DETAILED PROJECT REPORT

Technology Innovation Hub under NM-ICPS

On

Intelligent Collaborative Systems

At

Indian Institute of Technology Palakkad

INDIAN INSTITUTE OF TECHNOLOGY PALAKKAD

September 2021

CERTIFICATE

Name of the TIH:

IIT Palakkad Technology IHub Foundation

Technology Vertical:

Intelligent Collaborative Systems

1. This is to certify that the Detailed Project Report (DPR) on the Technology Vertical **Intelligent Collaborative Systems** 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 Palakkad, Ahalia Integrated Campus, Kozhippara P. O, Palakkad, Kerala - 678557** 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 **December 07, 2020** between Mission Office, DST, **Indian Institute of Technology Palakkad,** and **IIT Palakkad Technology IHub Foundation**.

Date : September 24, 2021
Place : Palakkad

Dr. Albert Sunny

Name and Signature of Project Director

Endorsement from the Head of the Institution

1. Certified that the Institute welcomes participation of **Dr. Albert Sunny** as the Project Director for the Technology Innovation Hub (TIH) and that in the unforeseen event of discontinuance by the Project Director, **Indian Institute of Technology Palakkad** 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 Tripartite Agreement, the Host Institute (HI) shall play its role and fulfill its responsibilities for the success of TIH.

Date : 24-09-2021

Place : Palakkad

P. B. Sunil Kumar

Name and signature of Head of Institution

Executive Summary

Intelligent collaborative systems (ICS) is an amalgamation of robotics, control, machine learning, networks, embedded systems, computer vision and fundamental theoretical models. This unique mix of diverse technologies allows one to address problems in a variety of application areas. The Technology Innovation Hub (TIH) in ICS at IIT Palakkad will address problems in Agriculture, Healthcare, Transportation, Surveillance, Exploration and Communication systems, with special focus on problems related to energy and safety. A section 8 company IIT Palakkad Technology I-Hub Foundation (IPTIF) has been established to carry forward the TIH-ICS activities. Through technology, fellowships, and entrepreneurship targets, IPTIF will upskill students, engineers, and researchers, create job opportunities, develop products and technologies, and generate revenue for further sustainability of the TIH-ICS. All targets would be addressed on equal footing ensuring global standards. A business incubator Technology Innovation Foundation IIT Palakkad (TECHIN) has been established at IIT Palakkad to drive entrepreneurship and startups in the local ecosystem, and will help IPTIF realize its entrepreneurial goals. In alignment with the Startup-India, Make-in-India, Design-in-India, and Atma Nirbhar Bharat ideologies, that are encouraged by the Indian government, TIH-ICS at IIT Palakkad would enable more jobs, improve self-reliance of businesses in our country, enable India to reduce dependence on foreign monopolies, and place India as a global technology-enabler.

1 Introduction

Modelling, analysis, control, devices, networks, robotics, data, and simulations are all building blocks of CPS technologies. Technology Innovation Hub (TIH) on Intelligent Collaborative Systems focuses on Intelligent collaboration (or Merger) of these building blocks to propel the application of high priority in the CPS National Mission. These applications include but are not limited to agriculture, healthcare, cybersecurity / privacy, industrial operations, transportation, surveillance, and communication.

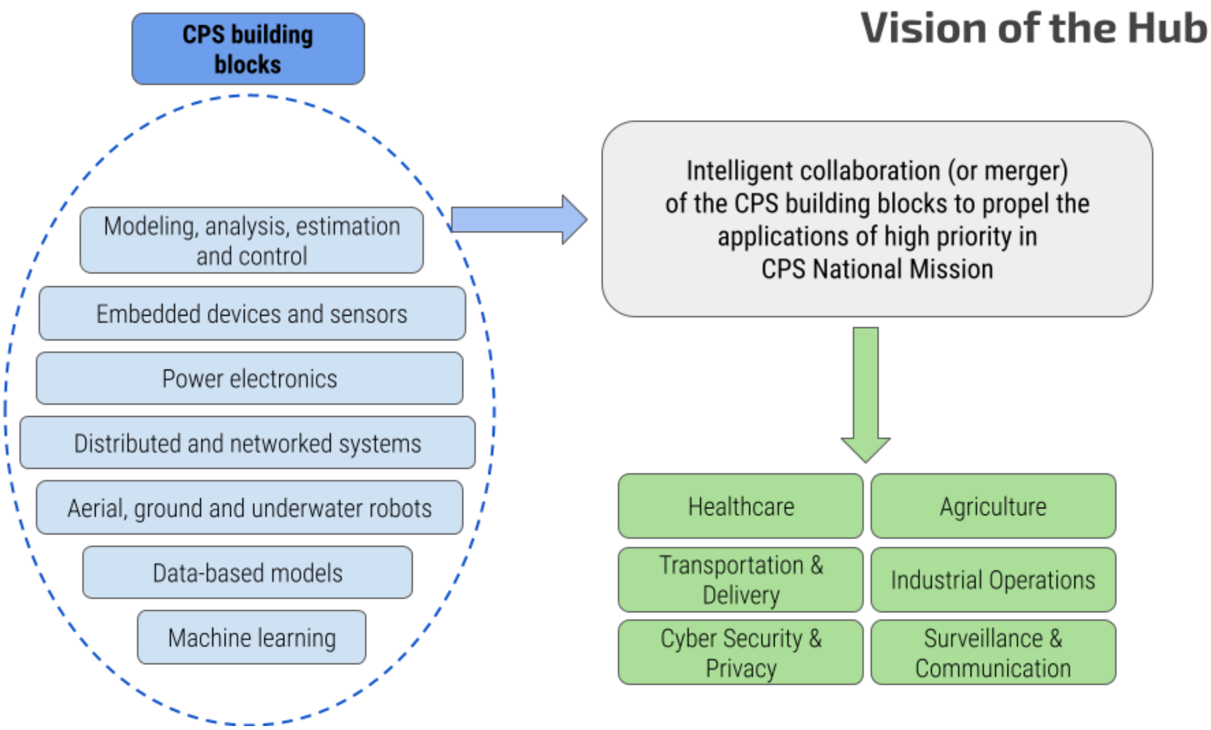


Figure 1.1: Vision of the hub

1.1 Focus Areas: Energy and Safety

Impact of implementing CPS technologies, in particular ICS, for addressing social problems cannot be overstated. The technical activities envisioned at TIH-ICS at IIT Palakkad via projects, startup initiatives, workshops and teaching will result in outcomes of immense benefit to several sectors including healthcare, agriculture, urban transportation, manufacturing, defence. The broad focus area of the technology development and entrepreneurial activities of TIH-ICS will be "***Intelligent and Autonomous Systems for Energy and Safety***."

In order to describe the impact on energy, we can take the example of the environmental footprint of two of the most popular electric vehicle technologies: the lithium ion battery and neodymium magnets for motors. Mining of deposits from earth and extraction of lithium/neodymium has a high ecological footprint. Lithium batteries also face an uncertain future in terms of the recycling effectiveness and efficiencies. Possible green alternatives for lithium are aluminium-air batteries or hydrogen-oxygen fuel cells, and for neodymium magnet motors could be induction/reluctance motors. Furthermore, renewable energies from solar, wind, tidal and geothermal sources can be used to extract hydrogen/oxygen from seawater, or recycle the aluminium from the aluminium-air batteries.

Solving such large scale problems will require deep system level thought process on all aspects, starting from mathematical models, process design which optimizes the ecological footprint, hardware and software design for large scale automation, performance monitoring, optimization on engineering costs, operationalizing and maintaining the entire battery/fuel manufacturing/recycling from renewables alone, etc. which are all integral to the Intelligent Collaborative Systems theme. Going further, plugging these green energy sources into electric vehicles, optimizing large scale battery swapping and refueling networks, creating automations for battery swapping, etc. gives us the overall impact on reducing the adverse effects of global warming.

To understand the impact of safety, let us consider rail, the most popular and cost-effective means of travel in our country. Most railway tracks, coaches and subsystems are monitored manually by humans which has only small fractional coverage, involves subjectivity and misses out on root cause analysis or predictability. In such a massive safety critical system, probable servicing/repair requirements, energy optimization, intervention, etc. should be performed pro-actively by prediction / estimation rather than by replacing parts after faults are identified. Even simple things like suggestions on train speed reductions on tracks that have been predicted to be weaker (based on long term data and mathematical model based studies) would improve safety and ensure longevity of railway systems. Saving on repairs and maintenance, and energy/materials required to perform such servicing will feed back into the impact on the energy domain we described earlier. Attempting to solve the safety problem in railways will involve handling complex mathematical models, large wireless sensor networks, estimation and data-based prediction models, optimization, and reliability engineering; all of which fall under the expertise of our hub.

Addressing technology development and startups under the energy and safety duality would have a very high impact for India and the rest of the world. Several such energy-safety duality can be found in the following examples:

- Energy optimal farming (raw materials, water, reduction of wastage in harvest, etc.), and ensure farmer safety in handling pesticides, high volume tasks, etc.
- Energy optimal and long endurance aerial vehicles for remote area communication, forest monitoring, wind farm servicing, etc. to ensure safety to natural resources and humans. Further, renewable energy based aerial vehicles can be prioritized.
- Robotic intervention class systems for underwater monitoring, battery swapping (large weight) in battery stations, etc. will ensure the safety and energy impacts.
- Usage of non-photovoltaic solar thermal systems for water desalination, fuel cell production, electricity generation, etc.
- Optimization of large scale structures for large lifetimes, health monitoring for early intervention, reducing servicing energy and increasing safety.
- Energy optimization of computational requirements for autonomous systems and at the same time ensure cyber security to ensure safety of the overall system.

Technologies / products envisioned in **intelligent systems for energy** include but are not limited to:

- Design of green motors, drivers, control.
- Optimization of green technologies for batteries. Examples include optimization methods for environmental impact minimization of battery recycling, optimization methods for renewable based fuel cell raw materials generation, etc.
- Modeling, control and design/optimization of renewable energy based charging systems.
- Automation of battery swapping systems for green batteries (ex: Aluminium air batteries).
- Transport optimization of battery swapping networks to renewable energy hubs.

Technologies / products envisioned in **autonomous systems for safety** include but are not limited to:

- Safety on inconsistent roads with heterogeneous traffic.
- Automated predictive health monitoring of rail network and subsystems.
- Automated intervention on railway networks using intervention class robots.
- Automated, secure and fault tolerant systems for railway signalling, rail crossing control, etc.
- Automated predictive health monitoring of public transport system (buses, metro trains).
- Large scale networking, data analytics, optimization and estimations for systems with uncertain nonlinear dynamics (trains, buses).

