processed similarly and converted into channel/session compensated i-vector representation. It is then matched with the enrollment i-vectors using cosine similarity scoring. And comparing the score with a predefined threshold (trained on a development set), the verification decision is made.

Face Recognition

Face detection and recognition:

Face recognition plays a very important role in modern application which includes biometrics, surveillance, Homeland security, behavioral analysis and e-commerce. Face recognition involves two major steps:

- Face detection
- Face recognition

Each of these steps goes through a step by step process of acquiring input images, preprocessing, feature extraction and classification. Following sections discuss the problem statement, challenges involved in both of these steps and state-of-art methods

Challenges in Unconstrained Face Identification:

There are few challenges in real time and unconstrained environments which are common for face detection and recognition.

- **Pose variation:** The person under observation may be looking at various directions while doing his regular activities. In such situations the face may be tilted towards left, right, up, down or any other direction making it difficult to detect and process the face identification.
- **Illumination variation:** Because of illumination variation, the detection and identification algorithms that are based on pixel intensities also suffer from misclassification, which reduces the overall classification rate.
- **Scale and Resolution variation:** The face regions in unconstrained environments are low in resolution and may have fewer pixels, which present a challenge to calculate enough information about the face to be recognized.
- **Occlusion:** The various objects in the environment may partially or fully cover the facial region of the human body resulting in occlusions.
- **Noise:** Apart from challenges mentioned above the unconstrained face detection and identification suffers from noise that is generated while the image or video acquisition process is in progress. In most of the cases the blur is added to the images or videos. Blurring makes images difficult to process for detection and identification of objects.

Both face detection and recognition has benefited a lot from deep learning and almost all the current state-of-art methods are based on deep learning. The developed technology will be built on top of these existing state of the art studies.

Advanced Networking Technologies

An autonomic robot design involves a lot of sensors and communication devices (wireless/cellular) for handling various interactions within the system and other systems of the environment. In order to handle various tasks of the environment, robots need to communicate with other robots and network/communication devices. Following are the major issues to be handled for various robotic interactions in the environment:

- Reliable and secure communication is necessary.

- Variety of application services require various Quality of Service (QoS) and QoE (Quality of Experience) requirements.
- For example, Health Monitoring Video Streaming/Conference applications require continuous video play out without freezing.
- In case of emergency situations, VoIP based assistant chat applications require maximum acceptable delay and jitter for better experience of voice calls.
- Quick and Seamless connections handovers are needed while mobility of robots.
- Unlike regular human random mobility patterns, robot's mobility patterns may be static and predictable patterns in specific scenarios/contexts of the environment.
- Taking advantage of robots predictable mobility patterns, we can develop robots specific quick and seamless mobility algorithms by considering common mobility patterns, speed and no mobility at all.
- Dynamic scaling of network services for handling unprecedented demands and failures in the robots environment.
- It is highly important for scaling of networking services seamlessly in automated environments without affecting services.

Advanced Networking Technologies necessary for handling issues of robot's interactions:

Fortunately, the evolution of software-based cloud networking technologies, 4G and 5G communication technologies are opening up new opportunities to handle a variety of issues and demands from communication (cellular/wireless) networks. Especially 4G and 5G technologies are evolved to handle requirements like high throughputs (100Mbps to 1Gbps speed), lower delay (<=1ms) and a huge number of devices' connections. In order to handle a variety of communication needs from autonomic robots, it is also important to virtualize network services to offer on demand invocation of network services at specific locations. Specifically, cloud-based networks can offer suitable platforms for deploying virtualized network services. Mainly, Software Defined Networking (SDN) and Cloud Networking technologies are offering simplified network management, optimal traffic load balancing and flows steering solutions for handling virtualized network services.

Security and Privacy

Robotics: Security and privacy, Security threats

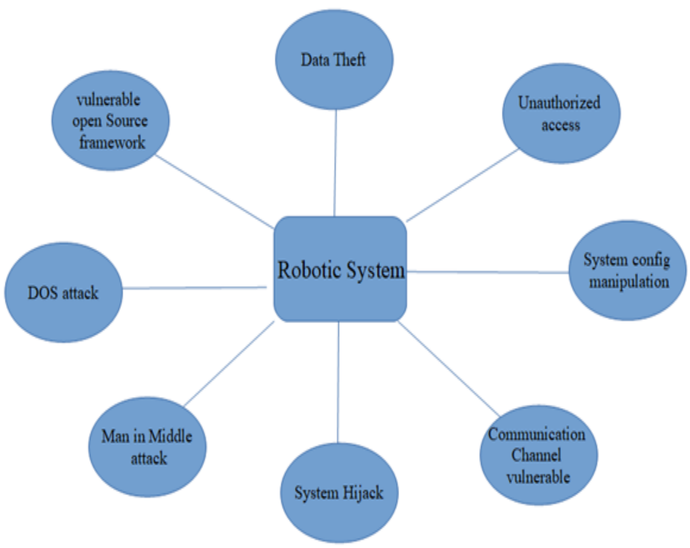


Figure 67: Possible attacks on the robotic system

Recent years we have witnessed service robots providing service to humans round the clock in hospitals, airports, hotels etc. There are challenges and opportunities associated with the safety of humans from robots and security of the data (Fig. 67). As robots are connected with the increasingly complex systems, the security of data theft, unauthorized access processing resources, manipulation of configuration, manipulation of programming code, vulnerable open source framework, manipulation of AI systems are challenging issues in security of robot systems.

Compromise on these issues may lead to destruction of robots, hijacking robotic intelligent systems and in-turn may cause greater damages and injuries to the human being (Fig. 68). A hijacked robot may cause physical damage to persons, might spy on people around, physical damage to house, electric system, equipment, deactivate alarms, unlock home security system, may stop recognizing legitimate users by voice, image and video.

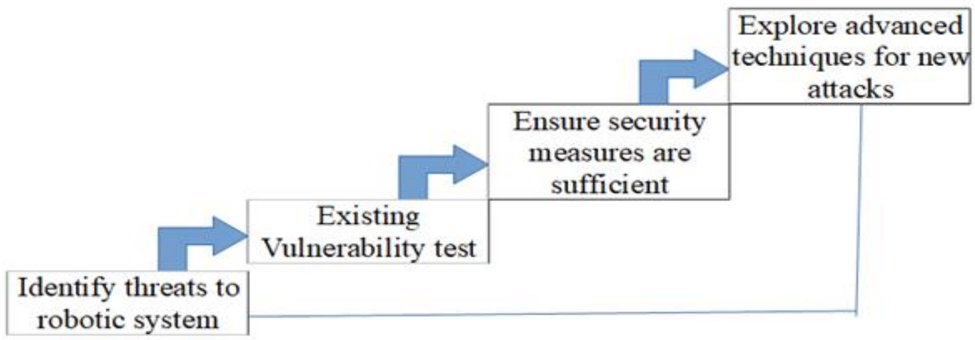


*Figure 68: Measure to ensure security and privacy robotic system (*doi: 10.1109/tits.2008.922880).

Modeling Robotic Security:

Robotic Security modeling is not a simple task, however we can apply basic system security measures

- Use Hashing / Messages authentication code to prevent code manipulation, commands manipulation
- Using embedded elliptical crystallographic solutions for key exchange and security coding
- Storing code files, configuration files by encrypting and hashing
- Authentication using Digital signature prevents unauthorized access to the central processing unit.
- Secured communication channel TLS provides security of data in transit, interfaces and communication channels.
- Factory restore methods to restoring the robot factory defaults
- Factory default security measures
- Security audits- log of security attacks and breach of security, help to enhance the security measures and mitigate and thwart any further such attempts. It also helps with the auto recovery mechanism.

Security measures to counter the attacks on robots can be implemented as shown in the Fig. 60.

7. Strategy

In this section, the strategy planned to achieve the various goals of this proposal including technology development, human resources and skill development, promotion of entrepreneurship, and fostering international collaboration has been discussed. Here we also discuss the on-going activities.

7.1 Strategy for Technology Development

In the following we describe the strategy planned for technology development in the two technology verticals of focus by this hub, namely: Intelligent and Autonomous Transportation Systems and Agriculture.

7.1.1 Autonomous Transport Systems (ATS)

7.1.1.1 Strategy for Unmanned Ground Vehicles (UGVs):

As part of the proposal, R&D will be undertaken for the development of various technologies that can be used in autonomous ground vehicles. A living lab which will be used for development and validation of the autonomous navigation and data acquisition frameworks developed for the autonomous vehicles will be established. The technology development comprises identifying the necessary challenges hindering the realization of autonomous vehicles in Indian context. The primary focus will initially be laid on 3 areas: Obstacle Detection using Multi-Sensor Fusion, Navigation and Control of the Vehicle, and Vehicular Communication Technologies. Additionally, System security and Power Management will also be considered as part of the project activities. Finally, we also lay an important focus on developing a standardized computing architecture or autonomous navigation in UGVs.

It is also proposed to create a working consortium with vehicle manufacturers and utilize their domain expertise in identifying the novel dominant requirements from a vehicular perspective thus avoiding reinvention of the technology. Additionally, it is proposed to utilize the vehicular developmental environments provided by the manufacturer to evaluate the hardware, software and algorithms under various test conditions. Outdoor testing on identified testing tracks will be performed along with the support of the vehicle manufacturer. In this regard, interactions have been initiated with vehicle manufacturers to on-board their support into the proposed project activities.

7.1.1.2 Strategy for Unmanned Aerial Vehicles (UAVs):

Challenges and strategy:

- ➢ **Stability**: A flying UAV undergoes six degrees of freedom, three translational and three rotational degrees of freedom. Moreover, wind makes a UAV even more unstable. The rotational motion of UAV is indicated by roll, pitch and yaw. INS-GNSS system helps to compensate for roll, pitch and yaw variations in the sensor data collected by the UAV.
- ➢ **Payload**: The drone battery can deliver a limited amount of power. This results in the limited payload capability of the drone. One of the approaches to deal with this problem is to divide the

- payload to multiple coordinated drones. The above approach, known as "Drone Swarming", is similar to the concept of the connected vehicles in ATS. The main idea behind Drone Swarm is that UAVs make their own decisions through the information shared with each other. It was inspired by swarms of bees or flocks of birds. UAVs would be able to perform several tasks thanks to being connected to a common network.
- **Multi-sensory perception system**: Multi-sensor integration (Fig. 69) is the key to a robust navigation system for drones. The various sensors that can be integrated are single and multi-channel LiDAR, RGB camera, stereo vision camera, INS-GNSS system, etc. LiDAR has been widely used for surveying purposes, by mounting it on the UAV. Just like autonomous vehicles, it is very helpful in providing the three-dimensional view of the surroundings to the UAV leading to obstacle detection, classification and tracking. However, LiDAR vision is blocked by a black region i.e., the region just below the UAV. Single Channel LiDAR will help to find obstacle distance vertically below the drone. Since the LiDAR does not give any color information, using an RGB camera complements it.

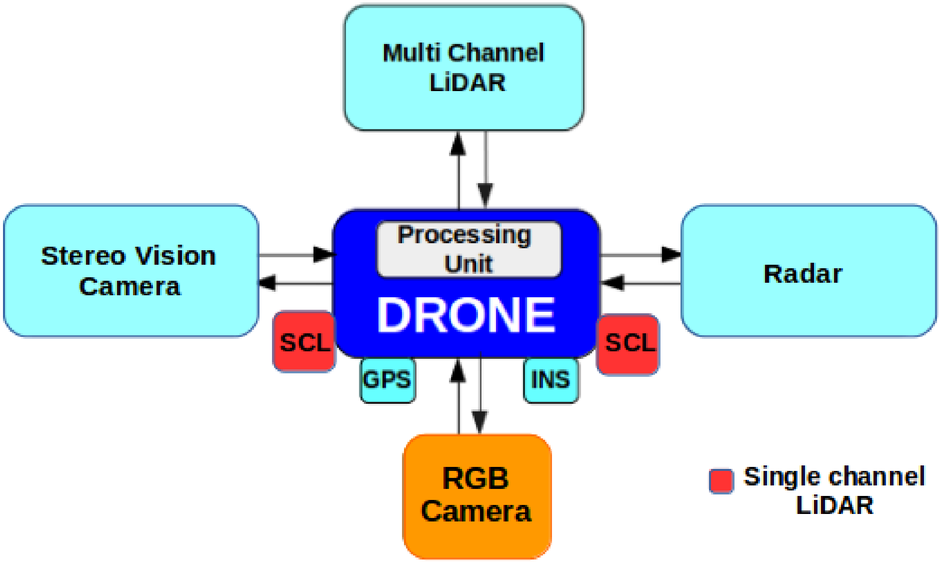


Figure 69: Multi-sensory perception system for UAV

- **High-speed Communication:** Unmanned Aerial Vehicles (UAV), or drone communication, are emerging areas of research that can be utilized in military or civilian domains. Drone communication maintains connections between drones and a ground station with an adequate data rate for fortifying real-time transmissions. Due to multi-sensor fusion, data become heavy large in size. Real-time transmission and communication of this data is a very challenging task. The delay should not be more than milliseconds. In some of the applications of UAVs e.g., passenger drone, not only very low latency but communication also should be very reliable. To solve this problem, ultra-reliable low-latency(URLLC) 5G communication will play a crucial role. Even with the advances of 4G LTE, the network is running out of bandwidth. The solution, as seen by 5G wireless network developers, is to add more bandwidth by using the frequency spectrum in the millimeter-wave frequency range. With hundreds of megahertz of wireless transmission bandwidth available at center frequencies such as 24, 28, and 38 GHz, 5G wireless networks will be capable of extremely high data speeds.

- **Edge Computing:** The data processing steps must be completed with a minimum run time. To minimize the run time, edge computing devices such as NVIDIA Jetson TX2 can be used as a processing unit.