1.2 Enabling End-to-end Green Energy: An Energy Moonshot Problem

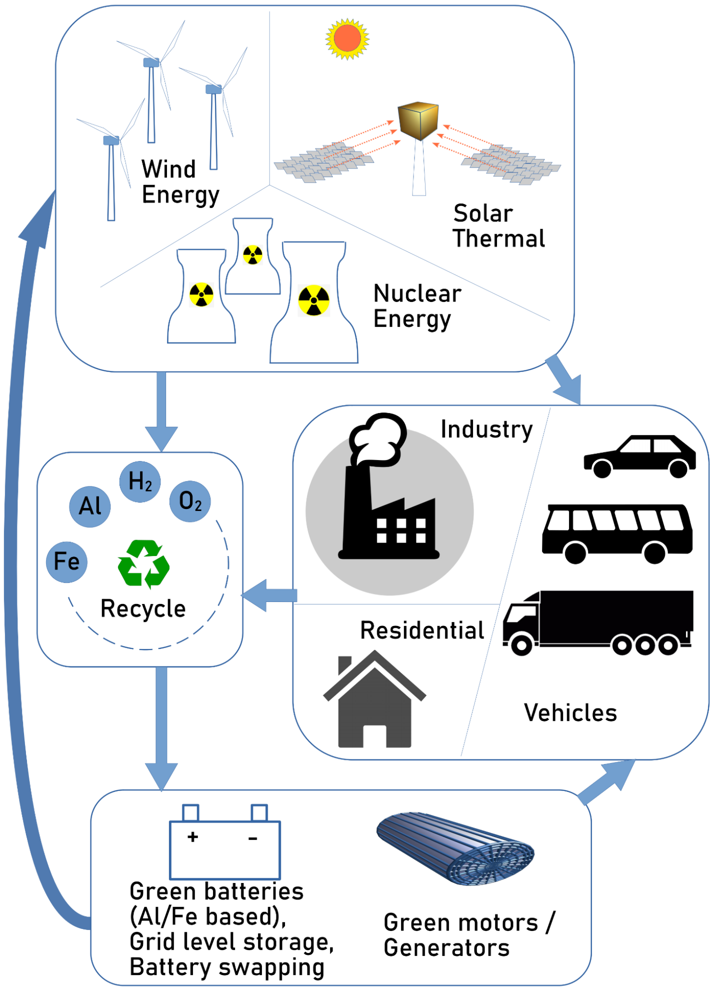


Figure 1.2: Broad example vision of green energy

As the world heads towards a lesser carbon emissions goal, we have to introspect to what extent fossil fuels are our primary energy source. Vehicles for transporting humans and goods are perhaps the most visible and spoken topics, which is being addressed by electric vehicle technologies. The impact of fossil fuel requirements in material mining, material processing, etc. are not very straightforward to visualize. In fact, while attempting to move from internal combustion engines to electric vehicles, we may inadvertently end up selecting a solution which may rely heavily on mining and material processing. Since the problem at hand is so vast, we broadly break it down into the following verticals:

1.2.1 Energy Technology Verticals

- Energy storage technologies that
  - Are more green (Ex: Iron/Aluminium batteries instead of Lithium)
  - Have high power/energy density (or approaching) on par with fossil fuels
  - Can store renewable energy (Ex: producing hydrogen using wind energy)
  - Are safe and economical (at large scale)
  - Have high reliability and lifetime (replacements should minimize material waste)
- Energy generation technologies that
  - Are more green (Ex: solar thermal, wind, etc.)
  - Have high power/energy density (Ex: Nuclear reactors)
  - Are safe to use (Ex: better nuclear storage/usage, better hydroelectric planning to avoid flooding risks)
  - Are economical at large scale
  - Have high reliability and lifetime (replacements should minimize material waste)
- Energy conversion technologies that
  - Are more green (Ex: eliminate usage of rare earth magnets in motors)
  - Have high efficiency and power/energy density
  - Are safe and economical
  - Have high reliability and lifetime (replacements should minimize material waste)
- Energy transportation/distribution technologies that
  - Are more green (Ex: microgrids and local renewables, distributed power plants)
  - Have easy accessibility (Ex: hydrogen can be filled as easily as petrol, battery swapping may take similar time as petrol filling)
  - Are more efficient, safe and economical
  - Have high reliability and lifetime (replacements should minimize material waste)

These four verticals are interdependent on each other, examples include: a windmill (energy generator) will use an electrical machine (energy conversion), microgrids (transport) will depend on availability of power plants/renewables (energy generator), hydrogen production (energy storage) tied to renewables (energy generator). Hence a green energy solution may involve working on isolated components or system level solutions, both equally being an impact problem.

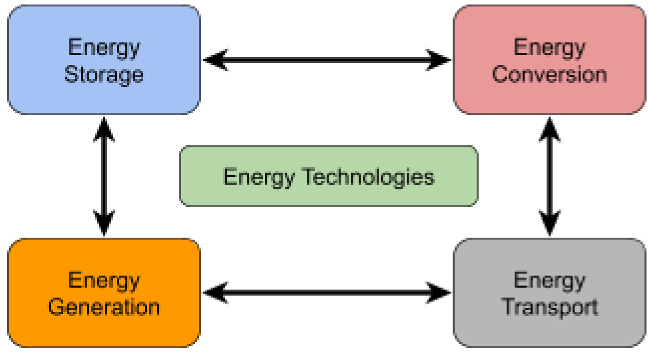


Figure 1.3: Energy technology broad classification

1.2.2 Energy Projects under TIH-ICS

Our plan to problems under the different energy verticals are below:

Internal and special external Projects:

- Switched reluctance motor (SRM) or induction motor designs
- Power electronics for SRM
- Perpetual gliders using solar and wind energy
- Windmill blade designs
- Switched reluctance generator designs
- Energy efficient distributed estimation and control of networked robots and its implementation architectures

Grand Challenges:

- 5/10/30/70/100 Kilowatt Lithium Polymer battery charger and battery management system; low weight for onboard charging systems, medium weight for external chargers.
- Battery swapping automation systems design, robotic manipulators for swapping batteries in cars, robotic manipulators for swapping grid level storage in the battery station.
- Battery life monitoring systems, predictive failure estimation, charging methodologies for battery life maximization.
- Grid level battery charging (100s of Kilowatts to several Megawatts).
- Automated assembly systems for large windmills, reducing deployment time and resources.
- 100 Kilowatt to megawatts generator design with very high power density (10 Kilowatt/Kg or above) for lighter windmills.

External Projects (Ministry or Inter-TIH projects)

- Hydrogen extraction from seawater using solar energy. Newer methods or improved product design, large lifetime and reliable operation.
- 5/10/30/50 Kilowatt battery pack design (low, medium and high voltages) using Lithium, Aluminium and Iron chemistries.
- 5/10/30/70/100 Kilowatt switched reluctance motor or induction motor with more than 2 Kilowatt/Kilogram power density and high efficiency.
- 5/10/30/70/100 Kilowatt motor drivers with high efficiency.
- High efficiency solar thermal systems for electricity generation, smaller size, 5/10/30/50 Kilowatt systems.
- High Voltage DC converter design, analysis and hardware development.
- HVDC transformers, fault tolerant designs.
- Battery pack designs for simplest battery swapping standard. This standard should be adoptable by all 4 wheeler vehicle manufacturers.
- Smaller and safer nuclear reactor designs.
- Safe and energy efficient extraction of Fissionable materials from mineral ores.
- Safe and reliable storage devices for spent nuclear fuel.

The above-mentioned problems have to be addressed at an interdisciplinary design / analysis level. Since this is the first of it's kind challenge to address a big scale energy related problem, we would prefer a large amount of upskilling among engineers as one of the desirable goals/outcomes. In this direction, several skill development workshops will be conducted for project teams, grand challenge contestants and general audience on design and analysis skills such as

- Mechanical CAD drawings
- Electrical PCB design, cabling diagram
- Component selection and calculations
- Sensors, signal processing and control algorithms
- Circuit and electro-mechanical detailed description
- Simulations of the system (Ex: circuit simulators, electromechanical simulators, dynamics models, etc.)
- Software based analysis of the system (Ex: electromagnetic simulations, thermal/stress/vibrations/bending analysis, etc.)
- Firmware code for microcontrollers / processors
- High level software for computer systems with implementation details such as platform, versions, prerequisite, etc.

- ○ Assembly instructions and Bill of materials, costing of technology

Several organizations are interested in partnering with IIT Palakkad in creating green energy technologies, including but not limited to:

- CDAC, Trivandrum
- SSEM (Society for Smart Electric Mobility), Coimbatore
- Anand Group, Pune
- Automotive Components Manufacturers Association (ACMA)
- L&T Defence
- VGuard
- ELGi Equipments, Coimbatore

In line with our focus of ICS for Energy, a few TIH-ICS postgraduate fellowships will be awarded to one of the flagship MTech programs on Power Electronics and Power Systems (PEPS) at IIT Palakkad. This program will help create researchers and industry professionals in the energy domain.

1.3 Predictive Intervention for Safety on Inconsistent Roads with Heterogeneous Traffic (PI-SIRHT): A Safety Moonshot Problem

In this section, we present details of a *moonshot* problem conceived to be taken up under its 'Safety' thrust area. The scope and structure of R&D involved in ICS targeting this problem, are crudely presented in Figure 1.3.

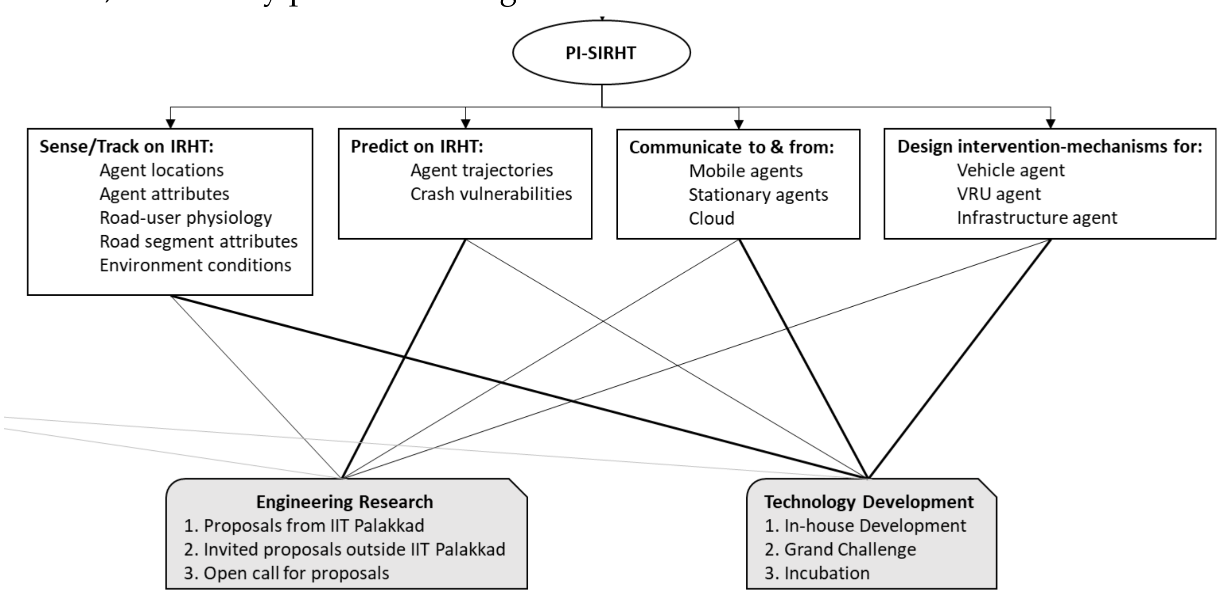


Figure 1.4: Scope and structure of R&D

The negative externalities of road crashes need no special introduction. In fact, in low- and middle-income countries such as India, the problems associated with road safety are more grievous when compared to developed nations due to scarcity of resources in enforcement, education, and engineering. They also contribute to distinctive conditions such as road inconsistencies and traffic heterogeneity, thereby complicating safety management.

The problem of traffic safety can be alleviated with intelligent real-time coordination of road-users, vehicles and infrastructure. It therefore inherently presents a platform with immense scope for intelligent collaborative systems where agents include both humans and machines. The standards and protocols that are being developed for ideal cases (consistent roads with homogeneous traffic) would not suffice for most parts of the world where roads are inconsistent and traffic is heterogeneous. This section attempts to outline the potential subproblems in different verticals of intelligent collaborative systems for safety on inconsistent roads with heterogeneous traffic.

Heterogeneous traffic involves multiple classes of vehicles such as different types of motor cars, motorised two/three wheelers, buses, trucks, commercial vehicles, non-motorised vehicles, carts, pedestrians etc. using the same carriageway with loose or no lane-discipline. This is the typical nature of traffic in many parts of the developing world including India, and calls for models and methods specifically designed and calibrated considering traffic heterogeneity. While some of them, e.g. premium cars, possess safety features, some others such as pedestrians and two-wheelers are vulnerable road users (VRU). Futuristically, one must also start accounting for various levels of connected and automated vehicles (CAV) in the traffic stream. This is the premise in which we address the traffic to be heterogeneous with CAVs and VRUs.