- **Real-time UAV Design for Multi-UAV coordination:** The time-critical nature of the UAVs, in terms of reaching the emergency site is an important parameter in the design of the UAVs. This design constraint relates to the optimization of the algorithm that runs on the UAV for flight from the starting point to the emergency site. The design requirement also determines the hardware components, such as rotor speed, speed of the processor running the mobility algorithm, etc. In these emergency situations, it is worth pondering coordinating among multiple UAVs for achieving a single goal. For example, at a fire site, a group of UAVs will extinguish the fire at the edges at the site, and some UAVs may extinguish fire in the inside region of the fire site; the reason being to extinguish fire at a faster speed and to avoid the spread of fire from other regions to already handled regions. Such a scenario where multi-UAVs are working together, there is a need for at least minimal coordination among the UAV to execute the task. This Multi UAV setup requires modelling and simulation of the algorithm, which is essentially distributed among UAVs.
- **Test Facility Establishment:** A testbed and development facility for the UAVs will be established. An area will be identified within the IIT Hyderabad campus for the establishment of the test facility which can also be used by all govt. and private stake holders. Importantly, we also plan on developing standard operating procedures for UAVs in various applications considered in this proposal.

7.1.1.3 Strategy for Unmanned Surface Vehicles (USVs):

The major challenges in ASV design are attributed to hull design, propulsion design, electronic devices, sensors selection and communication link. In the initial phase it is planned to build a surfing model as a prototype to develop navigation and control algorithms. The size, weight and robustness of the vehicle will be optimized to test the GNC system effectively. Hence, the initial attempt is planned such that the vehicle should be manageable by just one or two persons. The vehicle can thus be pushed into water using a launching trolley. The vessel will accommodate minimum payloads like echo-sounders, side scan sonar and sensors for bathymetry survey.

The major impact to the vehicle’s weight is contributed by the rechargeable batteries. The batteries should be selected as a compromise between its weight and the fact that it should provide the power for all the electrically-driven thrusters and for all electronics. The idea is to use Li ion batteries which can provide an operation time of three hours. Ultrasonic sensors will be used for close range distance measurements. Collision avoidance algorithms may be used in conjunction with sonar sensors or automotive radar sensors. For localization and vehicle state estimation a GPS receiver, a compass and IMU sensors shall be used.

To run the software for communication and mission handling, an embedded platform will be used. Wireless network is considered for the communication between the USV and the base station. This connection will be used to send all information about the current state of the ASV to the base station and the base station sends information about the mission to the ASV. A redundant communication link may be provided for critical requirements. Using the communication link, the ASV may be controlled manually if required.

The control and navigation software will be tested in simulation platforms before porting to the electronics. The vessel model shall be tested in model in loop simulation and later in hardware in the loop simulation integrating sensor and actuator models as well as physical interfaces to control and communication links.

7.1.2 Agriculture

The challenge for airborne agriculture is to produce useful information quickly and locally from the enormous data generated so that decisions and actions are taken at the same time. Due to the presence of multiple imaging sensors on-board, a huge amount of data is captured during every flight (Table 3). The time taken for analysis using software such as Pix4D, AgiSoft Photoscan, or uploading it to a cloud server for overnight processing of AI, ML algorithms not only costs money but also eats away the valuable time and information. For example; the picture quality depends on environmental conditions. The quality should be analyzed on the spot because a slight delay may change the environment drastically and may not be feasible to capture data which further affects the estimation of traits and yield. So, there is a need for real-time quality analysis while capturing images. Also, Crop health includes stress level, pest, disease detection, and nutrient deficiency. Monitoring of crop health is essential for better quality, quantity, and yield. The health of crops might be decayed in cases where a failure condition exists that demands immediate action. A slight delay can result in a loss of tens of thousands of dollars in terms of yield. Most of the agricultural fields in India and around the world are located in rural areas where the connectivity to the network is less. Hence, it is difficult to upload the data to the cloud, and processing gets delayed which may further affect the crop and its yield. Therefore, there is a need for edge computing devices enabling AI, so that the captured data can be processed and decisions can be taken in less time. The benefits of edge computing along with AI can change the future of PA and can help breeders to develop the disease and stress-tolerant crops with high yield addressing the global challenge.

In the on-going initiatives, we are working on crops like sorghum, maize, rice, chickpea. The AI/ML algorithms vary w.r.t growth stages of the crop. These developed algorithms will be taken to the next level by incorporating them into edge computing devices to get analysis there itself so that decisions can be taken in less time. Also, we will develop novel AL/ML-based algorithms for more crops such as mungbean, pearl millet, groundnut, etc. Also, other strategies opted from different aspects of the technology development include:

Autonomous Drones: Applications addressing high societal impact are chosen using UAVs as a primary component of every application. Autonomous Navigation of UAV's is proposed as a solution to address scalability in the wide area applications. Sensors and actuators will be connected to the drone system, where the drone navigates over the field of interest without any human intervention or control. Important sensors like vision, obstacle avoidance, GPS and other application specific sensors will be integrated as a hardware and software framework in the implementation of the above applications.

Computer Vision: The visual information captured through the cameras constitute the majority of the information. Computer Vision is the area of computer science which deals with the visual data for the different applications. Image classification, object detection, object recognition, face recognition, surveillance, etc. are some typical examples of computer vision. In this project, such techniques are needed to process the image/video data captured through cameras installed with the drones. The alternative strategies use the hand-designed features for different applications of computer vision.

However, the learning-based techniques have outperformed the traditional hand designed approaches.

Artificial Intelligence and Machine Learning: Artificial intelligence and machine learning based techniques have shown a great impact over the different applications. The cutting-edge advancements in machine learning will be used in this project for the supervised/unsupervised learning of the visual data to take the decision and give the commands to the drone manipulators to execute any task without human intervention.

The above-described strategy will be utilized for all the applications discussed and to achieve the proposed objectives. Also, the strategy will be improved as per the need basis during the project execution and challenges incurred.

7.2 Human Resources and Skill Development

At IIT Hyderabad, we have a long-standing tradition of developing next-generation technology with a pool of research experts, senior undergraduate students, and recent graduates from various engineering schools. We anticipate human resource development from a variety of engineering and science fields and at various levels leading to a strong human resources development that can solve difficulties across a wide range of industries, given the diverse nature of the proposed work.

The hub plans to develop IoT-based Cyber Physical Systems courses, degree programs, and certificate programs, as well as introducing interdisciplinary research programs (MS + PhD) in the broad areas of autonomous navigation and data acquisition Systems and Applications. One such program which is already initiated includes the M. Tech in Smart Mobility program which is purely inter-disciplinary involving the technological courses from various fields of Engineering including Electrical, Mechanical and Aerospace, Civil, Mathematics, Computer Science, Liberal Arts, Design, etc. The certificate programs that are proposed will emphasize skill development of students, faculties, industry professionals in the areas of autonomous navigation and data acquisition systems. The wide variety of areas provided through this initiative opens up many career paths in subjects such as AI, machine learning, modelling, simulation, embedded sensor development, cloud computing, IoT, and data analytics, as the traditional manufacturing business has reached saturation. Also, the hub will organize grand challenges, hackathons, ideathons, and symposiums for promoting innovation in India.

The hub plans to recruit manpower at various levels of the technology management and development, which enables everyone in enhancing their skills in the advanced technologies of the autonomous navigation. To encourage and promote the research in this area, the hub also plans to offer fellowships for chair professors, faculties, and students (both national and international). The teaching assistants, research scholars and students working in the hub will be actively involved in the course delivery process thus developing the next generation knowledge carriers.

7.3 Collaborations

The hub proposes several national and international collaborations for fastening the technology development. These collaborations comprise of academia, industries, and govt. agencies. These collaborations will comprise of joint technology development, exchange of researchers, organization of technical symposiums, development of testbed and testing facilities, etc. To start with TiHAN has already initiated the collaboration with Suzuki Motor Corporation, Japan, for the joint development of autonomous navigation technologies for use in unmanned ground vehicles. Also, several other opportunities are being explored actively. In the national front, the hub already has collaborated with the following entities:

- NVDIA - Collaboration in the development of standard computing architecture for autonomous vehicles. Specifically, the focus will be laid on the development of standardized architectures for Indian road conditions.
- Analog Devices India - Collaboration in electronics development and integration
- Honeywell - Collaboration involves setting up an AI/ML centers in diverse application areas.
- Skoruz - Collaboration in terms of market exploration and commercialization.
- SpringML - Collaboration in development of AI/ML framework developments
- nVipani - Collaboration in technology prototyping and AI/ML framework development
- Agma Technologies - Collaboration includes development of digital road infrastructure
- Marut Drones - Collaboration includes development of autonomous navigation systems for water quality monitoring.
- Efftronics Private Limited - Collaboration in IoT frameworks development
- Terra Drone - Collaboration includes knowledge sharing on the development of drone taxis and beyond visual line of sight communication technologies for UAVs.
- Q-Labs - Collaboration includes knowledge sharing on computations.
- NXP Semiconductors - Collaboration includes development of efficient processing architectures

Also, collaborations with the defense organizations under the Indian Govt. is being explored.

7.4 Innovation and Entrepreneurship Development

With the Indian govt. very keen on promoting the entrepreneurship and management activities through various schemes, the hub also plans to promote the entrepreneurship in the areas of autonomous navigation and data acquisition systems. Several schemes such as listed as below are planned for encouraging new experienced and budding entrepreneurial players:

- **TiHAN Grand Challenges and Competitions (GCC) -** for scouting innovations by delivering prototyping grants and seed fund support
- **TiHAN PRomoting and accelerating Young and Aspiring Innovators and Startups (PRAYAS)** - for funding cutting edge technology development in the areas of autonomous navigation and data acquisition systems
- **TiHAN Entrepreneur in Residence (EIR)** - to encourage graduating students to take entrepreneurship as career by providing support in the form of fellowship.

- **TiHAN Startups and Spinoff Companies –** to encourage graduating students to establish their dream venture in the technological verticals of Intelligent and Autonomous Transportation Systems and Agriculture
- **Technology Business Incubator (TBI)** – It is planned to collaborate with the IITH Technology Incubation Centers for the implementation of various schemes planned for promoting the entrepreneurship in India.
- **TiHAN Accelerator –** for supporting early-stage startups to move into revenue generation phase by accelerating the technology development and customer acquisition
- **TiHAN Seed Support System (SSS) -** To ensure timely availability of the seed support to the deserving incubated startups within TiHAN TBI, thereby enabling them to take their venture to next level and facilitate towards their success in the market place.

7.5 Ongoing Initiatives

IIT Hyderabad has already established three different Technology Business Incubators and one research Park in the new campus. The institute is actively working with industry, both established and new ventures to transfer knowledge and problem-solving skills. Incubating firms and research companies are part of IITH vibrant, creative, innovative, entrepreneurial network.

i-TIC Foundation IIT Hyderabad (hosted by Indian Institute of Technology Hyderabad), a Society, is an umbrella organization that has been formed with the precise idea to nurture startup culture in IIT Hyderabad. The goal is to create an 'amalgam' of research and industry by creating a very supportive and nourishing environment wherein research concepts can be taken up and integrated with industry for commercialization.

The other two incubators hosted by IIT Hyderabad are:
Foundation for CfHE - The Foundation for the Center for Healthcare Entrepreneurship, is sponsored by two IIT Bombay alumni, and is focused on making universal healthcare a reality. The center's objective is to catalyze healthcare innovation to bring about affordable solutions to address healthcare needs of India. The Center hopes to foster entrepreneurs to deliver a pipeline of cost-efficient solutions, which are increasingly 'commercialized'.

Fabless Chip Design Incubator (FabCI) - Fabless Chip Design Incubator, a flagship program being executed with the support of Ministry of Electronics and Information Technology (MEITY) precisely focuses on creating an ecosystem for grooming startups in the area of chip design.

8. Target Beneficiaries

NMICPS TiHAN at IIT Hyderabad create a network of engineers and technologists who can bridge the gap between academics and industry. Through innovation, our team will give the necessary support to turn novel ideas into advanced technologies. The creation of building blocks is intended to support the innovation and start-up ecosystem. The targeted beneficiaries are mentioned below.

8.1 Autonomous Transport Systems

8.1.1 Unmanned Ground Vehicles (UGVs)

The development of the testbed will become a national asset that can be used by industry, govt. agencies, R&D teams for testing the autonomous vehicles. The challenges identified for realizing the autonomous vehicles for Indian context will help in policy making and enacting legal terms. The outcomes of the project will result in the development of technologies, both in hardware, software and algorithms for various aspects of autonomous vehicles. These will be productized and offered to various automobile vendors for inclusion into their respective plans for autonomous vehicles. Transfer of Technology/Commercialization/Exclusive sale will be explored as part of the process, as is accepted by DST. Interactions with prospective ToT partner/end users/start-ups will be initiated and during the project execution time for technology commercialization. The major target beneficiaries for UGVs may include:

- Ministry of Road Transport, GOI.
- National Highway Authority of India (NHAI), GOI
- Private Automobile Sectors
- DRDO Organizations
- ARAI, Pune
- ICAT
- Border Security Force (BSF)
- Intelligence Bureau (IB)

8.1.2 Unmanned Aerial Vehicles (UAVs)

The following are the target beneficiaries:

- **Police Surveillance Team:** The automatic surveillance of the places that need attention is one of the major hurdles for the police officials. Such applications can be developed through the proposed project.
- Companies like Analog Devices, National Instruments, Efftronics Pvt. Ltd., Marut Drone Pvt. Ltd., Terradrone Pvt. Ltd. and nVipani expressed their interest in this application and agreed for possible collaboration in this area.
- We have also initiated the talk with DRDO Young Scientist Labs and SpringML Pvt. Ltd. to become a collaborator for this application.

- **Security Agencies:** The solutions planned to be developed through this project have the tremendous application opportunities for the security forces including border forces. The use of UAV for different applications can be used to avoid the major accidents for the security agencies.

- **Private Societies**: The private societies could be also the potential users to tackle the security riddles.
- **Large Organizations/Industries:** The large organizations such as universities, industries, etc. could be also the potential users for UAV based surveillance.
- **Mining Organizations/Industries:** Open Mining surveillance using autonomous UAV frameworks that will be developed part of this application theme for possible beneficiaries like Neyveli lignite corporation.
- **Public and Private Warehouses:** Surveillance and monitoring for large government/private warehouses where possible beneficiaries can be Food Corporation of India (FCI) and private e-commerce organization warehouses.
- Centre for High Technology (CHT), Ministry of Petroleum & Natural Gas.
- Department of Space (DoS).
- Department of Information Technology & Communication, Rajasthan.
- Directorate of Industry Interface & Technology Management (DIITM), Ministry of Defense.
- Department of Defense Production, Ministry of Defense.
- Ministry of New and Renewable Energy (MNRE).
- Department of Defense Research & Development, Ministry of Defense.
- Ministry of Housing and Urban Affairs (Smart Cities Mission) (MoHUA).
- There are various Non-Governmental organizations such as NAAM, LEISA, and others with whom We can work in collaboration in a synergistic manner and achieve our goals.

The beneficiaries of this project also include the students who will acquire skills to design and build drones using model-based development approach, which is the emerging industry standard to design cyber-physical systems for environment related applications. The skills that the students acquire will help them to get job opportunities in the core area of cyber-physical system design.

8.1.3 Unmanned Surface Vehicles (USVs)

There are lot many potential client bases for Autonomous Surface Vehicle. The key factors for the growth of market are increased demand for water quality monitoring, maritime security and threats and need for ocean data and mapping. The market for ASV is segmented into Application, size, propulsion system, modes of operation, payload and geography.

By application, the defense segment is expected to grow at the highest CAGR during 2018-2023.

The unmanned surface vehicle market has been segmented into small, medium, large, and extra-large based on size. Large ASVs are mainly used in Defense applications, such as ISR activities, combat operations, cargo & resupply, etc. To start with, it is planned to develop a small ASV which has potential market for data collection for scientific research.

The ocean contains incredible amounts of valuable data, but the large area and constantly changing conditions of our oceans can make them difficult to study. Oceanographic studies require a reliable means of data collection.

The user agency we would project for ASV is Indian Navy. Discussions were held with Indian Navy officials and the features of the product proposed to be developed and the implementation strategy were finalized taking their inputs.

8.2 Agriculture

The methods and technologies proposed here when implemented will be useful for agricultural scientists and Indian farmers. The proposed project will establish a state of the art research and test facility in Autonomous Navigation and Data Acquisitions for Precision agriculture. These facilities will be open to agricultural scientists, agro-based startups, and academic institutes on a chargeable basis. Technical Training and short courses will be offered to train the manpower and also for revenue generation. Also, following beneficiaries are expected in addition:

- The research aims at accelerating the standard crop phenotyping and genotyping procedures which significantly aids the agricultural researchers in developing better quality crops at a rapid pace.
- Helps in the development of advanced crop improvement programs through linkage to (http://excellenceinbreeding.org/);
- Industries providing Agriculture solutions such as Corteva, TCS, Infosys, and many other international agencies
- International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India
- Prof. Jayashankar Telangana Agricultural University, Hyderabad, India
- Semi-Autonomous Navigation algorithms for UAVs and UGVs - Robotics and autonomous vehicle manufacturers, service providers for agriculture, forest survey, event recordings, police and military etc.
- Secure Learning and Communications for Autonomous Navigation and Data Acquisition Systems - The developed prototype will be of immense value to transport companies such as OLA, UBER etc., and logistics companies such as VRL logistics, DHL, India Post and FedEx. In addition, the automation companies will also be benefited by our proposed solution as the distributed decision-making system is at the core of the products developed by these companies. As a standalone solution, it can be used in precision agriculture applications, and hence can lead to a startup.
- Speech Technologies for Autonomous Navigation - Any application that needs speech modality for autonomous navigation. These include development of navigation systems for tourist sites of India, drone operation and control etc.
- Farmers and Food Industry - The applications such as UAV based precision agriculture will be focused for the upliftment of the farmers.
- Moreover, such applications can be also used by the mass production by the food industries.
- Data collection systems for both Public and Private Research institutes like “ICRISAT”
- Database creation for large area surveys in implementation of government policies like “Soil cards”
- Insurance companies covering the agriculture sector
- Data for ground agriculture equipment manufacturers for autonomous pesticide/nutrition release systems
- The primary discussion has been done with potential Industrial stakeholders like nVipani Pvt. Ltd., Marut Drone Pvt. Ltd., Terradrone Pvt. Ltd. and Analog Devices Pvt. Ltd.

- Initially the project will be executed for the beneficiaries related to Mango and Paddy based on the market study suggested by industry collaborators.
- At present there is financial commitment from the industry collaborators, but they expressed their interest in the Public Private Partnership model in the coming future.
- Department of Land Resources (DLR), Ministry of Rural Development.
- ICAR Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmers Welfare.
- Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare.

Additional target beneficiaries include **Government Agencies and Public Sector Units** (Department of School Education and Literacy, Ministry of Education, Government of India, Ministry of Jal Shakti, Department of Drinking Water and Sanitation, intelligence Bureau (Ministry of Home Affairs), Government of India, Research & Analysis Wing, Direct General of Civil Aviation (DGCA), Naval Research Board, DRDO).

9. Time Frame: Targets, Milestones on Timeline / GANTT Chart

9.1 Development of Intelligent and Autonomous Transportation

1. Literature survey and manpower recruitment
   Duration: 4 Years (During 0 - 4 year after grant)

2. Procurement and integration of different sensors and UAV/UGV
   Duration: 3 years (During 2 - 4 years after grant)

3. Development of standard operating procedure (SoP) of different sensors for UAV and UGV
   Duration: 3 years (During 2 - 4 years after grant)

4. Sensor integration and calibration
   Duration: 3 years (During 2 - 4 years after grant)

5. Develop and demonstrate a prototype of remote controlled UGV in the initial phase of the project. Algorithms, hardware and software components required to demonstrate the prototype will be the developmental focus of this phase. Development of edge computing frameworks. In order to hit the road running it is proposed to integrate ready-made and COTS modules into the prototype, without reinventing the wheel. The various blocks elements of a UGV, namely the Sensors and Data Acquisition Interface, Navigation and Control Interface, Communication Interface and Power Supply will form part of the prototype demonstration which will be controlled by a remote user. The hardware for real-time interfacing of the various units, main processor board, software architecture and navigation algorithms will be developed as part of this phase.
   Duration: 3 years (During 2 - 4 years after grant)

6. Upgrade the existing prototype from a remotely controlled architecture to a semi-autonomous system. Here, the focus of the development will be in low latency, light weight and real-time dynamic algorithms targeting one or more system components. For example, the steering mechanism or braking mechanism will be autonomous and this architecture will be tested with a driver within the vehicle. Required software, hardware and algorithms for this will be developed for seamless and real-time navigation and control of the UGV. It is proposed to incorporate ML/AI techniques to improve the prediction required in various navigation aspects of the UGV.
   Duration: 3 years (During 2 - 4 years after grant)

7. Integration of multiple sensors (RGB camera, LiDAR, stereo vision camera, etc.) with the UAV, development of ML/AI based algorithms for obstacle detection and avoidance
   Duration: 2.5 year (During 0.5 - 3 years after grant)

8. Development of UAV intruder detection system
   Duration: 2 years (During 1 - 3 years after grant)

9. Multi-UAV coordination
   Duration: 3 years (During 1 - 4 years after grant)

10. Development of standard operating procedure (SoP) of different sensors for infrastructure inspection (power line, gas pipeline and railway track)
    Duration: 2 Years (During 0.5 – 2.5 years after grant)

11. Development of computer vision frameworks for autonomous power line detection. 3D modelling of power line using LiDAR and optical cameras
    Duration: 2 years (During 0.5 - 2.5 years after grant)

12. Development of autonomous frameworks for real-time detection of foreign matter on the power lines, detection of hotspots, strands, and corona detection
    Duration: 2 year (During 0.5 - 2.5 years after grant)

13. Development of Gas pipeline surveillance system for physical damage, corrosion, leak detection
    Duration: 3 years (During 1 - 4 years after grant)

14. Development of Railway track inspection system for track status monitoring, vegetation detection
    Duration: 3 years (During 1 - 4 years after grant)

15. Development of ground-based air and water quality monitoring network using aerial images
    Duration: 3 years (During 1 - 4 years after grant)

16. Development of soil erosion monitoring system UAVs (includes drone development with calibration and integration of sensors, real-time data processing at the edge, communication, AI frameworks for soil erosion detection)
    Duration: 3 years (During 0 – 3 years after grant)

17. Real-time demonstration of UAV based real-time CPS system for environmental monitoring
    Duration: 3 years (During 0 – 3 years after grant)

18. Development of standard operating procedure (SoP) for Surveillance
    Duration: 4 Years (During 1 - 4 years after grant)

19. Development of propulsion system, energy system, system controller, tracking and navigation system for ASVs
    Duration: 3 years (During 0.5 - 3.5 years after grant)

20. Real-time demonstration of autonomously navigating UAVs and UAV based cross border activity monitoring CPS system
    Duration: 2 years (During 3 – 5 years after grant)

21. Development of a Prototype AUGV which includes the Chassis & Body, Drive Method, Fuel Injector etc.

Duration: 2 years (During 2 - 4 year after grant)

22. Real-time demonstration of AUGV and real-time CPS systems on identified test track
    Duration: 4 years (During 2 - 5 years after grant)

23. Real-time demonstration of CPS based ASV
    Duration: 4 years (During 2 – 5 years after grant)

24. Production, Commercialization and ToTs
    Duration: 4 year (During 2 - 5 years after grant)

25. Establishment of living lab and testbed development
    Duration: 4 years (During 2 - 5 years after grant)

26. Urban Air Mobility (UAM) and ecosystem development
    Duration: 4 Year (During 2 -5 Year)

27. Autonomous Navigation of Bioinspired Micro and Nano Aerial Vehicle development including drone swarms for various applications
    Duration: 4 Year (During 2 -5 Year)

28. Autonomous Navigation of small category drones with high end sensors such as hyperspectral LIDAR, multispectral etc., for various applications
    Duration: 4 Year (During 2 -5 Year)

29. Development of Command Control Station TiHAN
    Duration: 4 Year (During 2 -5 Year)

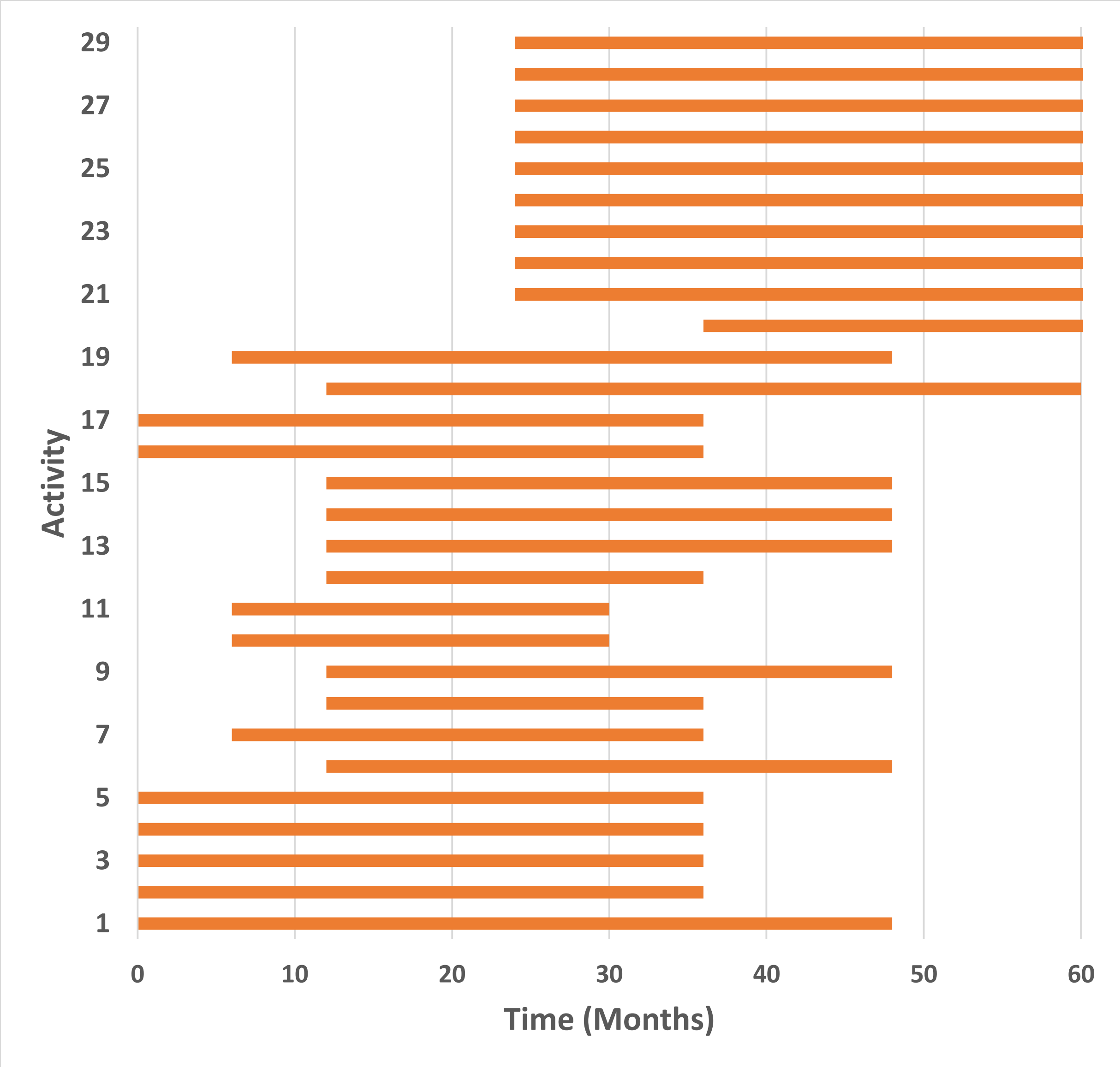


Figure 70: Gantt chart depicting timelines for the development of Autonomous Navigation and Data Acquisition Systems for Intelligent Transportation