To exacerbate the effects of traffic heterogeneity, resource-constrained parts of the world also suffer from road inconsistencies. Road inconsistency can be defined as one or more violation of driver expectations which in-turn, surprise drivers and make them drive in an unsafe manner. For instance, an unexpected curve or an unplanned road-space reallocation can make a road segment inconsistent. Indicators used for road inconsistency assessment are many, but can be primarily attributed to road geometry and operating speed. Inconsistency measures have shown high correlation with crash occurrence and have been included in safety performance functions for the prediction of accidents. In many parts of the world, road networks evolve organically with limited planning interventions, and naturally result in road inconsistencies. Moreover, in resource constrained environments, road attributes may change after construction due to piecemeal upgradation and maintenance. Also, encroachments and roadside activities affect sight distance and obstruction offset distance in the post-construction stages.

1.3.1 Verticals within the problem

The problem of Safer Inconsistent Roads with Heterogeneous Traffic (IRHT) spans different knowledge domains and involves subproblems in them. These knowledge domains are conceived as five verticals of this project, namely, traffic safety, sensors and hardware, computing and software, communication and policy and planning as given in Figure 1.4. ICS for Safer IRHT entails development of standards, protocols, models, methods, algorithms, etc. in the different verticals. Therefore, each vertical confronts specific subproblems that must be solved to tackle the grander challenge in hand. A potential list of subproblems is presented in this section.

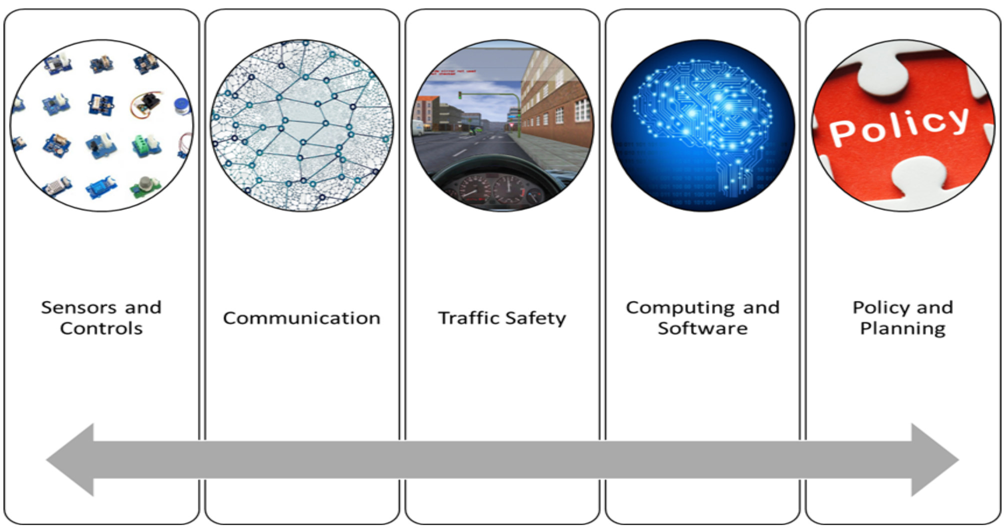


Figure 1.5: Different verticals in ICS for safety on roads with heterogeneous traffic

1. Potential subproblems in traffic safety modelling
    - Developing real time crash prediction models for heterogeneous traffic using:
        i. Driving simulator experiments
        ii. Surrogate safety measure
        iii. Traffic simulations
        iv. Trajectory predictions
        v. Historic crash data
    - Road network analysis
        i. Remote estimation of road geometry
        ii. Assessment of road network inconsistencies

iii. Segmentation and crash susceptibility

2. Potential subproblems in sensors and controls
    - Traffic state sensing
    - Infrastructural state sensing
    - Driver state sensing
    - Vehicle state sensing
    - Automotive safety and reliability
    - Feedback control
    - Reliability and security of the sensors and controllers
    - Fault-tolerant design
    - Sensor data fusion for accuracy and energy efficiency
3. Potential subproblems in communication
    - Vehicle to vehicle communication
    - Vehicle to infrastructure communication
    - Security solutions for all communication abstraction levels
    - Network and host intrusion detection and deterrent systems

4. Potential subproblems in computing and software
    - Software Vulnerability and Cyber Security
    - Identification
    - Data Privacy and authentication
    - Big data analytics and cloud based solutions
    - Automation of CCTV analysis

5. Potential subproblems in policy and planning
    - Accessibility
    - Equity
    - Privacy
    - Social cost benefit analysis
    - Cross domain policy design

1.3.2 Predictive interventions for IRHT of CAV and VRU

Intelligent collaborative systems typically have multiple components acting collaboratively to achieve a common goal. When the goal is safety on inconsistent roads with heterogeneous traffic of CAVs and VRUs, the collaboration would require prediction of unsafe conditions, such that an effective timely intervention can be made. For instance, a component in the system that tracks the position of vehicles can pass this information to another component that simulates the future-state and identifies the vulnerabilities. Such vulnerabilities are then informed to the relevant drivers or VRUs so that they may make corrective action. This is what is referred to as predictive intervention. When varying levels of automation get into vehicles, the task of making the corrective action too would come under the scope of the system. Such systems open up multiple challenges in terms of engineering research and technology innovation. Some such challenges are listed in the next section.

1.3.3 Major Challenges

The challenges listed in this section are associated with the long term implementation of ICS for Predictive Intervention for Safety on Inconsistent Roads with Heterogeneous Traffic of Connected and Automated Vehicles and Vulnerable Road Users. This does not constitute an exhaustive list, and need not represent comparable efforts in terms of solutions. Nevertheless, the challenges listed here for the rudimentary basis on which operations such as call for proposals and grand challenge competitions will be taken up in this thrust area.

I. *Automated assessment of infrastructural attributes on inconsistent roads*

Road infrastructural database is a significant essential for the vulnerability prediction and timely intervention. In developed economies, road-related attributes might be completely available and easily accessible in the public domain. However, in most other countries, especially low-and-middle income countries, data might be unavailable or if available might remain in the custody of a government agency, a concessionaire, or a private contractor who executes the work. Here, investigation of road infrastructural deficiencies is often neglected due to the lack of proper information or due to laborious assessment. To bypass this dearth of data, research has recently made a shift to remote and automated assessment of road attributes. Additionally, there has been a rapid increase in the deployment of newer technologies such as Internet-of-Things and cloud computing for developing data driven solutions to ensure better road safety and traffic management. However, these techniques also bring upon a plethora of challenges associated with their reliability, security and efficiency.

II. *Inconsistency based segmentation of road networks*

Road segmentation has a significant effect on the accuracy of vulnerability prediction. Segmentation is the process of organizing the explanatory variable database -- the predictors of crashes -- into homogenous groups. An improper road segmentation for safety analysis might lead to unobserved deficiencies. Different approaches to road segmentation have been adopted for road safety analysis.

III. Automated assessment of environmental conditions

Prediction of trajectory, and therefore, the estimation of crash vulnerabilities are dependent on the environmental conditions. For example, the attributes such as friction and visibility which greatly influence crash vulnerability depend on whether or not it is raining. An ICS targeting PI for SIRHT of CAVs and VRUs must necessarily include components that can assess environmental conditions.

IV. Vehicle and VRU tracking on IRHT

This is a crucial challenge to be solved for developing an efficient ICS targeting PI for SIRHT of CAVs and VRUs. Only after tracking the present location of the vehicles and road users in the traffic stream, can the system make any prediction and or intervention. Though many technology solutions exist for such tracking, various challenges require solving and scaling. The state-of-the-art technology for Vehicle and VRU tracking is still nascent and solving this challenge for SIRHT is both difficult as well as rewarding.

V. Location and class specific trajectory prediction on IRHT

Connected and autonomous vehicles pose challenges in proper communication which is very important in their smooth functioning. Knowing the traffic condition beforehand would help to improve the safety of CAV s especially under IRHT. Hence the prediction of traffic vehicles' trajectory plays an inevitable role in the field of safety by letting the CAVs aware about traffic participants behave in the near future so as to make appropriate decisions.

VI. Location and class specific Surrogate Safety Measures for IRHT

Earlier, crash analysis of road safety was based on the historical crash data only. This method in fact does not consider the vehicle trajectories for a given location and thus comparison between traffic network designs becomes difficult. Nowadays Surrogate Safety Measures (SSM) are widely in use because of its advantages over crash data based safety analysis. SSM does capture the near crashes which are very essential for improving safety and for reliable statistical safety modeling. SSM derived from the traffic conflicts are statistically connected to the crash frequency and severity. Crash frequency and severity are the powerful measures to the safety performance.

Predetermined thresholds are used to identify the traffic conflicts which in turn predicts the possibility of the crash based on their severity.

VII. Predictive Intervention design for different agents

By agents, we refer to the entities in a traffic stream, which could act as a node in the system. They could be vehicle-agents, pedestrian agents, two-wheeler agents, or infrastructure agents. Three groups of product development have been conceived based on which agent they are targeted to. These three are described below.

- **Product Group 1: Intervention design for vehicle-agent;** Intervention at the vehicle-agent would be different with respect to the level of automation present in the vehicle. While a Level 0 intervention would only mean a warning message passed on to the driver, Level 5 intervention would mean lateral and longitudinal driving action of an automated vehicle.

- **Product Group 2: Intervention design for VRU-agent;** Intervention at the VRU-agent would be in the form of a beep or haptic sign from a mobile phone or wearable device. This could also involve corrective driving action on wheelchairs, two-wheelers, etc.

- **Product Group 3: Intervention design for infrastructure-agent;** Intervention at the infrastructure could be in the form of beacons, sirens, signals etc. attached to infrastructure that communicates to all road users in the neighborhood. It could also be automated opening or shutting of entry/exit ramps or at-grade intersections.

VIII. Intelligent intervention system for different CAV-VRU proportions

As there could be multiple scenarios with varying proportions of CAVs, VRUs and other vehicle classes in the traffic stream, the intervention mechanisms can be optimally bundled as one system and used efficiently by single agencies. Such bundling would also require considerable research and development and analyze multiple alternatives of mixing and matching.

1.4 Target Beneficiaries

Several members of Indian society are in dire need of upskilling, startup support, knowledge expansion, research facilities and collaboration, mentorship on technology development and international exposure. The idea is to provide the benefits of the TIH to the beneficiary members and leverage their support in improving the research, job market and sustained business in the local ecosystem. In this direction, beneficiaries of the TIH would be the following

- Students
  - Undergraduate fellows, postgraduate fellows
  - Doctoral students, junior research fellows
  - Young startup ideators under CPS-Startup
  - Fabrication lab availing candidates
  - Winter school and conference attendees
  - Grand Challenge Participants
- Career professionals
  - Lab technicians, supervisors and managers
  - Faculty Fellows
  - Chair Professors
  - Legal, accounts and administrative positions
  - Grand Challenge Participants
  - Skill development participants
- Academic professionals
  - Call for proposal awardees
  - International collaboration projects
  - Collaboration with TIH projects
  - Fabrication facility availing individuals/teams
- Entrepreneurs
  - CPS-PRAYAS, CPS-SSS and CPS-DIAL
  - Entrepreneurship in residence participants
  - Grand Challenge Participants
  - Technology transfers from TIH to startups
  - Spin-off companies from TIH team

The beneficiaries are involved strategically to ensure the benefits they avail are contributed back to society through technology development, product development, job creation through upskilling and startups and achieving knowledge and technology on par with international levels, ensuring India is not dependent on monopolies.

1.5 Aims and Objectives

The overarching aim of TIH-ICS, in alignment with the national priorities, are the following

- Job creation
- Technological independence
- Skill improvement
- Startup support
- Knowledge expansion
- Research facilities and collaboration
- Mentorship on technology development
- International exposure

Brief aims and objectives of the four verticals are listed below

A. Technology Development

- Promote make-in-India technology and products that will help break away from dependence on global monopolies.
- Increase jobs in India by achieving technological independence.
- Encourage technology and product development oriented startups.
- Foster global collaborative research and development.
- Enable revenue generation by encouraging IP licensing.

B. Human Resource Development

- Enhance employability of UG students in CPS-related industries.
- Support PG programs that align with the CPS-ICS theme.
- Produce good-quality publications in the domain of CPS-ICS.
- Contribute to open-source hardware and software.
- Augment and enhance CPS-ICS research expertise.
- Enable Make-in-India initiatives through upskilling of job seekers.
- Invest in knowledge and skill development.

C. Startups and Entrepreneurship

- Create funding opportunities for technologies and products at various TRLs.
- Mentor budding entrepreneurs for their startup journey.
- Direct and indirect job creation
- Incubate startups that drive innovation.
- Increase on-job upskilling and training.
- Fund novel and innovative ideas.
- Identify and promote well performing startups.

- Create indigenous products.
- Create local supply chains that ensure robustness to global crisis situations.

D. International Collaboration

- Promote foreign investment in Indian technology and products.
- Enable knowledge and technology transfer to Indian academia and industries.
- Create global awareness for Indian technology and products.

The above mentioned aims and objectives are met through the targets given by the mission tripartite agreement as follows

Table 1.1: Aims and objectives in various verticals

Sl. No.	Target Area	Target (DST)	Year 1	Year 2	Year 3	Year 4	Year 5
1	**Technology Development**						
(a)	No. of Technologies (IP, Licensing, Patents, etc.)	19	0	2	4	7	6
(b)	Technology Products	12	0	1	3	3	5
(c)	Publications, IPR	36	2	6	9	9	10
(d)	Increase in CPS Research Base	62	0	31	21	10	0
2	**Entrepreneurship Development**						
(a)	Technology Business Incubator (TBI)	1	1	0	0	0	0
(b)	Start-up and Spin-off companies	32	4	8	8	8	4
(c)	GCC - Grand challenges and competitions	3	1	1	1	0	0

(d)	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	1	1	0	0	0	0
(e)	CPS- Entrepreneur in Residence (EIR)	20	5	5	5	5	0
(f)	Dedicated Innovation Accelerator (DIAL)	1	0	1	0	0	0
(g)	CPS - Seed Support System (CPS-SSS)	1	0	0	1	0	0
(h)	Job Creation	7750	0	0	7500	250	0
3	**Human Resource Development**						
(a)	Graduate Fellowships	210	42	42	42	42	42
(b)	Post Graduate Fellowships	39	0	9	10	10	10
(c)	Doctoral Fellowships	23	23	0	0	0	0
(d)	Faculty Fellowships	3	1	1	1	0	0
(e)	Chair Professors	3	1	1	1	0	0
(f)	Skill Development	380	60	80	80	80	80
4	**International Collaboration**	1	0	1	0	0	0

1.6 Strategy

Overall strategy for TIH-ICS is to move into a self-sustained mode. Strategies for implementing technologies, skill development, fellowships and entrepreneurship are briefly listed below

A. Technology Development

- Projects across several applications.
- Internal, special-external, and external project categories.
- Multidisciplinary fabrication and research laboratories.
- Planned timelines to interconnect startups, projects and grand challenges.
- Revenue generation.

B. Human Resource Development

- Award of UG, PhD fellowships through open calls.
- Award of PG fellowships to Masters program(s) that are in alignment with the CPS-ICS theme.
- Faculty and chair professor positions to augment and enhance CPS-ICS research expertise.
- Skill development oriented towards Make-in-India theme.

C. Startups and Entrepreneurship

- High risk and high potential startup funding (both ideation and preliminary stage startups).
- Capturing equity in good startups to ensure self-sustainability of TIH-ICS
- A grand challenge to address a key multidisciplinary technology creation.
- Generate about 7500 job opportunities through a grand challenge.

D. International Collaboration:

- Bi-lateral student/research exchange programs.
- Winter schools/workshops jointly conducted by Indian and international experts.
- Increase in CPS research base.

Detailed strategy of each of the above components is discussed in sections with the respective titles.

1.7 Executive Summary of Grand Challenges

Motto of our grand challenges are "**CREATING A GREEN AND SAFE FUTURE**", and the target applicants are all enthusiastic Indian citizens.

Grand Challenges are aimed at fostering innovation and research. The ambit of the grand challenge is a multiple-stage competition, and includes hardware, software, and prototype development activities. The incoming participants are expected in teams of strength 5 or above. The team size is kept high since these applications will require the involvement of participants from several domains, which include but are not limited to multispectral imaging, machine learning, control design in adverse environments, state estimation for position/mass, energy efficient state estimators and control designs, path generation and obstacle avoidance using optimization, collaborative control, resilience control under communication delays or random/malicious packet losses or jamming attacks etc, SLAM (simultaneous localization and mapping), hardware limited control and estimation strategies, hardware development and optimization, cyber security, etc. Each team can choose three of the following open-ended problems to address.

Topics of the grand challenges

Problem statements for the grand challenges will be selected from our focus area of Safety and Energy. Several of these problems will be sub-problems of our moonshot problems. A few possible problem statements are below:

Energy

- Design of green motors, drivers, control.
- Optimization of green technologies for batteries. Examples include optimization methods for environmental impact minimization of battery recycling, optimization methods for renewable based fuel cell raw materials generation, etc.
- Modeling, control and design/optimization of renewable energy based charging systems.
- Automation of battery swapping systems for green batteries (ex: Aluminium air batteries).
- Transport optimization of battery swapping networks to renewable energy hubs.

Safety

- Automated assessment of infrastructural attributes on inconsistent roads
- Inconsistency based segmentation of road networks
- Automated assessment of environmental conditions
- Vehicle and VRU tracking on IRHT
- Location and class specific trajectory prediction on IRHT
- Location and class specific Surrogate Safety Measures for IRHT
- Predictive Intervention design for different agents

- ➢ Intelligent intervention system for different CAV-VRU proportions
- ➢ Automated predictive health monitoring of rail network and subsystems.
- ➢ Automated intervention on railway networks using intervention class robots.
- ➢ Automated, secure and fault tolerant systems for railway signalling, rail crossing control, etc.
- ➢ Automated predictive health monitoring of public transport system (buses, metro trains).

Structure

We plan to have 3 grand challenges; one each in the first 3 years. They will progress via a multi-stage filtering process with progressively higher reward, proof of concept enhancement, and refinement in business plans, culminating in start-ups. Each stage will have a rigorous review process to select best performing teams for the subsequent round. In order to assist ideation of the product and business development, support will be provided to the participants via forums, webinars/seminars and workshops. Target beneficiaries of the grand challenge will be Indian citizens interested in technology and product development.

Deliverables

The outcomes of such grand problems will result in ***innovative software and hardware co-designs*** that solve sub-problems of our moonshot problems and also lead to possible commercial technologies/products.

1.8 Outcomes

Outcomes of the various activities and metrics to evaluate them are summarized in the following table. Detailed outcomes are presented in the sections corresponding to the respective targets.

Table 1.2: Measure of success for the various targets

Sl. No.	Target Area	Target (DST)	Measurable criteria for success (in 5th Year of the Hub)
1	**Technology Development**		
(a)	No. of Technologies (IP, Licensing, Patents, etc.)	19	IPTIF gets a revenue of at-least INR 2.15 Cr
(b)	Technology Products	12	

(c)	Publications, IPR	36	Publications in top-tier conferences/journals *OR* Contributions to open-source hardware and software.
(d)	Increase in CPS Research Base	62	Employment opportunities of researchers/engineers beyond their association with TIH-ICS.
2	**Entrepreneurship Development**		
(a)	Technology Business Incubator (TBI)	1	TECHIN (IIT Palakkad Incubator) is able to meet all the TIH-ICS Entrepreneurship Development targets.
(b)	Start-up and Spin-off companies	32	At-least 50% of the companies have received another round of investment.
(c)	GCC - Grand challenges and competitions	1	Creation of 7750 jobs and incubation of winners at TECHIN.
(d)	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	1	Development of prototypes of early stage ideas.
(e)	CPS- Entrepreneur in Residence (EIR)	20	At-least 50% of the entrepreneurs go ahead to become founders/co-founders of startups
(f)	Dedicated Innovation Accelerator (DIAL)	1	IPTIF gets a revenue of at-least INR 0.5 Cr
(g)	CPS - Seed Support System (CPS-SSS)	1	
(h)	Job Creation	7750	Participation of at-least 500 teams in Grand Challenge; each team with at-least 15 team members.
3	**Human Resource Development**		

(a)	Graduate Fellowships	210	Employment in CPS-related industries.
(b)	Post Graduate Fellowships	39	Successful graduation of the supported PG students.
(c)	Doctoral Fellowships	23	Publications in top-tier conferences/journals *OR* Contributions to open-source hardware and software.
(d)	Faculty Fellowships	3	
(e)	Chair Professors	3	
(f)	Skill Development	380	Successful completion of the skill development workshops/programs
4	**International Collaboration**	1	3 bi-lateral exchange program *OR* At-least 2 winter schools *OR* At-least 10 researchers/engineers inducted into the CPS research base.

1.9 Time frame

The start date is January 6, 2021, which is the date of signing the tripartite agreement between DST Mission, IPTIF and IIT Palakkad. This timeline also coincides with the major level approval of this DPR (minor revisions may follow, but not an activity stopper). The timeline Gantt chart for the activities would be as shown below, and this ties to the strategy of effective implementation of the TIH.

Table 1.3: Gantt chart for the various TIH activities.

	Year 1				**Year 2**				**Year 3**				**Year 4**				**Year 5**			
	Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Hiring admin staff																				
Hiring engineers and other technical staff																				

Infrastructure development			■	■	■	■	■	■												
UG and Doctoral PhD fellowship			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PG fellowships							■	■	■	■	■	■	■	■	■	■	■	■		
Faculty Fellowships, Chair Professors					■	■	■	■	■	■	■	■	■	■	■	■				
Technology Development (TIH-ICS projects)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Equipment Purchase			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Skill Development			■			■				■				■				■		
Call for Proposals (External)					■				■				■				■			
Startup proposals (CPS-Startup and EIR)				■	■			■	■			■	■			■	■			
Dedicated Innovation Accelerators (CPS-DIAL)						■	■													
Early Stage Startup (CPS-PRAYAS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Seed Support System (CPS-SSS)									■	■			■	■						
Grand Challenge	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
International Collaboration Proposals					■				■				■							

The above Gantt chart can be interpreted as follows:

- Finance under specific heads such as startups and entrepreneurship is made to coincide with the announcement timelines, in some cases the process would begin earlier (money disbursal at the end), an example would be CPS-startup and EIR that will have a review process at the end of which funds can be allocated at the start of next financial start year.

- Skill development workshops are aligned to summers, but announcements and arrangements happen in advance.
- International and national calls for proposals are aligned to the start of the financial years to ensure that their duration falls within the first 5 years of TIH.
- CPS-SSS seed funds are deferred to third year in order to benefit well-performing startups among the CPS-Prayas and CPS-Startup teams.
- The activities are aligned such that not more than two announcements and arrangement activities overlap in a quarter. Some of the programs which overlap in certain quarters are ensured to be long running activities and not a particular time constrained deliverable (as examples: academic masters and CPS-PRAYAS).

1.10 Evaluation

HGB would do periodic reviews to assess the performance of TIH-ICS, and to suggest course correction, if any. It is proposed to have multiple subcommittees to evaluate the following aspects of TIH.

- IPTIF administration staff
- Process and activities related to TIH-ICS
- All TIH-ICS targets mentioned in the tripartite agreement

*A detailed overview of the evaluation framework is presented in Section 3.3***.**

1.11 Environmental Impact

Environmental Impact Assessment for internal projects has been performed and can be found in the detailed proposal of the respective projects (refer Section 4.2). For external-facing projects, the investigators will be asked to do Environmental Impact Assessment as a part of the project submission process. They are also expected to propose measures to mitigate the adverse impact, if any. Environmental Impact Assessment of Entrepreneurship development will be performed by TECHIN (IIT Palakkad TBI).