9.2 Development of Autonomous Navigation and Data Acquisition Systems for Agriculture

1. Literature survey and manpower recruitment
   Duration: 4 Years (During 0 - 4 year after grant)

2. Procurement and Integration of UAVs with different sensors including LiDAR, multi-spectral camera, hyperspectral camera, ultraviolet camera, etc.
   Duration: 2 years (During 1 – 3 years after grant)

3. Sensor calibration

Duration: 2 years (During 0.5 – 2 years after grant)

4. Real-time CPS system development using calibrated sensors for integration with UAVs
   Duration: 3 years (During 0.5 – 3.5 years after grant)

5. Development of standard operating procedure (SoP) for data acquisition for agriculture application.
   Duration: 3 Years (During 1 - 3 year after grant)

6. Development of ground sensor network for monitoring soil parameters in the ICRISAT fields with cloud based data acquisition system
   Duration: 2 years (During 1 - 3 year after grant)

7. Data acquisition using UAVs for developing edge computing based frameworks for precision framework
   Duration: 3 years (During 0 - 3 years after grant)

8. Development of pest and disease detection algorithms
   Duration: 2 years (During 1 - 3 years after grant)

9. Development of AI based framework for analyzing the plant traits using aerial images
   Duration: 2.5 years (During 0.5 - 3 years after grant)

10. Development of AI based growth stage monitoring
    Duration: 2 years (During 1 - 3 years after grant)

11. Estimation of canopy coverage and flowering count using aerial images
    Duration: 2 years (During 1 - 3 years after grant)

12. Development of low-complex edge computing framework for estimation of plant traits
    Duration: 2 years (During 1 - 3 years after grant)

13. Development of an intelligent farmer assistance system
    Duration: 2 years (During 1 - 3 years after grant)

14. Real-time testing of pest and disease detection algorithms on edge computing platforms mounted on UAVs
    Duration: 2 years (During 2 - 4 years after grant)

15. Real-time end-to-end aerial CPS system demonstration for agricultural applications
    Duration: 2 years (During 3 - 5 years after grant)

16. Robot specification requirements
    Duration: 2 years (1 - 3 year after grant)

17. Automatic speech identification and recognition system development for robots
    Duration: 2 years (1 – 3 years)

18. Regional language speech synthesis (includes data collection and AI framework development) for robots
Duration: 3 years (2 – 5 years)

19. Face detection and recognition frameworks for robots
Duration: 2 years (1.5 – 3.5 years)

20. Obstacle detection and avoidance mechanisms for robots
Duration: 2 years (1.5 – 3.5 years)

21. Establishment of living lab and testbed development
Duration: 4 years (During 2 - 5 years after grant)

22. Leveraging the UAV-based technology for crop residue: an important resource for the crop-livestock farming community.
Duration: 2 years (1.5 – 3.5 years)

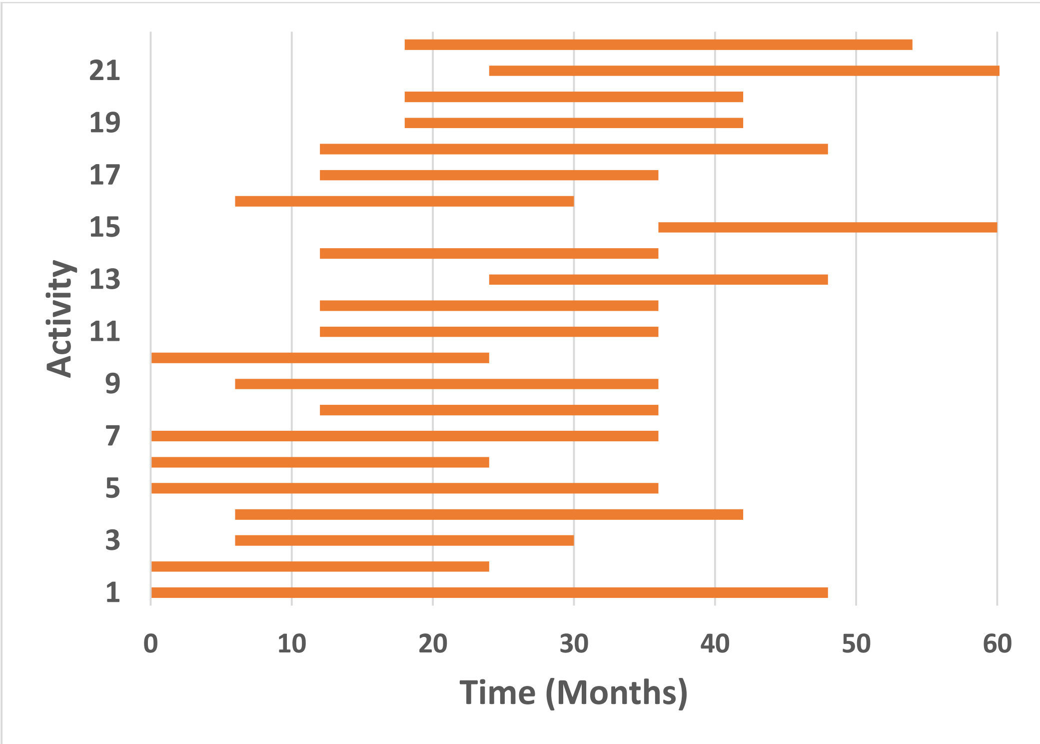


Figure 71: Gantt chart depicting timelines for the development of Autonomous Navigation and Data Acquisition Systems for Agriculture

10. Budget

a. Summary (in Crores)

Total Budget Required: 135 Crores INR

Item	Budget Head	Year 1	Year 2	Year 3	Year 4	Year 5	Total (in Crores)
A	Manpower	3.87	7.83	9.70	8.91	8.30	**38.6**
B	Travel	0.45	0.90	0.80	0.80	0.50	**3.45**
C	Technology Development	1.50	7.12	13.00	2.51	0.40	**24.53**
D	Skill Development	0.26	0.69	1.50	0.36	0.34	**3.16**
E	Innovation and Entrepreneurship and Startup Ecosystem	1.22	2.96	3.15	3.44	4.02	**14.79**
F	International Collaboration	0.70	1.50	1.85	1.18	0.69	**5.92**
G	Equipment	5.50	11.50	10.50	0.00	0.00	**27.50**
H	Capital Expenditure	6.75	3.50	3.50	1.80	1.50	**17.05**
	Grand Total in Crores (A+B+C+D+E+F+G+H)	**20.25**	**36.00**	**44.00**	**19.00**	**15.75**	**135.00**

Recurring and Non-Recurring Components of the Budget:

Sl. No.	Items	Budget Head / Year	Year 1	Year 2	Year 3	Year 4	Year 5	Total (in Crores)
1	G+H	Non-recurring	12.25	15.00	14.00	1.80	1.50	44.55
2	A+B+C+D+E+F	Recurring	8.00	21.00	30.00	17.20	14.25	90.45
	Total (in Crores)		20.25	36.00	44.00	19.00	15.75	135.00

b. Manpower (in Crores)

Summary:

Sl. No.	Budget Head	Year 1	Year 2	Year 3	Year 4	Year 5	Total Consolidated (in Crores)
1	Student Fellowships	1.69	3.61	4.52	4.27	3.90	**18.00**
2	Faculty Fellowships and Chair Professors	0.36	0.72	0.72	0.72	0.72	**3.24**
3	Research Staff	1.48	2.77	3.73	3.19	2.95	**14.11**
3	Staff (Admin)	0.34	0.73	0.73	0.73	0.73	**3.25**
	Total (in Crores)	**3.87**	**7.83**	**9.70**	**8.91**	**8.30**	**38.60**

Justification:

Student Fellowships: The hub plans to offer around 125 Post Graduate fellowships, 45 PhD fellowships, 22 Post-Doctoral fellowships, 300 internships over a period of 5 years

PG Fellowships:

A total of around 100 2-Year PG fellowships and 25 3-Year PG fellowships will be offered over a period of 5 years through various Academic program initiatives in collaboration with IITH

2 Year PG Fellowships (each student will be funded for 2 years)					
Year	New Fellowships	Active Fellowships	Fellowship per person per month (INR)	Fellowship per person per year (Crores)	Cumulative
Year 1	20	20	14000	0.017	0.336
Year 2	20	40	14000	0.017	0.672
Year 3	20	40	14000	0.017	0.672
Year 4	20	40	14000	0.017	0.672
Year 5	20	40	14000	0.017	0.672
Total Fellowships	**100**	**Total Budget (in Crores)**			**3.024**

3 Year PG Fellowships (Each student will be funded for 3 years)					
Year	New Fellowships	Active Fellowships	Fellowship per person per month (INR)	Fellowship per person per year (Crores)	Cummulative
Year 1	5	5	14000	0.017	0.084
Year 2	5	10	14000	0.017	0.168
Year 3	5	15	14000	0.017	0.252
Year 4	5	15	14000	0.017	0.252
Year 5	5	15	14000	0.017	0.252
Total Fellowships	**25**	**Total Budget (in Crores)**			**1.008**

PhD Fellowships:

TiHAN plans to offer around 45 PhD fellowships over the period of 5 years

PhD Fellowships (Each student will be funded for 5 years)					
Year	New Fellowships	Active Fellowships	Fellowship per person per month (INR)	Fellowship per person per year (Crores)	Cumulative
Year 1	12	12	45000	0.054	0.648
Year 2	14	26	45000	0.054	1.404
Year 3	14	40	45000	0.054	2.16
Year 4	5	45	45000	0.054	2.43
Year 5	0	45	45000	0.054	2.43
Total Fellowships	**45**	**Total Budget (in Crores)**			**9.072**

Post-doc Fellowships:

TiHAN plans to offer around 22 Post-doc fellowships over the period of 5 years

Postdoctoral Fellowships (Each student will be funded for 2 years)					
Year	New Fellowships	Active Fellowships	Fellowship per person per month (INR)	Fellowship per person per year (Crores)	Cumulative
Year 1	4	4	62000	0.0744	0.2976
Year 2	10	14	62000	0.0744	1.0416
Year 3	5	15	62000	0.0744	1.116
Year 4	3	8	62000	0.0744	0.5952
Year 5	0	3	62000	0.0744	0.2232
Total Fellowships	**22**	**Total Budget (in Crores)**			**3.2736**

Internships:

A total of 250 internships (of 1 and 2 month categories), and 50 long-term internships (6 month categories) will be offered by the hub

Internships (1 & 2 months category, Total: 250) for IITians and other university students					
Year	New Fellowships	Active Fellowships	Fellowship per person per month (INR)	Fellowship per person per year (Crores)	Cumulative
Year 1	50	50	12000	0.0036	0.18
Year 2	50	50	12000	0.0036	0.18
Year 3	50	50	12000	0.0036	0.18
Year 4	50	50	12000	0.0036	0.18
Year 5	50	50	12000	0.0036	0.18
Total Fellowships	**250**	**Total Budget (in Crores)**			**0.9**

Internships (6 months project category, Total: 50) for IITians and other university students					
Year	New Fellowships	Active Fellowships	Fellowship per person per month (INR)	Fellowship per person per year (Crores)	Cumulative
Year 1	10	10	12000	0.0144	0.144
Year 2	10	10	12000	0.0144	0.144
Year 3	10	10	12000	0.0144	0.144
Year 4	10	10	12000	0.0144	0.144
Year 5	10	10	12000	0.0144	0.144
Total Fellowships	**50**	**Total Budget (in Crores)**			**0.72**

Faculty Fellowships and Chair Professors:

Over a period of 5 years, the hub plans to provide faculty fellowships and visiting faculty fellowships (international faculty). Also, a sponsorship for visiting chair professors will be provided.

Staff:
The hub plans to recruit the research staff and admin staff under the R&D portfolio and administration of the hub and the Section 8 company. We will recruit CEO/CTO/COO, General Managers, Research staff at various grades (I-IV), Staff for admin, accounts, stores and purchase, legal, company secretary. Auditors. The estimate is provided for the requested budget from DST to support the activities. However, TIH will continue similar activity with the revenue generated over the period also.

c. Travel (in Crores)

Travel (in Crores)	Year 1	Year 2	Year 3	Year 4	Year 5	Total Consolidated
Domestic travel / Field Travel/ project meetings	0.241	0.5	0.4	0.4	0.2	1.741
International Travel	0.212	0.4	0.4	0.4	0.3	1.7115
Total	**0.453**	**0.9**	**0.8**	**0.8**	**0.5**	**3.4525**

Justification: Travel among the multiple collaborators and HI within the country for project meetings. Field visits for sensor deployment and UAV based data collection for different applications: Agriculture field - number of visits changes with crop growth stage, visit to water bodies, traffic junctions, pollution data, infrastructure - power lines, rail tracks, gas pipes. National conferences, workshops, training programs.

d. Technology Development (in Crores)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Technology Development	1.5	7.12	13	2.51	0.4	24.53
Total	**1.5**	**7.12**	**13**	**2.51**	**0.4**	**24.53**

Justification: For Expert Driven New Knowledge Generation for development of Products / Prototypes from existing Knowledge (by Experts or teams – For proof of concept for various applications).
Custom designed drones and gimbals for specific application like hyper-spectral camera mounting, Lidar mounting etc. Prototype design and development for Proof of concept for various applications, PCB making, System integration, Data purchase, Consumables, Developmental/maintenance cost incurred in test bed. Technology and product delivery in specific sectors for Autonomous Navigation.

e. Skill Development (in Crores)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Skill Development	0.384	0.69	1.5	0.364	0.34	3.278
Total	**0.384**	**0.69**	**1.5**	**0.364**	**0.34**	**3.278**

Justification: Conducting of periodic Workshops, training, seminar, conferences, knowledge sharing activities among the HI and collaborators, and also for others.

Development of course materials & e-Course, development fund for projects done, CPS infrastructure development fund.

Conducting Professional Skill Development workshops, Upgrading PG Programme & conducting Advanced Skill Training Schools.

f. Innovation and Entrepreneurship and Startup Ecosystem (in Crores)

The following are the various schemes that will be undertaken by the Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN)

Year-wise Total Budget Allocated for Each Scheme						
Item	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
TiHAN CPS GCC	0	0.3	0.3	0.55	0.55	**1.7**
TiHAN CPS PRAYAS	0.5	0.15	0.45	0.15	0.45	**1.7**
TiHAN CPS EiR	0.072	0.108	0.288	0.288	0.324	**1.08**
TiHAN CPS Startups & Spinoff Companies	0.45	1.05	1.5	1.5	1.95	**6.45**
TiHAN CPS TBI	0.2	0.4	0.41	0.4	0.4	**1.81**
TiHAN CPS DIAL	0	0.35	0	0.35	0.35	**1.05**
TiHAN Seed Support System (SSS)	0	0.6	0.2	0.2	0	**1**
Total	**1.222**	**2.958**	**3.148**	**3.438**	**4.024**	**14.79**

Justification:

- A total of 4 grand competitions and challenges will be conducted under the scheme TiHAN CPS GCC over a period of 5 years.

TiHAN CPS GCC (Maximum 4 challenges over 5 years)																
Item	**Qty. Year 1**	**Amount per Grant**	**Year 1**	**Qty. Year 2**	**Amount per Grant**	**Year 2**	**Qty. Year 3**	**Amount per Grant**	**Year 3**	**Qty. Year 4**	**Amount per Grant**	**Year 4**	**Qty. Year 5**	**Amount per Grant**	**Year 5**	**Total Consolidated (Crores)**
Prototyping Grants	0	0.05	0	3	0.05	0.15	3	0.05	0.15	5	0.05	0.25	5	0.05	0.25	0.8
Seed Fund Support	0	0.15	0	1	0.15	0.15	1	0.15	0.15	2	0.15	0.3	2	0.15	0.3	0.9
Total (Crores)			**0**			**0.3**			**0.3**			**0.55**			**0.55**	**1.7**

- A total of around 7 startups will be funded over a period of 5 years under the TiHAN CPS PRAYAS scheme.

TiHAN CPS PRAYAS																
Item	**Qty. Year 1**	**Amount per Grant**	**Year 1**	**Qty. Year 2**	**Amount per Grant**	**Year 2**	**Qty. Year 3**	**Amount per Grant**	**Year 3**	**Qty. Year 4**	**Amount per Grant**	**Year 4**	**Qty. Year 5**	**Amount per Grant**	**Year 5**	**Total Consolidated (Crores)**
Innovation grant for incubator/incubatee	1	0.1	0.1	0	0.1	0	3	0.1	0.3	0	0.1	0	3	0.1	0.3	0.7
Fab Lab	1	0.3	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0.3
Consumables	1	0.1	0.1	1	0.15	0.15	1	0.15	0.15	1	0.15	0.15	1	0.15	0.15	0.7
Total			**0.5**			**0.15**			**0.45**			**0.15**			**0.45**	**1.7**

- A total of 30 students will be funded under the TiHAN CPS EiR scheme over a period of 5 years.

TiHAN CPS EiR																
Item	**Qty. Year 1**	**Amount per Grant**	**Year 1**	**Qty. Year 2**	**Amount per Grant**	**Year 2**	**Qty. Year 3**	**Amount per Grant**	**Year 3**	**Qty. Year 4**	**Amount per Grant**	**Year 4**	**Qty. Year 5**	**Amount per Grant**	**Year 5**	**Total Consolidated (Crores)**
Scholarships	2	0.036	0.072	3	0.036	0.108	8	0.036	0.288	8	0.036	0.288	9	0.036	0.324	1.08

- A total of 43 startups will be funded under TiHAN CPS Startups and Spinoff Companies scheme.

TiHAN CPS Startups and Spin-Off Companies																
Item	Qty. Year 1	Amount per Grant	Year 1	Qty. Year 2	Amount per Grant	Year 2	Qty. Year 3	Amount per Grant	Year 3	Qty. Year 4	Amount per Grant	Year 4	Qty. Year 5	Amount per Grant	Year 5	Total Consolidated (Crores)
Startups	3	0.15	0.45	7	0.15	1.05	10	0.15	1.5	10	0.15	1.5	13	0.15	1.95	6.45

- A technology business incubator with specified focus on autonomous navigation and data acquisition systems will be setup at IIT Hyderabad campus.

TiHAN CPS TBI																
Item	Qty. Year 1	Amount per Grant	Year 1	Qty. Year 2	Amount per Grant	Year 2	Qty. Year 3	Amount per Grant	Year 3	Qty. Year 4	Amount per Grant	Year 4	Qty. Year 5	Amount per Grant	Year 5	Total Consolidated (Crores)
TBI	1	0.2	0.2	1	0.4	0.4	1	0.41	0.41	1	0.4	0.4	1	0.4	0.4	1.81

- A startup accelerator will be setup for fostering the growth of early-stage startups will be set under the scheme TiHAN CPS DIAL

TiHAN CPS DIAL																
Item	Qty. Year 1	Amount per Grant	Year 1	Qty. Year 2	Amount per Grant	Year 2	Qty. Year 3	Amount per Grant	Year 3	Qty. Year 4	Amount per Grant	Year 4	Qty. Year 5	Amount per Grant	Year 5	Total Consolidated (Crores)
DIAL	0	0.35	0	1	0.35	0.35	0	0.35	0	1	0.35	0.35	1	0.35	0.35	1.05

- A total of 5 startups will be funded under the scheme TiHAN Seed Support System over a period of 5 years.

TiHAN SSS																
Item	Qty. Year 1	Amount per Grant	Year 1	Qty. Year 2	Amount per Grant	Year 2	Qty. Year 3	Amount per Grant	Year 3	Qty. Year 4	Amount per Grant	Year 4	Qty. Year 5	Amount per Grant	Year 5	Total Consolidated (Crores)
Seed Funding	0	0.2	0	3	0.2	0.6	1	0.2	0.2	1	0.2	0.2	0	0.2	0	1

g. International Collaboration (in Crores)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
International Collaboration	0.7	1.5	1.85	1.18	0.69	5.92
Total	**0.7**	**1.5**	**1.85**	**1.18**	**0.69**	**5.92**

Justification: Cost sharing based projects, consultancy projects.

International and National conferences/seminar/workshop for Faculties/students, Hospitality, joint PhD programs and internship activities with international collaborators.

Inviting International experts under specific domain areas.

h. Equipment (in Crores)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total (INR in Crores)
Equipment	5.50	11.50	10.50	0.00	0.00	27.50
Total	**5.50**	**11.50**	**10.50**	**0.00**	**0.00**	**27.50**

Justification: All major equipment proposed to be procured related to the project worth of 27.5 crore is listed below.

Sl. No.	Generic Name	Model No.	Justification	Qty.	Spare Time	Cost (in Crores)
1	INS/GNSS (Inertial navigation system)	Advanced Navigation Spatial Dual (International)	For navigation system for UAV/UGV	5	0	0.40
2	Multispectral camera	Airphen (International)	For agriculture sector application, nutrient and crop disease analysis	3	50	0.30
3	DGPS System/rtk	Trimble R10 (International)	Creating Ground Control points to prepare the field for drone flying, drone stability, accurate localization	3	50	0.60
4	Hyperspetral camera	Hyperspetral camera	For agriculture, environment monitoring, nutrient and crop disease analysis	3	50	2.00
5	Electric test vehicle	Hyundai (International)	Test vehicle with ADAS for autonomous unmanned ground vehicles with multiple sensors integrated	10	30	1.00
6	Gimble	Custom design, DJI Ronin2/ Copterlab (International)	For mounting Thermal/RGB/Hyperspectral camera and LiDAR on UAV	15	50	1.00
7	High speed processor/server/shared memory	Dell Proliant (Ingternational)	Dedicated facility for AI/ML/DL framework development	10	0	2.00
8	RGB camera	Zenmuse X5s (International)	For all five sectors application, nutrient and crop disease analysis, perception for UAV/UGV/ASV	5	0	0.25
9	Canopy analyzer	LI-COR, CID-Bioscience (International)	For Agriculture - LAI estimaton	2	0	0.50
10	Edge computing devices	NVIDIA TX2,Xavier/Intel NUC (International)	Required for on-board edge computing	50	0	0.75
11	UV sensor	Honeywell FSL100 (International)	Hotspot detection for powerline inspection	1	50	0.10
12	Small Drones	DJI (International)	Drone swarming applications	50	50	1.00

13	Computing facility	Microsoft surface studio/Dell precision tower	Dgx servers, Computing - Handheld, Desktops workstations for students and project staffs for developing AI/ML frameworks for various applications mentioned in the project	50	0	2.50
14	Drone	Freefly systems alta 8 (International)/DJI/Ideaforge	UAV systems for different sectors- high end sensors like Lidar, Hyperspectral imager/RGB/Multispectral etc	10	0	1.05
15	Sensors for agriculture	NPK, pH meter, field scout (International)	For agriculture: soil nutrient analysis	2	50	1.00
16	Gimble for small drones	DJI (International)	Gimbles for mounting sensors on small drones for swarming	25	50	1.25
17	Other sensors - multiple sensors for autonomous navigation	Realsense, Leddartech (International)	Stereo vision camera, LiDAR sticks, Single channel LiDAR, RF, Ultrasonic sensor	20	50	2.00
18	LiDAR	32/64/128 channel (International)	Sensor for perception of UAVs, Number of channels depends on application	5	50	3.55
19	Test Facility	HIL/MIL/SIL tools for ADAS	Software-in-Loop, Model-in-Loop, Hardware-in-Loop for Advanced Driver Assistance Systems	2	50	6.00
20	Thermal camera	FLIR Vue Pro (International)	Gas pipeline, Power line, rail track inspection, Agriculture	2	50	0.25
Total (in Crores)						**27.50**

i. Infrastructure and Capital Expenditure (in Crores)

Item/Justification	Year 1 (in Crores)	Year 2 (in Crores)	Year 3 (in Crores)	Year 4 (in Crores)	Year 5 (in Crores)	Total (in Crores)

Infrastructure for test roads and road side units etc, Furniture, electricity, stationary, internet cost, projectors	6.75	3.5	3.5	1.8	1.5	**17.05**

Justification:

Infrastructure for Test Bed for Autonomous Navigation including test tracks, ATS, VMS, control rooms, hanger facilities, smart poles, Road Side Units etc. Furniture, Rent, Maintenance, Electricity, Stationary, Internet Cost, Projectors etc.,

11. Targets/Outcomes of the Hub Spread Over 5 Years

11.1 Technology Development

TIH at IITH, is envisioned to be source of fundamental knowledge in the area of technology vertical – Autonomous Navigations and Data Acquisition Systems for different modes such as Remotely operated vehicles, aerial vehicles, surface vehicles, ground vehicles for different applications. Hub plans to create state of the art testbed facilities – **Living Labs/Testbed in Autonomous Navigations** like test tracks for autonomous vehicles, simulators – SIL, HIL, VIL etc, for ground and aerial vehicles. This testbed is envisaged as the destination for the collaborative research platform for academia, industry, R&D labs both national and international. Accordingly, Hub will generate technology, patents, publications, white papers, participate in standards, human resource development, skill development, startup ecosystems, R&D collaborations with academia, industry, R&D labs.

A. Summary of Outcomes

- The living lab and the test facility center established will be an asset of national importance which can be used by both Govt. and Private entities for research, development, and testing of autonomous navigation and data acquisition systems
- At least 30 IPRs will be filed including patents, copyrights, and trademarks
- A total of 100 publications in both peer reviewed and internationally reputed journals and conferences will be targeted
- A knowledge base comprising of datasets, standardized architectural references will be developed in the area of Autonomous Navigation and Data Acquisition Systems (UAVs, ROVs, etc.)
- A total of around 30 research to product translations via. startup commercialization and technology transfers are expected by the end of the 5 years
- A total of 40 startups (approximately) who are working in the broad areas of autonomous navigation and data acquisition systems with cutting edge technology products will be funded at various levels to promote the in-house R&D, innovation, and entrepreneurship.
- Several fellowships (faculty, student, interns), grand challenges, hackathons, ideathons, and product prototyping challenges in the areas of autonomous navigation and data acquisition systems will be organized to generate new ideas which will have direct impact on various application sectors in India.
- Importantly, the hub with its cutting-edge technology portfolio will be an enabler for the creation of job ecosystem at various skill levels.

The Hub ensures responsible for delivery, on a best-efforts basis, of deliverables and targets mentioned below:

S No	Target Area	Targets					
		1stYr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
1	**Technology Development**						
(a)	No of Technologies (IP, Licensing, Patents, etc.)	3	5	7	10	10	35
(b)	Technology Products	3	5	7	10	10	35
(c)	Publications, IPR and other Intellectual activities	15	50	50	70	80	265
(d)	Increase in CPS Research Base	5	10	25	25	25	90
2.	**Entrepreneurship Development**						
(a)	Technology Business Incubator (TBI)	1	-	-	-	-	1
(b)	Start-ups & Spin-off companies	3	7	10	10	13	43
(c)	GCC - Grand Challenges & Competitions	0	1	1	1	1	4
(d)	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	1	-	1	-	1	3
(e)	CPS-Entrepreneur In Residence (EIR)	2	3	8	8	9	30
(f)	Dedicated Innovation Accelerator (DIAL)	-	1	-	1	1	3
(g)	CPS-Seed Support System (CPS- SSS)	-	1	-	1	-	2
(h)	Job Creation	100	700	2600	3300	4000	10700
3.	**Human Resource Development**						
(a)	Graduate Fellowships	60	60	60	60	60	300
(b)	Post Graduate Fellowships	20	25	25	25	30	125
(c)	Doctoral Fellowships	10	15	10	5	0	40
(d)	Faculty Fellowships	3	3	3	3	3	15
(e)	Chair Professors	0	3	3	0	0	6
(f)	Skill Development	50	110	110	120	120	510
4.	**International Collaboration**	1	1	1	1	1	5

11.2 HRD and Skill Development

TIH at IITH works on the most advanced technologies in the area of research and development of autonomous navigation and data acquisition systems for UAVs, RoVs. The main focus would be to realize the real-time CPS system implementation for UAVs/ROVs with high end sensors for various applications. Hence, a significant amount of manpower will be trained in the areas of artificial intelligence, signal processing, sensor integration and development for autonomous navigation and data acquisition systems for UAVs/RoVs. Below are the objectives of skill and manpower development:

- ➢ High end Skill development - Manpower with advanced and unique skillset at various levels will be trained over a period of 5 years - Postgraduate fellowships, PhD fellowships, Postdoc fellowships. Also, a number of internships will be offered within the hub. Thus recruited manpower will be trained on various advanced technologies including sensor integration to mobile platforms like UAVs, complete system development with various calibration processes, artificial intelligence, signal processing, development of autonomous navigation and data acquisition systems for UAVs/RoVs.
- ➢ Chair Professors, Faculty fellowships, Visiting Faculty fellowships will be offered in the specific domains within the hub.
- ➢ New academic programs such as **M. Tech in Smart Mobility** which is an interdisciplinary program will be offered.
- ➢ Train manpower in the areas of entrepreneurship and motivate towards startup ecosystem under various schemes described in the earlier section.
- ➢ Organization of periodic workshops in various technologies of UAVs, ASVs, and autonomous ground vehicles for training students from all across the country, employees from various industries/R&D labs. Development of training kits/manuals as part of the skill development programs.
- ➢ Organization of grand challenges, hackathons and ideathons for technology and talent hunt.
- ➢ Organization of symposiums for talent and business exchanges.