1.12 Legal Framework

The legal framework for executing the various components are described in the respective chapters. Suitable consultants will be onboarded to execute these as per applicable legal regulations.

2 Finance

The section 8 company of TIH-ICS Palakkad, IIT Palakkad Technology I-hub Foundation (IPTIF) has been granted a tentative maximum budget of INR 100Cr, which has to be utilized over a period of 5 years with the following yearly recurring and non-recurring split mandated by the mission.

Table 2.1: Budget split (in Cr.) provided by DST Mission

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Recurring	5.25	15.5	26.5	17.25	13.5	78
Non-Recurring	2	12	3	3	2	22
Total	7.25	27.5	29.5	20.25	15.5	100

2.1 Expenditure

Keeping in mind the targets, recurring and non-recurring split, and the overall priority that we foresee for each of the activities, the following top-down budget is proposed for the high level targets

Table 2.2: Top down budget split among the high-level targets

		Total Budget (in Cr)	Year 1		Year 2		Year 3		Year 4		Year 5	
Sl. No.	**Target Area**		**R**	**NR**	**R**	**NR**	**R**	**NR**	**R**	**NR**	**R**	**NR**
1	**Technology Development**	**42.66**	**1.11**	**0.50**	**7.38**	**4.06**	**10.29**	**2.50**	**6.24**	**3.00**	**5.58**	**2.00**
2	**Entrepreneur-ship Development**	**22.37**	**1.75**	**1.00**	**6.23**	**0.00**	**7.83**	**0.00**	**3.78**	**0.00**	**2.78**	**0.00**
3	**Human Resource Development**	**14.68**	**1.04**	**0.00**	**3.47**	**0.00**	**3.82**	**0.00**	**3.82**	**0.00**	**2.53**	**0.00**
4	**International Collaboration**	**5.00**	**0.00**	**0.00**	**1.25**	**0.50**	**1.95**	**0.50**	**0.80**	**0.00**	**0.00**	**0.00**
5	**TIH Operations**	**14.25**	**1.35**	**0.50**	**2.61**	**2.00**	**2.61**	**0.00**	**2.61**	**0.00**	**2.61**	**0.00**
	TOTAL	**100**	**5.25**	**2.00**	**20.94**	**6.56**	**26.50**	**3.00**	**17.25**	**3**	**13.5**	**2**

Note: ***In the 2nd year, DST mission provides INR 15.5 Cr and 12 Cr under the recurring and non-recurring budget heads, respectively. However, the projected expense under the recurring budget head in the 2nd year is INR 20.94 Cr. Therefore, if needed, the budget will be appropriated after taking consent from the TIH ICS hub governing body.***

2.1.1. Technology Development

Technology development involves patenting, licensing, product development, improving CPS knowledge among engineers/researchers, and publications. We propose a project based approach to deliver these targets, as the quantum of money is difficult to allocate on a per individual target basis. The total budget for Technology development is about 50% of the entire budget. This will ensure higher success of the targets, as IP, licensing and product development carries higher failure risks compared to other verticals. Further, as per the mission mandate approximately 50% of **INR 42.66 Cr** has been allocated to external facing projects. Broadly the technology development projects are classified into:

- **Internal projects: 13.12 Cr (30.7% of Technology budget)**
- **Special external projects: 8.46 Cr (19.8% of Technology budget)**
- **External and inter-TIH projects: 21.08 Cr (49.5% of Technology budget)**

Year-wise budget splits for the above projects are presented in the following table.

Table 2.3: Detailed technology development budget

Sl. No	Target Area	Anticipated Targets	Total Budget (in Cr)	Year 1		Year 2		Year 3		Year 4		Year 5	
				R	NR	R	NR	R	NR	R	NR	R	NR
1	**Technology Dev.**		**42.66**	**1.11**	**0.50**	**7.38**	**4.06**	**10.29**	**2.50**	**6.24**	**3.00**	**5.58**	**2.00**
(i)	Internal projects	14 Tech, 8 Products	**13.12**	0.23	0.14	2.09	2.31	2.75	0.77	2.15	0.61	1.82	0.25
(ii)	Special external projects	4 Tech, 7 Products	**8.46**	0.29	0.07	2.15	1.25	2.78	0.54	1.18	0.20	0.00	0.00
(iii)	External and Inter-TIH projects	27 Tech, 14 Products	**21.08**	0.59	0.29	3.14	0.50	4.76	1.19	2.91	2.19	3.76	1.75

The strategy is to aim for a larger number of technologies and products, so that even with a 60% success rate, technology targets promised to mission will be met. This strategy will be explained in detail in the Technology Development chapter. The CPS research base increase is assigned to each one of these projects, as it is natural to hire project manpower to execute the projects. Publications are also a natural outcome of two activities: (i) projects and (ii) the research work of PhD students (doctoral fellows).

2.1.2. Entrepreneurship Development

The entrepreneurship activities involve several modes of funding startups and entrepreneurs, this carries a risk in between the technology development (very high risk) and human resource development (low risk). In order to facilitate the activity, operational costs are provided to the IIT Palakkad Business Incubator - Technology Innovation Foundation IIT Palakkad (TECHIN). All the startup funds will be routed through TECHIN to reduce operational complexities. The grand challenge fund could be disbursed by IPTIF and TECHIN together, but the modality is not fully established yet. The job creation has been addressed in the Entrepreneurship chapter in detail through the grand challenge.

Table 2.4: Detailed entrepreneurship development budget

Sl. No	Target Area	Total Budget (in Cr)	Year 1		Year 2		Year 3		Year 4		Year 5	
			R	NR	R	NR	R	NR	R	NR	R	NR
2	**Entrepreneurship Development**	22.37	**1.75**	**1.00**	**6.23**	**0.00**	**7.83**	**0.00**	**3.78**	**0.00**	**2.78**	**0.00**
(a)	Technology Business Incubator (TBI)	**5.00**	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
(b)	Start-up and Spin-off companies	**4.80**	0.00	0.00	1.20	0.00	1.20	0.00	1.20	0.00	1.20	0.00
(c)	GCC - Grand challenges and competitions	**5.05**	0.75	0.00	1.25	0.00	3.05	0.00	0.00	0.00	0.00	0.00
(d)	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	**3.80**	0.00	1.00	1.6	0.00	0.40	0.00	0.40	0.00	0.40	0.00

(e)	CPS- Entrepreneur in Residence (EIR)	**0.72**	0.00	0.00	0.18	0.00	0.18	0.00	0.18	0.00	0.18	0.00
(f)	Dedicated Innovation Accelerator (DIAL)	**2.00**	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00
(g)	CPS - Seed Support System (CPS-SSS)	**2.00**	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00

2.1.3. Human Resource Development

Human resource development is a low risk target, as this is a regular type of work that academic researchers are generally comfortable with and have extensive experience.

Table 2.5: Detailed HRD budget

Sl. No	**Target Area**	**Total Budget (in Cr)**	**Year 1**		**Year 2**		**Year 3**		**Year 4**		**Year 5**	
			R	**NR**	**R**	**NR**	**R**	**NR**	**R**	**NR**	**R**	**NR**
3	**Human Resource Development**	**14.68**	**1.04**	**0.00**	**3.47**	**0.00**	**3.82**	**0.00**	**3.82**	**0.00**	**2.53**	**0.00**
(a)	Graduate Fellowships	**2.60**	0.52	0.00	0.52	0.00	0.52	0.00	0.52	0.00	0.52	0.00
(b)	Post Graduate Fellowships	**1.76**	0.00	0.00	0.24	0.00	0.59	0.00	0.59	0.00	0.34	0.00
(c)	Doctoral Fellowships	**7.00**	0.40	0.00	1.70	0.00	1.70	0.00	1.70	0.00	1.5	0.00
(d)	Faculty Fellowships	**1.53**	0.00	0.00	0.51	0.00	0.51	0.00	0.51	0.00	0.00	0.00
(e)	Chair Professors	**1.05**	0.00	0.00	0.35	0.00	0.35	0.00	0.35	0.00	0.00	0.00
(f)	Skill Development	**0.76**	0.12	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.16	0.00

2.1.4. International Collaboration and TIH Operations

International collaborations budget will be used for mobility of researchers and students for a short period of time in partnering institutions. It will also be used to conduct winter schools and invite keynote speakers. In this direction, a total of INR 5 Cr is allotted from years 2 to 4.

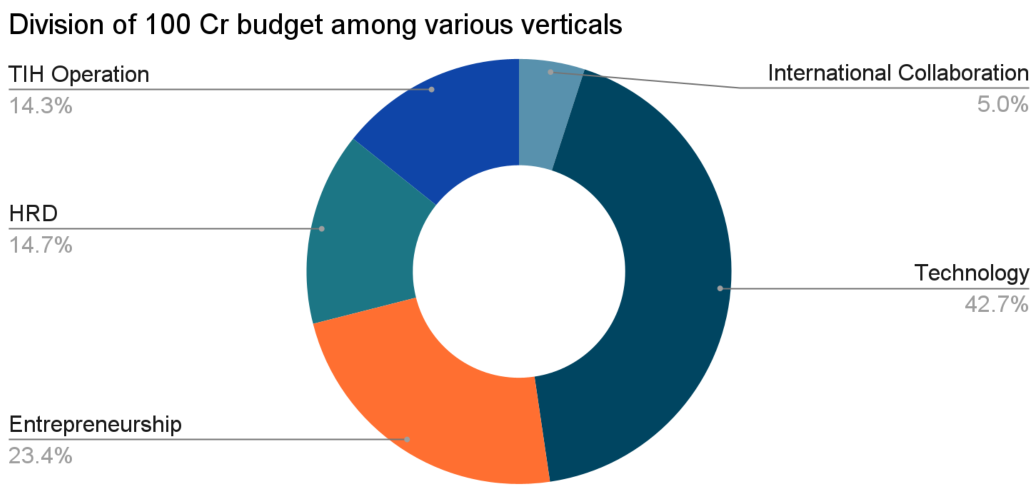
TIH functioning requires resources such as management staff (CEO, associates, office assistants, etc.), fabrication laboratory to enable the product/technology development, skill development and startup targets and some money set aside for Capex/Opex/Contingency related to basic office space for TIH employees, fabrication lab space, some space for meetings and visitors, and the associated infrastructure.

Table 2.6: Detailed TIH operations budget

Sl. No	Target Area	Total Budget (in Cr)	Year 1		Year 2		Year 3		Year 4		Year 5	
			R	NR	R	NR	R	NR	R	NR	R	NR
4	**International Collaboration**	5.00	**0.00**	**0.00**	**1.25**	**0.50**	**1.95**	**0.50**	**0.80**	**0.00**	**0.00**	**0.00**
5	**TIH Operations**	14.25	**1.35**	**0.50**	**2.61**	**2.00**	**2.61**	**0.00**	**2.61**	**0.00**	**2.61**	**0.00**
(a)	TIH Management	**4.30**	0.30	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
(b)	TIH Capex	**2.50**	0.00	0.50	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
(d)	TIH Opex	**4.30**	0.30	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
(f)	Mobility and TIH Contingency Fund	**3.15**	0.75	0.00	0.60	0.00	0.60	0.00	0.60	0.00	0.60	0.00

2.2. Cost Benefit Analysis

Budget distribution among the four verticals is illustrated by the following figure.



Technology and product development is assumed to be of highest risk. Hence , it is given at 50% of the overall budget. Rational for this strategy is as follows

- Exposure to patenting, licensing, product development and pushing to higher TRL levels is not a widespread practice in the current Indian ecosystem. Hence, the budget is kept on a higher side to ensure that targets are met despite failures.
- External technology/product development projects are open to academicians and entrepreneurs alike. Hence, we have augmented the entrepreneurial activities in an indirect way. Since startup founders and teams are enthusiastic about product development, commercialization and growth, they will be able to deliver good technologies/products through such calls for proposals.
- Several HI faculty members associated with TIH-ICS have product development experience in startups and multinational organizations. Hence, only one-fourth of the technology budget is utilized by internal projects to deliver at-least 60% of the technology targets.

Entrepreneurship and startups have medium level risk in comparison to product/technology development for the following reasons

- Emergence of several business incubators, accelerators and startup ecosystems in the past two decades has created awareness of startup opportunities among individuals who are committed to a startup journey.
- Journey of a startup would extend much beyond the existence of TIH. It is often difficult to define stringent milestones for their state and performance. Hence, they are often evaluated based on how much their strategy, product or business ideas have matured over a period of time.
- Some of the entrepreneurship and startups funds are given on equity and/or loan basis. Such schemes are beneficial for IPTIF. Hence, the risk is lesser than direct investment to develop a product.

- IIT Palakkad's business incubator TECHIN would be monitoring and mentoring entrepreneurs that any external TBI. This, in turn, would ensure a better success rate.

Human Resource Development is a low risk target, since the execution of these targets will be done by academicians and they have extensive experience in handling these types of targets. Nevertheless, a better fellowship amount is expected to attract the best talent in the country. The international collaborations is also envisioned as means to augment the HRD targets by engaging in winter schools, exchange programs, etc.

Functioning of TIH-ICS requires a baseline investment, which supports all of the IPTIF activities. The management salary is set at about 10% of the total technology budget. This is a good industry benchmark for hardware and software development. The fabrication lab and CAPEX/OPEX on some incubation space will help in achieving other targets. They will also serve as a revenue generator.

Table 2.7: Table comparing the risk, cost and benefit of the the various verticals

Vertical	Risk	Cost	Benefit
Technology Development	High	High	High
Human Resource Development	Low	Low	High
Entrepreneurship and startups	Medium	Medium	High
International Collaborations	Low	Low	Medium
TIH Operations	Medium	Medium	High

2.3. Revenue

In order to define the sustainability of the IPTIF beyond 5 years, we created a projection of the regular running costs required for IPTIF based on the data in Table 2.6.

Table 2.8: Projected IPTIF running budget

Sl. No.	Header	Yearly Expenses
1	TIH Management	1 Cr

2	TIH Opex	1 Cr
3	Fab lab Opex and Capex, and Contingency	1 Cr
	TOTAL	**3 Cr**

The running cost of 3 Cr per year in the 5th and 6th year has to be met based on the following sources of revenue

- **Fabrication lab rentals**: Assuming an average of 100 days of renting in a year, with a revenue of INR 10,000/day gives us a revenue of INR 10,00,000 per year.
- **Government project overheads**: Government projects have overhead caps for different bracket of project money
  - 10% upto 1 Cr
  - INR 15,00,000/- or 10% (whichever is less) from 1 Cr to 5 Cr
  - INR 20,00,000/- from 5 Cr to 20 Cr
  - Case-by-case decision for above 20 Cr

  Let us assume that we get at-least one project of INR 10 Cr in a year. This will give us INR 20,00,000/- as the overhead.
- **Overheads from industry CSR funding**: Assume 10% with annual funds incoming as INR 2 Cr, which gives INR 20,00,000/-
- **Startup equity and loan recovery**: About 50 startups will be invested in equity/loan basis (Spin-offs, Grand challenge winners, DIAL, SSS), with a minimum quantum of INR 10,00,000/startup. Assuming 10% recovery on year-on-year basis gives INR 50,00,000/-
- **IP licensing and monetization**: About 19 technologies and 12 products are guaranteed from IPTIF. Assume an annual license fee of INR 5,00,000/technology, and INR 10,00,000/product. Then, the revenue will be INR 2.15 Cr. This is sustainable if the product and technology numbers are steadily maintained thereafter, which assuming fresh project money is incoming, shouldn't be a problem.
- **VC and industry investments**: Assume about 5 startups are tied up to VCs and industries on a yearly basis, and IPTIF receives a consultancy/referral fee of INR 10,00,000/startup giving a revenue of INR 50,00,000.

Table 2.8: Projected IPTIF revenue in the 5th year

Sl. No.	Header	Revenue
1	Fabrication lab rental	0.10 Cr

2	Govt. project overheads	0.20 Cr
3	Overhead of industry CSR funds	0.20 Cr
4	Startup equity and loan recovery	0.50 Cr
5	IP licensing and product monetization	2.15 Cr
6	VC and industry investments	0.50 Cr
	TOTAL	**3.65 Cr**

The strategic leadership of the CEO, management and board of directors of IPTIF along with the partnership of TECHIN is crucial to sustain TIH-ICS beyond 5 years.

3 TIH Operations

TIH-ICS will be managed by a hub governing body. This HGB shall be the Apex body for overall supervision, control, directions and mid-course correction in the implementation of Hub at Host Institutes. It will be the final authority to provide guidelines for implementation and operating the Hub and all other matters related to them. HGBs will have full financial and administrative powers, including approvals to, re-appropriation of the budget within the ceiling of sanctioned budget, sign Memorandum of Understanding (MoU) with International institutions and approve Collaboration foreign visits, partner with industry, receive/ support for projects in their domain areas to academic, R&D institutions, Industry, other funding agencies and linkages with existing TBI at IIT Palakkad.

HGB would meet at least twice a year, with an initial kick‑off meeting scheduled no later than one month after the TIH's inauguration. The decisions of the HGB are binding on the TIH. Broadly, the HGB would decide on issues related to:

- Technical and financial report overviews for past / future periods.
- Any alteration in the Memorandum of Understandings (MoUs) with the Hub proposed for amendment by the members.
- Premature completion/termination of the ongoing projects.

3.1 Management

IPTIF, a section 8 company, has been set up by the IIT Palakkad to meet the mandates put forth by mission for the TIH-ICS hub. This company has a Board of Directors, of which Director, IIT Palakkad is an ex-officio member. IPTIF Board of Directors will appoint a dedicated full time Chief Executive Officer (CEO) with desired domain and management expertise and other core team/supporting staff who will oversee the activities of IPTIF, including but not limited to meeting the mandates the TIH-ICS hub awarded to IIT Palakkad. The CEO would be endowed with appropriate administrative and financial power by the IPTIF Board of Directors, and is responsible for realizing the TIH-ICS target with guidance and approval from the HGB. A team of administrative staff will help the IPTIF CEO manage the day-to-day operations of IPTIF. Details of each management position and their responsibilities are listed in the following table.

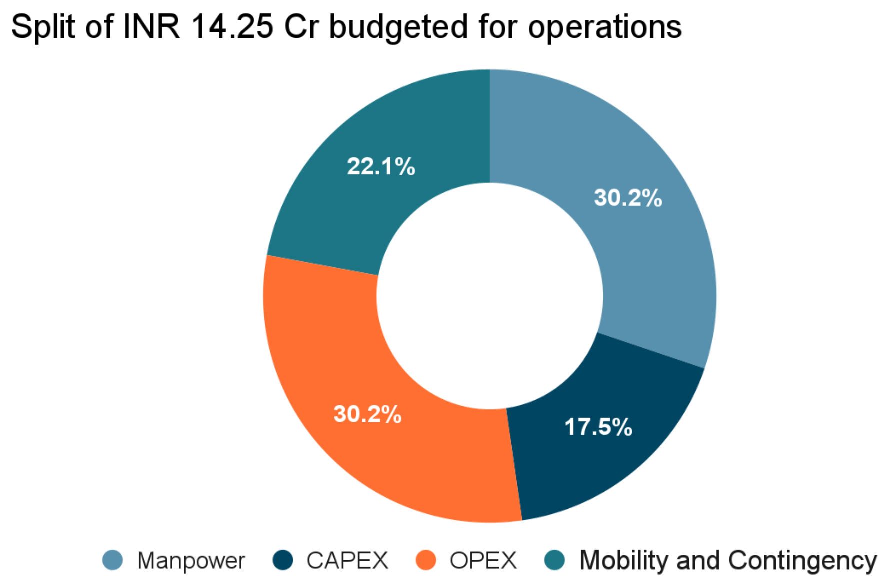
Table 3.1: Various Administrative Roles in IPTIF

Position	No.	Responsibilities

Chief Executive Officer (CEO)	1	Technical Vision of Hub, Industry Liaison, Regional Academic Networks, Startups, Financial and revenue planning
Administrative Associate	1	Execution of Administrative tasks from CEO, Medical/Leave/Allowance management, HR matters and Issues
Finance Associate	1	Financial Trail, statutory procedures, Accounting, Business plans proposals, other business related tasks from CEO
Purchase Associate	1	Getting/handling quotations, purchase orders, invoices, customs clearance, tender matters, payments, stores entry and vendor management
Legal Associate	1	Patenting, IP, Tech transfer, Liaising with Law firm, Equity and loan agreements, MoUs
IT Admin/Associate	1	General IT support, website, network and server setup and maintenance, computer setup and maintenance
Junior Assistants	5	Assisting various associates

3.2 Expenditure

For the efficient management of day-to-day running of IPTIF, for facilitating academic, industrial, and international outreach programs, and for managing the various administrative, financial, and legal functions a total of INR 14.25 Cr has been budgeted for a period of 5 years. A breakup of the expenditures is presented below.



3.2.1 Capital Expenditure (CAPEX)

The Capital Expenditure budget of about INR 2.5 Cr, spread across the first couple of years, is meant for multiple activities. The first set of expenses are related to infrastructure development activity and other allied capital expenditure such as, office partitions, civil modifications, painting, power supply boards. A few other important expenses include logo and website creation, office automation software and networking solutions. The year-wise split is as follows

		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
CAPEX	**Non-recurring**	0.5 Cr	2 Cr			

3.2.2 Operational Expenditure (OPEX)

The OPEX of running TIH-ICS is estimated at INR 4.3 Cr for a period of 5 years. The three major heads under which a large part of the operational expenditure are budgeted are rental, electricity, water and internet charges. The other charges pertaining to operational expenditure consist of maintenance, housekeeping charges, regular civil and electrical/electronics maintenance, hiring of security staff, consumables such as printing, stationary and unforeseen contingency expenditure. The year-wise split is as follows

		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
OPEX	**Recurring**	0.3 Cr	1.0 Cr	1.0 Cr	1.0 Cr	1.0 Cr

3.2.3 Management Manpower Expenditure

A dedicated administrative and management team will be fundamental for the smooth running of the TIH-ICS, particularly for facilitating academic, industrial, and international collaborations and outreach programs of the TIH-ICS, for managing the various administrative, financial, and legal functions of the TIH-ICS, and for planning the financial self-sustenance of the TIH-ICS beyond the initial five years. Emoluments for the various roles in IPTIF as below.

Table 3.2: Salary structure for various IPTIF positions.

Position	**Consolidated monthly emoluments**
Chief Executive Officer (CEO)	INR 2,60,000/-
Associates	INR 60,000/-
Junior Assistants	INR 40,000/-

The year-wise split of management manpower expenditure is as follows

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Recurring	0.3 Cr	1.0 Cr	1.0 Cr	1.0 Cr	1.0 Cr

3.2.4 Mobility and Contingency Fund

Additional expenses such as travel allowances and expert sitting fees are anticipated for the administrative and management activities of the TIH-ICS. To meet such expenses, A total of **INR 3.15 Cr** has been budgeted as a mobility and contingency fund for a period of 5 years. The year-wise split is as follows

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Recurring	0.75 Cr	0.6 Cr	0.6 Cr	0.6 Cr	0.6 Cr

3.3 Evaluation

IPTIF will implement rigorous periodic review mechanisms to ensure that the organization and its employees are working efficiently, and its commitments to

TIH-ICS hub are fulfilled. The following table summarizes the evaluation frequencies and evaluator for personnel, activities and targets of TIH-ICS.