11.3 Innovation, Entrepreneurship and Start-up Ecosystem

To promote the innovation, entrepreneurship, and start-up ecosystem in the area of autonomous navigation and data acquisition systems, the following activities will be undertaken:

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) Technology Business Incubator (TBI) - A technology business incubator with specified focus on autonomous navigation and data acquisition systems will be setup at IIT Hyderabad campus for promotion of entrepreneurship activities at TIH IITH. Collaboration will the other existing TBIs through MoU will also be executed as part of this.

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) Grand Challenges and Competitions (GCC) for scouting innovations - To find & nurture new and innovative solutions in the areas of autonomous navigation and data acquisition systems for major challenges being faced by the society that are viable and sustainable. A total of 4 grand competitions and challenges will be conducted under the scheme TiHAN CPS GCC over a period of 5 years. A total of 20 prototyping grants and seed funding for 8 startups will be offered.

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) PRomoting and accelerating Young and Aspiring Innovators and Startups (PRAYAS) - The program facilitates and enables innovators annually across the country in translating their ideas into prototype through funding support to maximum. A total of more than 5 will be funded over a period of 5 years under the TiHAN CPS PRAYAS scheme.

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) Entrepreneur in Residence (EIR) - To encourage graduating student to take to entrepreneurship by providing support as a fellowship. A total of 35 students will be funded under the TiHAN CPS EiR scheme over a period of 5 years.

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) Startups and Spinoff Companies - To encourage graduating students to take to promote startups. A total of 45 startups will be funded under TiHAN CPS Startups and Spinoff Companies scheme.

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) Accelerator - A startup accelerator will be setup for fostering the growth of early stage startups will be set under the scheme TiHAN CPS DIAL

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) Seed Support System (SSS) - To ensure timely availability of the seed support to the deserving incubatee startups within TiHAN TBI, thereby enabling them to take their venture to next level and facilitate towards their success in the market place. A total of 5 startups will be funded under the scheme TiHAN Seed Support System over a period of 5 years.

Also, inventions and innovations are keywords on which the foundation of Indian Institute of Technology Hyderabad (IITH) is based. The endeavor is to create an ambience where the research concepts are taken from ideation to prototype to product/commercialization stage. A strong academic and industry integration in addition to excellence in academic research forms an integral part for achieving the same. TIH will rigorously work on creating a dynamic startup ecosystem by contributing a significant amount of the received funding. Also, TIH proposes to organize bi-yearly activities on organization of grand challenges, hackathons and ideathons for technology and talent hunt.

12. Cost Benefit Analysis

The investments made for the project is expected to pay-off in following diverse ways:

- The Test best developed for Autonomous Navigation of Vehicles (Ground, Aerial) will be open to Industry, Labs, Academia on paid basis for performing their studies/research
- The Start-up and incubation initiatives of the research group will convert the developed solutions into significant monetary benefits with coordination of interested companies.
- The technology transfers and IP licensing options will be critically explored for revenue generation
- Infrastructure on pay per use basis will be provided for third parties (such as testing tracks, standardization measurements etc.)
- Equity sharing based startup incubation will be adhered by the hub.
- Fund generation from CSRs, private investments will be aggressively pursued.
- Cost-sharing based international projects will enable revenue generation in both Indian and overseas markets.
- The developed solutions will be targeted to be affordable to the possible extent with efficient and compact design of the drones, accessories, etc.
- Resource sharing such as UAVs and other accessories for different applications will be one of the major advancements leading to the overall low cost solutions. Most of the application themes of this proposal fall under the societal benefit of the country. However, these application themes have a great potential to be self-sustained with the help of revenues generated through the IPs, ToTs, Consultancies and PPP based funding.
- The center will be financially sustainable by also implementing various schemes to generate revenues through
  - Certification Courses
  - Consultancy
  - Development, R&D activities specific to clients - National and International
  - Intellectual Property Rights
  - Entrepreneurship and startup ecosystem development
  - New Academic Programs in collaboration with Host Institute – IITH

13. Management plan

Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (UAVs, ROVs, etc.) – TiHAN at IITH may adopt the following management plan proposed.

The entire management activity will be held by the Hub Governing Board (HGB) constituted by IITH, which directs the Board of Directors of the Technology Innovation Hub on Autonomous Navigation and Data Acquisition Systems (TiHAN) for timely actions. The Hub Governing Board is currently constituted as follows.

Sr. No.	Name of Members	Designation
Head of the Host Institute		
1	Prof. B. S. Murty Director of the IIT Hyderabad	Chairman
Academic Representatives		
2	Dr. Kiran Kumar Kuchi Dean R&D, IIT Hyderabad	Members
3	Dr. S. Surya Kumar Faculty Incharge Entrepreneurship, IIT Hyderabad	Members
4	Dr. Bheemarjuna Reddy Tamma Professor, Department of Computer Science and Engineering, IIT Hyderabad	Members
Industry Representatives		
5	Mr. Samir Kumar Managing Director, Inventus (India) Advisors	Members
6	Mr. Kumar N. Sivarajan Chief Technology Officer, Tejas Networks	Members
7	Dr. Gopichand Katragadda Founder and CEO at Myelin Foundry	Members
8	Mr. Krishna Bodanapu Managing Director and CEO, Cyient Ltd. & Chairman of CII for 2020-21	Members
Mission Director, Mission Office, DST		
9	Dr. K R Murali Mohan Mission Director, NM-ICPS and Scientist-G and Head, ICPS Division, DST	Members
Project Director TIH		
10	Dr. P. Rajalakshmi Professor, Dept. of Electrical Engineering, IIT Hyderabad	Member-Secretary

The operational structure can further be divided into five different wings in terms of their responsibilities namely: R&D Wing, Academic Wing, Industry Relations Management Wing, Technology Business Incubator Wing, and Finance and Administration Wing. Each of their duties are summarized below (Fig. 70):

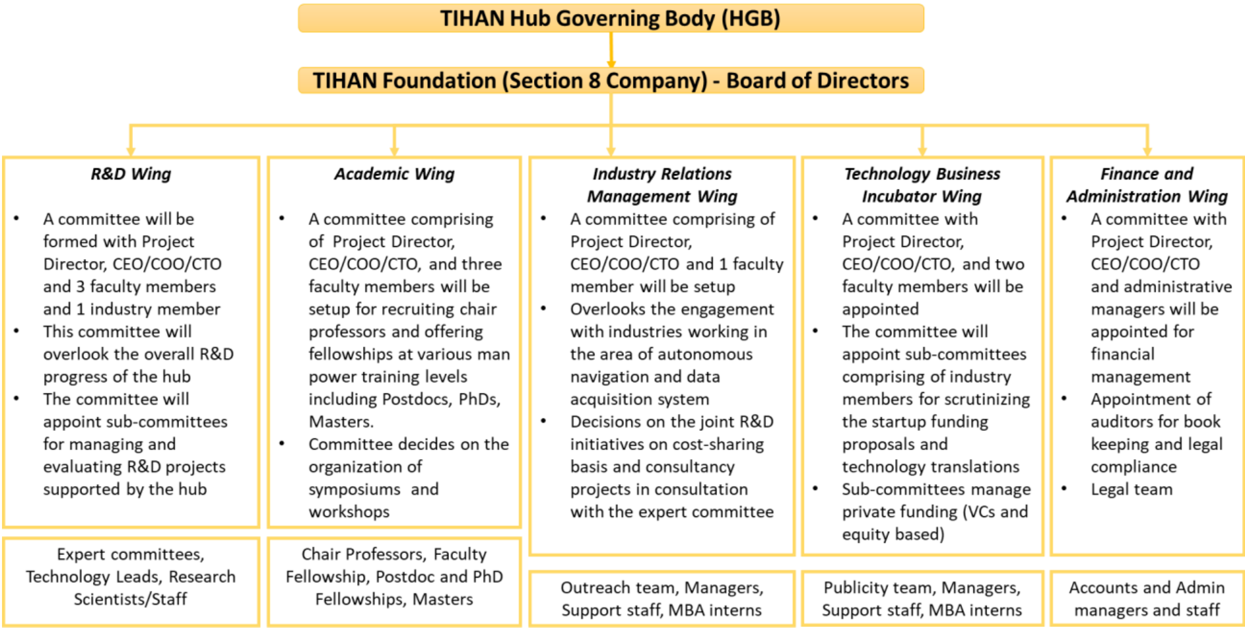


Figure 70: Management structure of the proposed TIH at IITH

R&D Wing: The hub plans to constitute a committee constituting of Project Director, faculty members, industry expert along with CTO/COO/CEO for directing the R&D portfolio of the hub. The committee can appoint sub-committees in a timely manner on need basis for driving the R&D in various application verticals. The wing also comprises of the R&D manpower recruited at various expertise levels for performing research and developmental activities pertaining to the TiHAN research interests.

Academic Wing: The hub plans to constitute a committee with Project Director, faculty members and CEO/COO/CTO for planning various academic and skill development activities by offering fellowships, training manpower at various levels including Chair professors, visiting faculty fellowships, Postdoc fellowships, PhD, Post graduate, and internships.

Industry Relations Management Wing: The industry relations team strives for the engagement of industry partners in the R&D being performed by the hub. Also, they pursue the opportunities for joint R&D projects with industries, technology transfer and commercialization activities. The hub plans to constitute a committee with Project Director, a faculty member, industry expert and CEO/CTO/COO to drive the activities. Manpower including managers, support staff and business interns will be recruited for the operations.

Technology Business Incubator Wing: The technology business incubator plays a key role in promoting innovation, entrepreneurship, and startup ecosystem by promoting and nurturing the startups growth with different schemes. They also actively scout innovations in the area of autonomous navigation and data acquisition systems. A committee with Project Director, 2 faculty members and a CEO/COO/CTO will be appointed for overlooking the activities.

Finance and Administration Wing: The team focuses on the financial and legal aspects of the hub. Includes the appointment of auditors and IP team. A committee with Project Director, CEO/COO/CTO, financial administrators, and a faculty member will be appointed for overlooking the activities.

Also, the **SOP** - standard operating procedures for the stores and purchase, general administration, recruiting of the manpower and budget utilization will be developed to adhere to the guidelines of the NM-ICPS Mission.

14. Evaluation

TIH at IITH after the appointment of Hub Governing Body (HGB), along with technical expert committee will periodically review and monitor the technical and financial status of the research project funded by the hub. The HGB will periodically monitor the project in all respects including technical financial progress including initiatives towards commercialization of products, of the project funded by the hub. Every project will be reviewed by the expert committee and the HGB twice yearly, and further funding for the research area will be decided only upon the satisfactory evaluation of the HGB. Also, the Board of Directors (BoD) will meet 4 times a year to review the performance, implementation and growth of the hub.

For the research staff and students working under the hub, the evaluation will be comprising of monthly progress report submissions and periodic evaluation from the expert faculty members supervising the teams. The students and staff will also be encouraged to disseminate their research in popular journals, conferences, symposiums, etc., and appropriate IPR filing will be considered at every stage of the technology development. For the administrative staff, performance appraisals will be conducted on periodic basis, to evaluate their performance and contributions to the hub.

15. Risk Analysis

The proposed R&D work spans end to end research, starting from the idea to end product development including commercialization. This kind of translational research has its own associated risk depending on the target product or application development. We envisage that all the factors involved would be efficiently handled at different stages with the expertise involved in the Hub, both at the research and administrative front.

15.1 For Autonomous Transport Systems include UAVs, UGVs and USVs

The proposed objectives are achievable considering the team's and PI's expertise in the domain.

15.2 For Agriculture

If the solution is used to designing autonomous vehicle systems, then the current legal system in India does not allow the use of such vehicles. TIH and CIs are also looking into ethical as well as legal issues faced by such autonomous vehicle systems as a part of this project. Therefore, we are confident that this aspect of the project will be handled by proposing policies to the government that enables usage of autonomous vehicles without compromising on the safety. In the case of autonomous systems for agriculture, to the best of our knowledge, there is no legal issue.
Commercial Viability: The question of whether the product results in enough revenue to be commercially viable seems very important. TIH has strong national and international collaborations. They are capable of testing our products on a large scale by promoting farmers to get benefits using the product. We will be working closely with the collaborators to get feedback and identify the problems to be tackled using autonomous vehicle systems right from the beginning. Some of the NGOs are also interested in taking the products directly to the farmers.

Speech is the most preferred mode of communication provided the speech technology performance is good. If speech technologies are tuned for Indian languages, requirements and operating conditions, then it is going to be an attractive USP of the proposed system. The investigators of this project are in talk with multiple companies from transportation, power transmission, robotics etc. who can get benefited by the product related to autonomous vehicles. Therefore, by continuously doing market surveys, and adapting the solutions to it keeps the revenue risks very low.