➢ **IPTIF Administration Staff**

Sl. No.	Role	Evaluation Frequency	Evaluator
1	CEO	6 Months	IPTIF Board of Directors
2	All associates	6 Months	CEO
3	All junior assistants	6 Months	CEO

➢ **IPTIF Process and activities**

Sl. No.	Name of the Process	Evaluation Frequency	Evaluator
1	Purchases	6 Months	Evaluation committee constituted by HGB
2	Finance and Audit	6 Months	
3	Infrastructure Development	6 Months	

➢ **TIH-ICS Targets as per tripartite agreement**

Sl. No.	Target	Evaluation Frequency	Evaluator
Technology Development			
1	No of Technologies (IP, Licensing, Patents etc.)	Internal review every 6 months External review every 12 months	Internal by HGB and IPTIF CEO External by an independent evaluation committee constituted by HGB
2	Technology Products		
3	Publications, IPR and other Intellectual activities		
HRD & Skill Development			
4	Skill development	Internal review every 12 months	Evaluation committee constituted by HGB
5	Graduate Fellowships		
6	Postgraduate Fellowships		
7	Doctoral Fellowships		
9	Faculty Fellowships		

10	Chair Professors		
Entrepreneurship & Start-ups for CPS			
11	Grand Challenges and Competitions	Internal review every 6 months	Internal review by TECHIN (IIT PKD TBI) and IPTIF CEO
12	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)		
13	Entrepreneur In Residence		
14	Start-ups & Spin-off companies	External review every 12 months	External review by an independent evaluation committee constituted by the HGB
15	Technology Business Incubator (TBI)		
16	Dedicated Innovation Accelerator		
17	Seed Support System		
International Collaboration			
18	International Collaborations	Internal review every 12 months	Evaluation committee constituted by HGB

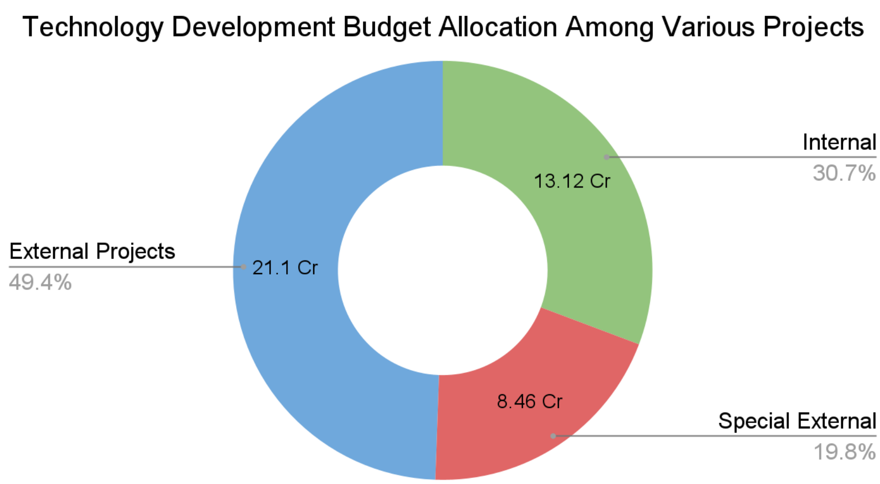
3.4 Legal Framework

The CEO with the help of the legal associate will ensure that all IPTIF activities adhere to the legal requirements of the section 8 company and the Government of India. The products developed under the aegis of the IPTIF will strictly follow both Indian and International laws and standards.

4 Technology Development

The technologies developed in TIH-ICS will target the energy and safety domains. ICS being an amalgamation of robotics, machine learning, networks, embedded systems, computer vision and fundamental theoretical models, the outcoming technology will be spread out in aforementioned application areas, instead of a single application theme. A total of about **INR 42.68** Cr is set aside for technology development. Further, this budget is split into 3 categories as shown in the following figure.

4.1 Strategy



TIH-ICS proposes to support 9 internal projects (from IIT Palakkad faculty members) that together will deliver 14 technologies and 8 products. A number of external projects will also be funded such that even with a 60% success rate of these projects, TIH-ICS will be able to meet the targets specified in the tripartite agreement. The planned technology/product deliverables from the various projects are mentioned in the table below.

Table 4.1: Planned technology and product targets assuming a risk of 60% success rate.

		Year 1	Year 2	Year 3	Year 4	Year 5	Total
Internal	**Technology**	0	2	4	6	2	14
	Product	0	1	2	3	2	8
Special External	**Technology**	0	2	1	1	0	4

	Product	0	0	6	1	0	7
External & Inter-TIH	**Technology**	0	0	4	11	7	22
	Product	0	0	2	6	6	14
Total	**Technology**	**0**	**4**	**9**	**18**	**9**	**40**
	Product	**0**	**1**	**10**	**10**	**8**	**29**

Remark*: All project proposals (internal and external) will be reviewed and approved by an independent evaluation committee constituted by IPTIF. This committee will be entrusted with assessing viability and TRL of the deliverable mentioned in a project proposal. This committee can ask for clarifications and suggest revisions to the proposals. This committee will also ensure that the proposed projects contribute to the year-wise technology requirement, and fit within the year-wise budget allocation.*

4.1.1 Internal Projects

9 internal projects (from IIT Palakkad faculty) that together will deliver ***14 technologies and 8 products***. Year-wise budget allocation for the 9 internal projects (from IIT Palakkad faculty) are presented in the table below.

Table 4.2: Year-wise budget allocation for the 9 internal projects.

In Lakhs	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Recurring	23.01	209.12	270.68	215.03	181.82	**892.66**
Non-recurring	13.74	231.21	77.74	60.74	25.19	**408.6**

4.1.2 Special External Projects

IPTIF would like to augment and diversify its technology development targets by inviting project proposals, in the domain of ICS, from the following established researchers.

Sl. No.	Name	Institute	Area of Expertise in ICS
1	Asokan T	IIT Madras	Robotics

2	Ramkrishna Pasumarthy	IIT Madras	Modeling and control of complex physical systems
3	Arun Mahindrakar	IIT Madras	Nonlinear control
4	Bharath Bhikkaji	IIT Madras	Dynamics and control
5	Jayant Kumar Mohanta	IIT Jodhpur	Robotics
6	Abhishek	IIT Kanpur	Autonomous rotary wing unmanned air vehicles, Inverse flight dynamics simulation with applications to experimentation
7	Mangal Kothari	IIT Kanpur	Autonomous Systems, Nonlinear and Optimal Control, Cooperative Control
8	Ravi Banavar	IIT Bombay	Optimal control, nonlinear control, geometric mechanics

The above-mentioned individuals can send their project proposals to IPTIF after approval of the DPR. All proposals will be reviewed and approved by an independent evaluation committee constituted by IPTIF. This committee will be entrusted with assessing viability and TRL of the deliverable mentioned in a project proposal. ***At-least 4 technologies and 7 products are expected to be delivered by special external projects***. About INR 8.46 Cr is allocated for special external projects spread across 5 years as shown in the following table.

Table 4.3: Year-wise budget allocation for special external projects.

In Lakhs	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Recurring	29.0	214.6	278.1	118.8	0.0	**640.5**
Non-recurring	7.0	125.0	53.8	19.8	0.0	**205.6**

4.1.3 External and Inter-TIH Projects

A total of about **INR 21.1 Cr** is allocated for external and inter-TIH projects spread across 5 years as shown in the following table.

Table 4.4: Year-wise budget allocation for the external and Inter-TIH projects.

In Lakhs	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Recurring	59.0	315.0	476.1	290.1	376.6	**1516.8**
Non-recurring	29.0	50.0	119.2	219.2	175.5	**592.9**

This budget will be used to have targeted calls for proposals, in areas that the Mission, Govt. organizations (public sector units) and the industry feel additional thrust is needed. A technologies relevant to the TIH-ICS theme, Make in India mission and Aatmanirbhar Bharat are:

- Agricultural crop assessment, automated ripe fruit/vegetable extractors, etc.
- Consolidating supply chain of agriculture (data intelligence and apps)
- Surveying of forests, agricultural lands, lakes and wasteland
- Parcel delivery drones for commercial and emergency situations
- Intercontinental seabed fiber optic cable monitoring, servicing, upgradation
- Monitoring of off-shore wind turbines and oil rigs
- Automated cleaning of wind turbines and tall structures
- Self-launching and self-landing lower altitude satellite fleet
- Energy efficient architectures for autonomous electric vehicles
- Elderly and paraplegic assistive devices
- Automated warehousing solutions

These projects would be fulfilled by the engineering teams of the Section - 8 company or through external project proposals.

4.2 Details of Internal Projects

Details of the 9 internal projects from IIT Palakkad are below:

I. IXT: Information eXchange for Things

Investigators: Albert Sunny, Sandeep Chandran, Vivek Chaturvedi

Regulatory and Environmental Risks: None

Technologies to be Developed:

- A reference architecture that enables private entities to enable interoperable services (free for early adopters)
- A mobile application for intelligent logistics and farm management. This will be the prototype end-point for mobile devices.

- An SDK for end-point device developers (for end-points with hardware component in them, library-based end-points)
- A complete system stack (hardware and software) development framework for end-point providers and developers (end-points inside system software)
- An enhanced reference architecture that incorporates learnings from earlier implementation effort, and inputs from industry and academic partners
- A scalable and secure cloud-based implementation of the IXT framework. This implementation will allow monetization of IXT end-point services.
- An integrated farm-to-market logistics solution that leverages the IXT framework.

Startup Opportunities:

- Incubate and spin-off multiple startups that leverage the framework to offer innovative services and solutions to the farming sector.
- Experimental data-sets can be created and licensed (or sold) to researchers and industries that wish to develop intelligent applications.
- Revenue from sale and licensing of reference implementations.
- Consultancy for local government bodies and other companies

Summary:

Modern day cloud computing frameworks allow individuals to seamlessly create services with customized specifications. We envision a similar framework that allows users to create solutions using collaborative systems. The system stack that provided an unified interface for individual system developers is an end-point to our framework. These end-points would have properties such as controllability and observability, and therefore form the ports through which data can be sourced and intelligent solutions can be delivered.

The framework developed above can be deployed in the field of agriculture to solve challenges faced when delivering harvests to customers. The agents engaged in packaging, stowing, loading, unloading, and transportation are the end-points of this collaborative model. Using the data generated by the end-points, we will develop intelligent logistics that warehouse food and deliver products from farms to customers in a quick and cost-effective manner. The primary goal of this logistics solution is to reduce wastages and transportation costs for a farmer, thereby increasing his income. This solution would require monitoring truck movements, pooling delivery and pick-up requests from customers and farmers respectively, and intelligent management of warehouse capacity by managing logistics of perishable and non-perishable food items. This serves as a proof-of-concept of an intelligent solution built using the unified framework. We envisage several other similar solutions for optimizing other agriculture related activities. The objectives of this project are:

- Design and develop the architecture, model, and secure APIs for this framework, along the similar lines of IUDX (https://www.iudx.org.in/explore-iudx/).
- Develop an intuitive and easy to use web-app that developers/users/companies can use to create intelligent solutions using their end-point devices.
- Develop a standard interface that can leverage other co-located services (such as services offered by smart cities).
- Develop and maintain a repository of standard services that users can use for different purposes such as simulations, academic experiments, and rapid prototyping of solutions.
- Design and develop an intelligent application using the unified framework that does the following:
    - Plan optimal location and capacity of storage (dry, wet, or cold) facilities in a geographical region.
    - Predict harvest, and automatically plan associated logistics such as equipment, labor, and transportation.
    - Enables multi-modal and on-demand deliveries with features such as cost and time estimation of deliveries.

II. Cyber Physical Systems in Collaboration with Artificial Intelligence for Smart Agriculture

Investigators: Satyajit Das, Mrinal Das, Sahely Bhadra, Sreenath V

Regulatory and Environmental Risks:
Since the project involves micro UAVs to be operated between 200 feet of altitude, DGCA (Director General of Civil Aviation) clearance is not necessary. The project only involves flying micro UAVs over farmlands which will not cause harm to human life or commercial property due to crashes.