16. Legal Framework

Legal framework for the entire operations will be adhered to the framework proposed by the NM-ICPS office as per the tripartite agreement. The sharing of IP, revenue sharing etc. will be followed as per this agreement. For each of the technology developed, individually this has been discussed in sections.

16.1 Autonomous Transport Systems (ATS)

In India the Motor Vehicles Act, 1988 provides the basis for the legal aspect of driving. The Act does not recognize any possibility of Autonomous Vehicle. Moreover, a driving agent ought to be a human is a kind of prerequisite for any kind of driving engagement. The transference of driving agency from human to any non-human entity is absolutely objectionable in the Indian legal aspect. Therefore, at present it is illegal to use autonomous vehicles in India. Though there was an amendment on the Motor Vehicle Act in 2017, it is not evident whether the testing or the use of AVs is legally permissible or not. Such a scenario in Indian context gives a very strong reason to look at the different legal aspects to facilitate judicially the introduction of AVs on the roads and also adopt it at the policy level. Though the project specifically focuses on the Indian scenario, we will have a comparative look at the legal situations in other countries. Also, for the UAVs, we will adhere to the guidelines imposed by the DGCA on flying. ASV is rarely used in the country as the cost is very high and an affordable product is not developed in the country so far. Because of this, any policy or legal framework is currently not in place for the use of ASV. Maybe in the years to come, when the technology becomes affordable and more manufacturers make their entry to the field, a legal framework may come into force. Also, TIH will abide by any legal requirements as is required for the proposed areas. However, the expertise of the TIH legal team will be taken to arrive at the same. Also, this project helps government agencies in formulating the legal terms for autonomous vehicles, especially in India. As our Hon. Prime Minister is laying significant interest on the development of smart cities, we sincerely believe this project is a need of the hour.

16.2 Agriculture

- In this project, UAVs are the primary mode for data acquisition. But, In India, flying of UAVs is governed by the regulations imposed by DGCA. Also, restrictions are imposed on the time of flying and the place of flying. So we need to take prior permission from the concerned authority before UAV flight.
- Necessary legally bound agreements are proposed to be signed with user agencies for commercial exploitation of proposed technologies. The same will be carried out under the overall guidance of the legal cell of the TIH. With the help and guidance from the legal cell of the TIH, necessary legal agreements related to technology transfer, field trials etc., will be undertaken.
- Proper permissions will be taken from the concerned authorities for the usage of UAVs for the testing purpose.
- Project will also take care of privacy issues.
- No damage to any public and/or private properties will be ensured during the implementation and testing of the project.
- MoUs might be signed with industries for promoting PPP for sustainability of this project.

17. Environmental Factors

The proposed activities of the hub are to be carried out at the campus of IITH Hyderabad. Hence no adverse effects on the environmental factors are envisaged out of this project. However, as part of this research, the hub will importantly focus on identifying any potential environmental impact that the both technology verticals such as Autonomous Transport Systems (ATS) and agriculture will impose.

18. Facilities

The following facilities shall be shared by the HI & collaborators:

1. Shared computational facilities such as GPU servers such as DGX-1 and DGX-2.
2. Software: Licenses for Cadence, Synopsys, Mentor Graphics, Matlab for system simulation and analysis
3. Measurement instruments: Network analyzer, Spectrum analyzer, Oscilloscope, Vector signal generator, Arbitrary function generator, Logic analyzer.
4. Software defined 5G base station and user equipment, NBIoT
5. 3D Fabrication facilities
6. Velodyne 3D LiDAR - low end
7. Soil parameters calibration facilities
8. Leasyscan facility
9. Lysimetric facility
10. Precision field facilities
11. IITH already has a testbed deployed in NH65 under the multi-modal transportation project for real-time traffic monitoring which can be utilized for development of autonomous vehicles. This work is in collaboration with Japan.
12. Automatic Weather Station (AWS)
13. Differential GPS (DGPS)
14. DJI Phantom 4 PRO
15. Rainfall Simulator
16. Driver Simulator
17. HPC Cluster
18. Rapid Prototyping Machine
19. High Speed PIV
20. INS/GNSS

19. TIH Team Expertise

1. IIT Hyderabad has been ranked consecutively **within top 10 in the NIRF Engineering** ranking for the last three years.
2. IIT Hyderabad (the host institute for this TIH) has a significant experience in helping many of the upcoming institutes of national importance in mentoring and setting up the institute which include: **IIIT Raichur, IIT Bhilai, IIIT Sri City, CUK, IIIT Naya Raipur**.
3. In International front, IIT Hyderabad plays an active role in developing academic plans for **Woosung University** in the areas of AI, IoT, CPS, Industry 4.0 etc.
4. IIT Hyderabad also has international joint PhD programs with universities like Swinburne University, Universities in Japan
5. IIT Hyderabad was among the **first academia in India to get fund for center on CPS technologies** during the period 2010 to 2016.
6. IITH has collaborative projects funded by International agencies like JST, JICA in the areas of Data Sciences (DS), IoT for various applications like Agriculture, Transportation
7. IITH was the first to start a B. Tech program in AI, after which AICTE has now started AI and DS program in all NAB accredited colleges in India. IITH helped in giving inputs to the curriculum template for this program
8. IIT Hyderabad has already incubated 3 section 8 companies CfHE, FabCI, and iTIC Foundation which exclusively incubate startups focusing on healthcare, VLSI, and core technology domains, respectively.
9. As the campus is spread across a wide geographical area and with the construction of new infrastructure such as research parks, etc., allocation of 30,000 Sq. ft. is relatively easier.

19.1 Expertise available with the team members in executing the project

Please refer to Table 4 under Section 19.2

19.2 Summary of roles and responsibilities of all team members

Table 4: Team members with their expertise, roles and responsibilities

List of Faculty from IIT Hyderabad with their expertise, roles and responsibilities:

S No	Faulty Name	Designation	Area of Expertise	Department
	Prof. B S Murty	**Director, IIT Hyderabad**	**Material Science**	
1	Dr. Abhinav Kumar	Assistant Professor	Wireless communications and networking, green cellular networks, user network selection, device to device communication	Electrical Engineering
2	Dr. Aditya Siripuram	Assistant Professor	Signal processing, Sparse representations, Sampling techniques	Electrical Engineering
3	Dr. Antony Franklin	Associate Professor	Mobile Networks (5G), Internet of Things	Computer Science and Engineering

4	Dr. Ashok Kumar Pandey	Associate Professor	Linear and Nonlinear Vibration MEMS Vehicle Dynamics	Mechanical & Aerospace Engineering
5	Dr. Bheemarjuna Reddy Tamma	Professor	Converged Radio Access Technologies, SDN/NFV for 5G, M2M/IoT, Mobile Social Networks in Proximity, Green ICT and Network Security	Computer Science and Engineering
6	Dr. C Krishna Mohan	Professor	Video Content Analysis, Computer Vision, Pattern Recognition, Machine Learning, Deep Learning	Computer Science and Engineering
7	Dr. Deepak John Mathew	Professor	Photography, Elements of design, Aesthetics, History of Design	Design
8	Dr. Digvijay S. Pawar	Assistant Professor	Traffic Safety, Mixed traffic flow modeling and simulation, Traffic Monitoring management and control, Driver behavior analysis	Civil Engineering
9	Dr. G V V Sharma	Associate Professor	Wireless Communications	Electrical Engineering
10	Dr. J Balasubramaniam	Professor	Connectives in Multivalued-Logic Approximate Reasoning Issues in High Dimensional Data Analysis	Mathematics
11	Dr. K Siva Kumar	Associate Professor	Multilevel inverter, open end winding induction motor drives, switched model power conversion	Electrical Engineering
12	Dr. K. Sri Rama Murty	Associate Professor	Signal Processing, Speech Analysis, Pattern Recognition	Electrical Engineering
13	Dr. Ketan P Detroja	Associate Professor	Advanced Process Control, Quality control, Customer feedback control, Identification, Co-operative Control.	Electrical Engineering
14	Dr. Kiran K Kuchi	Professor	Communication theory, Signal processing for communications, Network MIMO, Interference mitigation, Modem algorithms and implementation, Wireless systems.	Electrical Engineering
15	Dr. Kotaro Kataoka	Associate Professor	Wireless Networking	Computer Science and Engineering
16	Dr. Lakshmi Prasad Natarajan	Assistant Professor	Information Theory, Wireless communications	Electrical Engineering
17	Dr. M V Panduranga Rao	Associate Professor	Applications of formal methods	Computer Science and Engineering
18	Dr. Mahesh M S	Associate Professor	Aeroelasticity, Acoustic-Structure Interaction , Computational Mechanics	Mechanical & Aerospace Engineering
19	Dr. Manish Singh	Assistant Professor	Data Mining, Information Retrieval and Databases	Computer Science and Engineering

20	Dr. Maunendra Sankar Desarkar	Assistant Professor	Machine Learning, Data Science, Information Retrieval, Natural Language Processing and Generation	Computer Science and Engineering
21	Dr. Nishanth Dongari	Associate Professor	Microfluidics, Rarefied Gas Dynamics, Compressible Gas Flows, Thin Film Coatings, Molecular Dynamics	Mechanical & Aerospace Engineering
22	Dr. Praveen T	Assistant Professor	Systems and Networking Network Security Software-Defined Networking ML for Networks	Computer Science and Engineering
23	Dr. R Prasanth Kumar	Professor	Robotics, multibody dynamics, autonomous/intelligent systems, navigation	Mechanical & Aerospace Engineering
24	Dr. Rajalakshmi Pachamuthu	Professor	Wireless communications, Wireless sensor networks, UAV-based sensing, Embedded systems, Cyber Physical Systems/Internet of Things (CPS/IoT), Converged network modelling, Energy efficiency, Green communications.	Electrical Engineering
25	Dr. Sathish Kumar Regonda	Assistant Professor	Urban and Rural Flood Modeling Climate Sciences Data Sciences Statistical Modeling Techniques Ensemble Forecasting	Civil Engineering
26	Dr. Sathya Peri	Associate Professor	Parallel Computing Distributed Systems Algorithm analysis Networking algorithms	Computer Science and Engineering
27	Dr. Shashank Vatedka	Assistant Professor	Information Theory and Coding	Electrical Engineering
28	Dr. Shivaji	Assistant Professor	Design for Sustainability Sustainability Assessment LCA Architecture Theory Innovation by System Design New Age Products/Services	Design
29	Dr. Sireesh	Professor	Pavement Geotechnics Geosynthetics Recycled Materials Ground Improvement	Civil Engineering
30	Dr. Siva Rama Krishna Vanjari	Associate Professor	Pavement Geotechnics Geosynthetics Recycled Materials Ground Improvement	Electrical Engineering
31	Dr. Srijith P.K	Assistant Professor	Machine learning	Computer Science and Engineering

32	Dr. Sumohana Channappayya	Associate Professor	Image and Video Quality Assessment, Multimedia Communication, Biomedical Imaging, Machine Learning	Electrical Engineering
33	Dr. Sundaram Vanka	Associate Professor	Mathematical modeling, Simulation and prototyping of wireless systems and networks, especially low power applications.	Electrical Engineering
34	Dr. Suriya S Prakash	Professor	Precast Systems Prestressed Concrete Structural Concrete Behavior Structural Strengthening	Civil Engineering
35	Dr. Surya Kumar S	Professor	Additive Manufacturing 3D Printing Gradient Objects Fabrication Weld and Laser Based Deposition FEA during deposition 4D Printing Smart Material (shape memory alloys) CNC Machining	Mechanical & Aerospace Engineering
36	Dr. Venkatesham B	Associate Professor	Vibrations, Engineering Acoustics, Industrial Noise control, Acoustic-Structural Coupled Systems and Sound Quality	Mechanical & Aerospace Engineering
37	Dr. VidyaSagar	Distinguished Professor	Machine Learning, Compressive Sensing, Sparse Control, Stochastic Process	Electrical Engineering
38	Dr. Vineeth N Balasubramanian	Associate Professor	Deep Learning, Machine Learning, Computer Vision	Computer Science and Engineering
39	Dr. Zafar Ali Khan	Professor	Space-Time Coding for MIMO Channels, Distributed Space-Time Coding and Cooperative Communication, Coding for Multiple-Access and Relay Channels, Network Coding, Space-Time Signal Processing	Electrical Engineering
40	Dr. B Umashankar	Professor	Foundation Engineering Reinforced Soil Soil-Structure Interaction Recyclable Materials in Geotechnics	Civil Engineering
41	Dr. Phanindra K B V N	Associate Professor	Groundwater modeling Soil-water-plant interactions Remote sensing & GIS Eco-hydrological processes	Civil Engineering
42	Dr. Pradeep Kumar Yemula	Associate Professor	Smart Grids, Power System Control Centers, Information Technology Architectures	Electrical Engineering

List of Faculty Outside IIT Hyderabad with their expertise, roles and responsibilities:

S. No.	Name of Team Member	Affiliation	Area of Expertise	Roles/ Responsibilities
1	Dr. Sunita Choudhary	Scientist, ICRISAT	Crops physiology, agronomy phenotyping	Agricultural Scientist
2	Dr. Jana Kholova	Scientist, ICRISAT	Crops physiology, agronomy, modelling phenotyping	Agricultural Scientist
3	Dr. Raja Vara Prasad	Assistant Professor, Dept. of Electrical Engineering, IIIT Sri City	Smart Cities, Wireless Sensor Networks, Internet of Things, Computer Vision	IoT and computer vision development
4	Dr. Shivaram Dubey	Assistant Professor, Dept. of Computer Science and Engineering, IIIT Sri City	Computer Vision, Deep Learning, Biomedical Image Analysis, Biometrics	AI/ML for computer vision applications
5	Dr. Balaji Raman	AssociateProfessor, Dept. of Electrical Engineering, IIIT Sri City	Theory and application of statistical signal processing in the areas of radar and wearable robotics. Application of pattern recognition in the areas of image processing, remote sensing and wearable robotics.	Robotics Engineering
6	Dr. Kandimalla Divyabramham	Assistant Professor, Dept. of Electrical Engineering, IIIT Sri City	High-frequency Asymptotic Techniques for Electromagnetic Scattering and Propagation Modeling, RCS Studies, Design of Passive Components for RF and Wireless Applications	Wireless Networking
7	Dr. Ameer Mulla	Assistant Professor, Dept. of Electrical Engineering, IIT Dharwad	Optimal Control, Multi-agent Systems, Differential Games, Human-in-Loop Control, Robotics	Design control algorithms for human-in-the-loop navigation of UAVs and UGVs
8	Dr. B. N. Bharat	Assistant Professor, Dept. of Electrical Engineering, IIT Dharwad	Signal processing, Wireless communications and networks	Design algorithms for secure estimation in an autonomous navigation systems.

9	Dr. Gayathri Ananthanarayanan	Assistant Professor, Dept. of Computer Science and Engineering, IIT Dharwad	Computer architecture and embedded systems, with specific focus on Power, Thermal and Performance modeling, characterization and management.	Design Efficient Processors
10	Dr. Jolly Thomas	Assistant Professor, Humanities and Social Sciences, IIT Dharwad	Metaphysics, Philosophical Logic, Philosophy of Language and Epistemology	Study and suggest ethical issues related to autonomous navigation and data acquisition
11	Dr. S. R. Mahadeva Prasanna	Professor, Dept. of Electrical Engineering, IIT Dharwad	Speech Signal Processing, Speech Enhancement, Speaker Recognition, Speech Recognition, Speech Synthesis, Handwriting Processing, Pathological Speech Processing	Development of speech technologies for relevant fields
12	Dr. Naveen Kadayinti	Assistant Professor, Dept. of Electrical Engineering, IIT Dharwad	Design of mixed signal integrated circuits and their test	Communication protocols for multi-vehicle systems
13	Dr. Naveen M. B.	Assistant Professor, Dept. of Electrical Engineering, IIT Dharwad	Communication and signal processing with focus on wireless communication and the Internet of things (IoT).	Development of low cost CMOS compatible inertial MEMS sensors
14	Dr. Pratyasa Bhui	Assistant Professor, Dept. of Electrical Engineering, IIT Dharwad	Power System, Smart Grid	Design of power modules and drives for the motors that will run the robots.
15	Dr. Rajshekar K	Assistant Professor, Dept. of Electrical Engineering, IIT Dharwad	Computer architecture, hardware reliability, hardware security, accountability issues in heterogeneous 3PIP-containing SOCs, and micro architectural simulation.	Design efficient processors
16	Dr. Ruma Ghosh	Assistant Professor, Dept. of Electrical Engineering, IIT Dharwad	Development of gas sensors for - Healthcare, Environmental Monitoring and Agriculture ,	Development of electro-chemical sensors for soil data acquisition from agricultural farms

			Graphene based devices ,Micro and Nano-fabrication	
17	Dr. Somashekara M A	Assistant Professor, Dept. of Mechanical Engineering, IIT Dharwad	Additive Manufacturing 3D Printing Gradient Objects Fabrication Weld and Laser Based Deposition FEA during deposition 4D Printing Smart Material (shape memory alloys) CNC Machining	3D printing for prototyping
18	Dr. Shrikanth V.	Assistant Professor, Dept. of Mechanical Engineering, IIT Dharwad	Vibration Analysis	Vibration Analysis
19	Dr. Tejas P. Gotkhindi	Assistant Professor, Dept. of Mechanical Engineering, IIT Dharwad	Elasticity, Computational Mechanics, Composite materials	Applications of RoV for structural data acquisition
20	Dr. Ramesh Athe	Assistant Professor, Humanities and Science, IIIT Dharwad	Systematic Review and Meta-analysis, Application of advanced statistical methods in medicine, nutrition, public health, techno-logy, and social science. Statistical/Bio-stati-stical tools including advanced multivariate methods and clinical Trials.	Study and suggest ethical issues related to autonomous navigation and data acquisition
21	Dr. Anil Kumar Rangisetti	Assistant Professor, Dept. of Computer Science and Engineering, IIIT Dharwad	Software Defined Wireless Networks, 4G Networks, Internet of Things, 5G Networks	Wireless Networking
22	Dr. K. T. Deepak	Assistant Professor, IIIT Dharwad, Dept. of Electrical Engineering	Speech/Audio Processing and Machine Learning	AI/ML for computer vision applications
23	Dr. Kavi Mahesh	Director, IIIT Dharwad	large semantic datasets, understanding the ontological and epistemological models of such data and	Data analysis

			developing quantitative analytical methods	
24	Dr. Pavan Kumar C	Assistant Professor, Dept. of Computer Science Engineering, IIIT Dharwad	Coding Theory, Data Communication, Formal Languages and Automata Theory, Cryptography and Applied Mathematics	Information Theory
25	Dr. Rajendra Hegadi	Associate Professor, Dept. of Computer Science Engineering, IIIT Dharwad	Computer Network, Cryptography & Network Security	Security for autonomous vehicles
26	Mr. Aravind C R	Scientist E, Strategic Electronics Group (SEG), C-DAC Trivandrum	Acoustic Landmine Sensor System, Acoustic Torch, Submarine Echo sounder	Development of ASV
27	Mr. Arun Gopalakrishnan	Principal Engineer, Strategic Electronics Group (SEG), C-DAC Trivandrum	Digital system Design. Digital signal Processing	Development of algorithms for data processing
28	Mr. Harikrishnan B	Principal Engineer, Strategic Electronics Group (SEG), C-DAC Trivandrum	Software defined radio (SDR)	Communication aspects
29	Mr. Joby Thomas	Principal Engineer, Strategic Electronics Group (SEG), C-DAC Trivandrum	Design and development of Remotely operated underwater vehicle	Development of ASV
30	Mr. Rajesh K R	Scientist F, Strategic Electronics Group (SEG), C-DAC Trivandrum	System level architecture design of Acoustic and Ultrasonic based embedded system products, design and testing of DSP based system	Architecture design of ASV
31	Mrs. Sindhu R	Scientist G, Strategic Electronics Group (SEG), C-DAC Trivandrum	Underwater drone, Computerised Control and Instrumentation, SCADA systems	Development of ASV
32	Mr. Rajesh R	Scientist E, Strategic Electronics Group (SEG), C-DAC Trivandrum	Design and implementation of Wi-Fi based imaging system, Wearable drone	Communication and data processing

33	Dr. Yegna Narayana	INSA Senior Scientist, IIIT Hyderabad	Signal Processing, Speech and Image Processing, Neural Networks	AI/ML frameworks for autonomous vehicles
34	Dr. Sunnam Venkata Srikanth	Joint Director, C-DAC Hyderabad	Embedded System Design, IoT, Communication	AI/ML frameworks for autonomous vehicles
35	Mr. Vivek Nainwal	Principal Technical Officer, C-DAC Hyderabad	Embedded System,V2V, V2I communication	V2V communication technologies
36	Mr. Santosh Sam Koshy	Joint Director, C-DAC Hyderabad	development in the Linux Kernel and Device Drivers, Real Time Operating Systems (RTOS), Discrete Electronic Hardware Design, Internet of Things (IoT) and Wireless Communications	OS and driver development for sensor integration
37	Ms. P. R. L. Eswari	Senior Director, C-DAC Hyderabad	Cyber Security	Security frameworks for autonomous vehicles
38	Mr. Mahesh U Patil	Associate Director, C-DAC Hyderabad	Cyber Security	Security frameworks for autonomous vehicles
39	Mr. Tapas Saini	Principal Technical Officer, C-DAC Hyderabad	Machine Learning/Artificial Intelligence	AI/ML frameworks for autonomous vehicles
40	Mr. Jerry Daniel	Senior Director, C-DAC Trivandrum	Control and Instrumentation	Development of autonomous vehicles
41	Mr. Senju Panicker	Joint Director, C-DAC Trivandrum	Control and Instrumentation	Development of autonomous vehicles
42	Mr. Lijo Thomas	Principal Technical Officer, C-DAC Trivandrum	Control and Instrumentation	Development of autonomous vehicles
43	Ms. Shalu	Project Engineer, C-DAC Trivandrum	Control and Instrumentation	Development of autonomous vehicles

20. National / International Collaboration for TIH

1. IIT Dharwad

Collaboration in the development of human in loop autonomous navigation frameworks for remotely operated vehicles for use in agriculture.

2. CDAC Hyderabad

Collaboration includes development of technologies for autonomous ground vehicle system and intelligent transportation systems. Also, includes the development of C-V2X communications infrastructure for the testbed being planned at IIT Hyderabad under the hub.

3. CDAC Trivandrum

Collaboration includes development of technologies for autonomous surface vehicles used for defense and surveillance applications. Important focus will be laid on the development of autonomous navigation frameworks and remotely controllable vehicle operating on water surfaces.

4. IIIT Sri City

Collaboration includes development of technologies for air and water quality monitoring systems (both terrestrial and UV based), intrusion detections using UAVs and ground infrastructure.

5. IIIT Dharwad

Collaboration in the development of robots for several applications including agriculture, human assistance, elderly management, etc.

6. ICRISAT, Hyderabad

Collaboration for developing the tools and methodologies in order to enable the cost-effective high throughput and standardized phenotyping services to assist crop-improvement programs using UAVs and RoVs. Also, includes development of quality datasets using UAV imaging for promoting R&D in the crop phenotyping and genotyping.

7. Indian Navy

Collaboration in testing of the autonomous surface vehicles in real-time and identification of challenges in the development of autonomous surface vehicles.

8. Indian Space Research Organization (Discussion in Progress)

Collaboration in remote sensing.

9. University of Agricultural Sciences (UAS) Dharwad

Collaboration in the development of pest and disease identification frameworks using the UAV images for assisting farmers.

10. IIIT Hyderabad

Embedded system based fault tolerant control and autonomous navigation of an Unmanned Aerial Vehicle (UAV)

11. IIITDM Kancheepuram

Visibility Enhancement Algorithm for Vision Intelligence System based on Environment Visibility Conditions.

12. IIIT Hyderabad & IIIT Sri City
    Design, development and development of energy efficient smart EDGE devices for real time traffic flow prediction and control.

13. NTU Singapore on CEATRAN testbed (on-going)

14. University of Michigan on M-City testbed, USA.

15. Saintgits College of Engineering, Kottayam

16. KLE Technological University, Hubballi,

17. International Livestock Research Institute (ILRI)

18. IIT Delhi

19. Nagarjuna University.

20. YSR Horticulture university

21. Industry Collaboration / Partnership

- Suzuki Motor Corporation - Collaboration in the development of autonomous ground vehicles, establishment of living lab and test facility. Importantly, the level 4 autonomous car development is envisaged with a specific focus on the Indian road and traffic conditions. Includes development of optimal sensor system, computing framework, vehicle integration and testing.
- NVDIA - Collaboration in the development of standard computing architecture for autonomous vehicles. Specifically, the focus will be laid on the development of standardized architectures for Indian road conditions.
- Maruti - Autonomous Road Vehicles and Test Bed Facility.
- L&T Defense – Autonomous Navigation technologies for UAVs.
- ANRA – UAV Technologies and command control stations.
- ALTRAN – Sensors, Testbed, 5G and Connected Vehicles.
- CYIENT – HD Maps, Autonomous Navigation.
- Infenion – Sensors and Autonomous Navigation
- Tata Consultancy Services (TCS) – UAVs for Agriculture applications and high throughput phenotyping
- Automotive Research Association of India (ARAI), Pune
- Continental Automotive Components (India) Private Limited.
- OPTIMUSLOGIC Systems (India) Pvt Ltd
- Midwest Technologies
- Vehant Technologies Pvt. Ltd.
- Invento Robotics.
- Indian Navy
- nVipani Pvt. Ltd.
- SpringML Pvt. Ltd.
- Marut Drones
- Steredian Semiconductors Pvt Ltd
- Suryodaya Infra Projects
- ATS Planners and Engineers
- OVIYA Technologies
- Infenion Technologies Asia Pacific International
- Robot space Robotics
- Sandhaan Labs Private Limited Through the Institute Collaboration
- iTIC Foundation, IIT Hyderabad.
- Analog Devices India - Collaboration in electronics development and integration
- Honeywell - Collaboration involves setting up an AI/ML centers in diverse application areas.
- Skoruz - Collaboration in terms of market exploration and commercialization.
- SpringML - Collaboration in development of AI/ML framework developments
- nVipani - Collaboration in technology prototyping and AI/ML framework development
- Agma Technologies - Collaboration includes development of digital road infrastructure
- Marut Drones - Collaboration includes development of autonomous navigation systems for water quality monitoring.

- Efftronics Private Limited - Collaboration in IoT frameworks development
- Terra Drone - Collaboration includes knowledge sharing on the development of drone taxis and beyond visual line of sight communication technologies for UAVs.
- Q-Labs - Collaboration includes knowledge sharing on computations.
- NXP Semiconductors - Collaboration includes development of efficient processing architectures

22. Plan for revenue generation and sustainability

- The proposed hub will establish state of the art research and test facility in Autonomous Navigation and Data Acquisitions for UAVs, ROVs. These facilities will be open to Industry, startups, and academic institutes on chargeable basis.
- The living lab and the test facilities that will be established can be utilized by private and government agencies on a paid basis.
- The developed Intellectual Properties (IP) and technology will be licensed or Technology Transfer to startups or industry based on the requirement. Hence, this will be one of the major revenue sources for the hub.
- Technology consortium will be established for long term sustainability and funding support.
- Technical Training and short courses will be offered to train the manpower and revenue generation
- Hub will also provide training for employees from R&D companies in state-of-the-art technologies such as High end sensor integrations to Mobile platforms – LiDAR, Hyperspectral, UAV operation and integration, etc.
- Generating CSR funds and industry sponsorships for the technology development
- On a 50:50 cost sharing basis, the TIH will explore joint technology development and marketing with foreign institutions including Swinburne University, Japanese universities with which IIT Hyderabad has already established collaborations and signed MoUs.

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