Technologies to be Developed:
The overarching objective is to propose technological innovations, implement them and deliver it to society with the hope that a farmers' income is doubled. In this project we propose to build a complete stack for Unmanned Aerial Vehicles (UAVs) which will scout, track, detect and prevent multiple causes of crop failure such as pests, diseases, locust attacks, weeds, droughts/floods, damages from wildlife.

- **Low cost CPS based surveillance framework**: The UAVs will be mounted with multi-spectral sensors capable of identifying a wide range of parameters such as thermal behaviour, vegetation indices and plant pathogens. An onboard computation unit will communicate with the sensors for near sensor data analytics.A surveillance system will be developed to protect farmlands from animals.

- **Lightweight AI models:** Affordable, large scale and light AI based models will be built for real time detection of already grown plant diseases and early prediction of various kinds of plant diseases and abnormality from photographic and thermal imaging.
- **Incremental Machine Learning models:** An incremental machine learning mechanism will be built that will upgrade itself on a daily basis based on observations on the previous day [7]. Data from multiple sources will be used in a collaborative manner for learning non-linear patterns from noisy data [8].
- **Surveillance data analysis framework**: Signals collected by UAVs will be processed at the server backend. This backend module is powered by deep learning, signal processing, and optimization. Just to illustrate the concept, images sent by the UAVs will be processed by CNN and FFN to detect the presence of pathogens.
- **Hardware-Software codesign framework**: Energy efficient hardware software codesign [9] framework will be developed for UAVs for the following applications in specific.
    - Light but efficient neural network on chip for spatiotemporal hotspot detection of pest and plant disease from image of plant parts and also detection of weed to increase productivity.
    - Early stage disease and paste attack detection is always beneficial to farmers, but is almost infeasible by humans. While machine learning or deep learning based algorithms will be able to learn the temporal pattern in textural and structural aspects of various parts of a plant to detect precursors of some abnormal growth or early stage of plant diseases [5,6].
    - Yield prediction including automatic count of number of mature fruit or vegetables for region specific for better planning for harvesting, storage and marketing.
- **Farmer facing apps:** The entire monitoring and control of farm fields will be provided through easy to use webapps and mobile apps.
- **Setting up a multimedia Database Management System:** a stream of large numbers of information from visual, sound and other sensors will be stored, indexed, preprocessed, and retrieved efficiently.

Startup Opportunities:

As part of Startup India initiative and TIH activity, the plant pathogen detection system will be transitioned to a startup in the third or fourth year, by which we expect to be at

TRL-3. The market and employment opportunity is immense, as manufacturing, maintenance of surveillance systems in smart agriculture will generate a lot of business catering to pressing needs in India.

Summary:

Agriculture is the backbone of our country, with more than 70% of the population directly or indirectly involved in it. To become a truly self-sufficient country, there is an enormous responsibility on this sector to feed the huge population. Moreover, this sector contributes to 18.1% to the overall GDP and possesses much more potential to contribute to the growth of the nation [1] [2]. However, there are several challenges in this domain: (i) reduction in farming land, (ii) ageing of farmers, (iii) increasing pest attack, (iv) plant pathogens. Some of these challenges can be addressed with the help of technological innovations.

Artificial intelligence (AI) and cyber physical systems teaming up together can foster higher crop yields, better pest detection and management, seamless and efficient surveillance of farmlands. This is the central theme of this project (Figure 1).

This project aims to employ machine learning models to learn about potential plant pathogens, production quantity, optimizing various processes in the supply chain and shorter farm-to-market time strategies. The effectiveness of the AI techniques depends heavily on the data acquisition. Cyber-physical systems and Internet-of-Things (IoT) can act as channels between real objects and AI systems to capture information and signals and perform responsive actuation prescribed by the AI systems.

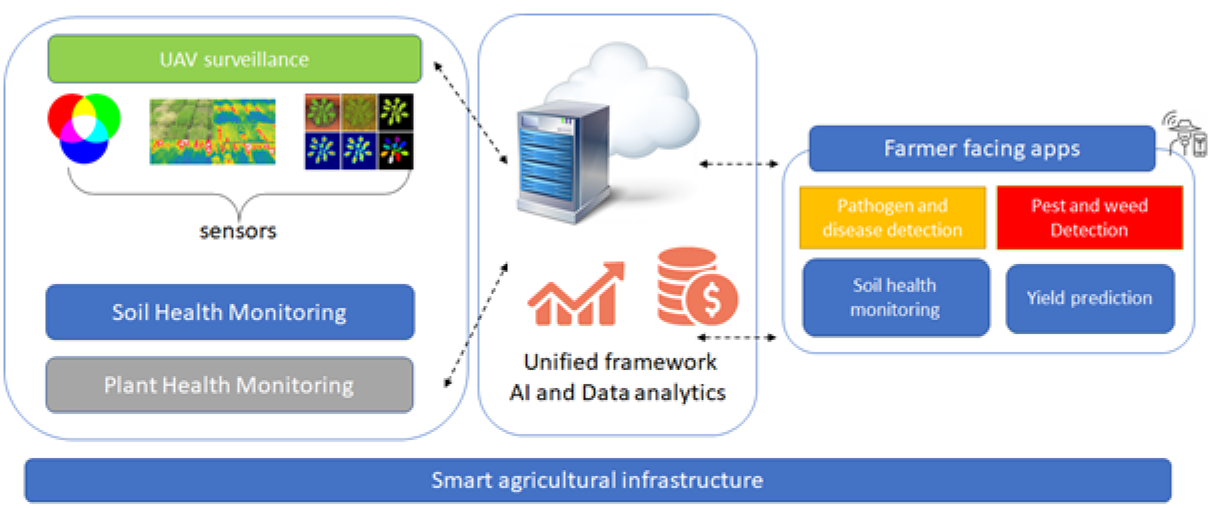


Figure 1: Theme of the project

On the one hand, automated surveillance of the farmlands will help to detect upcoming diseases, locust attack, flood, damages from wildlife. Continuous surveillance requires a highly energy efficient computing stack [3] and lightweight machine learning models for better efficiency. On the other hand, interconnecting existing and new models (e.g., crop, soil, water and weather), creating public-private spaces for data sharing, and developing technologies will create data-based assets that can be used to optimize agricultural productivity and the food pipeline all the way to consumer demands.

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III. Energy Efficient Distributed Estimation and Control of Networked Robots and its Implementation Architectures

Investigators: Shaikshavali Chitraganti, Subrahmanyam Mula, Vijay Muralidharan, Sneha Gajbhiye

Regulatory and Environmental Risks: None

Technologies to be Developed:

- Algorithms would be developed for efficient distributed estimation and they will be implemented on FPGA platforms.
- The developed FPGA prototypes would then be deployed on the real time wheeled mobile robot setup.

Startup Opportunities:
The developed technologies can support real-time data processing with high energy efficiency and thus can support a range of applications. They would be indegenious and quite generic in nature in a sense that it can be applied to any dynamical system, apart from wheeled mobile robots, performing applications such as precision agriculture, surveillance of a certain territory, and a group of autonomous vehicles involved in strategic applications. Any startup opportunity in these areas can be explored.

Summary and Objectives:
Networked control systems have been receiving a lot of attention due to increase in the applications of autonomous vehicles, swarms of robots etc [1],[2], which are also termed in general as multiagent systems, communicating via a network for a coordinated operation. Usually the state of the system is estimated via a remote estimator or local estimators using the measurements transmitted by sensors of each of the agents, which are powered by batteries with limited energy. Towards effective usage of battery, there have been efficient measurement scheduling and transmission mechanisms [3],[4], broadly called event based scheduling, the resulting state estimation problems are not trivial, because the estimator does not have the measurements at each time instant.

In general apart from the usual additive process noise and the measurement noises, multiplicative noise also appears in the measurements in many scenarios, for instance in fading or signal reflection [8]. Further there is a possibility of correlation between additive process and measurement noises at the same or one epoch apart [6], [7], [8]. For such various noisy conditions and event based transmissions, state estimation has been addressed in [1], [4], [9], [10], [11] etc. On the other hand, in a networked system to utilize the spatial information of each agent, distributed estimation has been employed. Different from the single agent case, in distributed estimation, for a given agent, not only its measurement is used, but also the neighbouring agents measurements are also used to obtain its state estimate in [12], [13] etc, and in the event based framework [14]. So far the distributed estimation in various noisy conditions with energy efficient sensor transmissions are yet to be addressed. In addition, these subsystems are often battery powered, which demands energy efficiency at the architecture level also. Further VLSI implementations of such estimators are yet to be explored in literature to the best of our knowledge. Dedicated VLSI architectures are needed for the implementation of the most computationally complex estimation algorithms [15-18]. Traditionally, estimation algorithms and their VLSI implementation have been somewhat isolated from each other. While algorithm designers focus on improving the performance as the case of event-based estimation, VLSI designers strive for implementation flexibility, which results in long transition time from algorithm to its final VLSI implementation. The proposed research aims to bridge the ever-growing gap between estimation algorithm design and its implementation using a holistic approach that spans the architecture, circuit design, algorithm, and theory levels. Thus, the first step in this project is to study the existing estimation algorithms in the VLSI implementation prospective, reformulate them to make them VLSI friendly without degrading the performance. Second step is to explore the design space for implementing the reformulated algorithms for area, throughput and power. Fixed point bit width analysis for the required accuracy in estimation performance needs to be analysed at this stage. Different architectural techniques such as pipelining/parallel processing would be explored for achieving the required energy efficiency without hampering the throughput. Circuit level power reduction techniques such as clock gating and power gating would also be explored to reduce the power consumption further. Finally, the architecture would be implemented in FPGA platforms to obtain the actual numbers on silicon area, throughput and power consumption and the prototype would be used in the network control system to evaluate its real-time performance. The objectives of this project are

- Obtain a mathematical model of networked wheeled robots and devise a transmission scheduling of measurements.
- For a networked robots, developing distributed state estimation algorithms in various noisy environments with energy efficient measurement transmissions
- To reformulate the distributed state estimation algorithms to make them VLSI friendly and to design VLSI architectures for the reforumated algorithms. Compare with the existing results in the literature with the setup designed
- To Implement the designed VLSI architectures on FPGA platforms and deployment of the developed FPGA prototype in a practical application setting.

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IV. Development of Low-altitude Microsatellites Using Long-endurance Glider-plane Collaboration

Investigators: Vijay Muralidharan, Sneha Gajbhiye, Shaikshavali Chitraganti, Anirudh Guha, Arun Mahindrakar, Ramkrishna Pasumarthy

Regulatory and Environmental Risks:

Since the project involves flight in airspace, DGCA (Director General of Civil Aviation) clearances have to be obtained. The process is laborious and would be undertaken after consistent flight endurance at lower altitude flights. The project also involves flying over human population, which may cause harm to human life or commercial property due to crashes. To avoid this, the weight and size class will be kept sufficiently small to mimic a micro satellite as well. Though Airbus and Boeing have achieved endurance solar planes, their size and weight are significantly high, hence a big obstacle for mass autonomous deployment. Since we have deviated from their solution in size and weight, it opens up a whole array of challenges which is very novel to solve. The glider will also use communication technology, hence subjected to suitable electromagnetic compatibility tests.

Technologies to be Developed:
As we describe the functionality requirement of the glider plane, we realize several challenges that the aircraft will face, and we will granularly split these into individual products. The glider will have to climb to stratosphere elevation, thereby facing extreme temperatures (-75 to 60 degree Celcius), possible ice formation, higher solar radiation, wide wind velocity (0-220Kmph), turbulence, etc. These challenges gives out the following subsystems:

1. **Military grade, wide temperature range bidirectional power converter:** Since we are proposing the propellers would act as a wind turbine in some regimes, there is a need for power to be continuously transferred in either direction safely to charge the battery. In the case of cars, the regenerative braking system only works for a small period of time, but a power converter which works equally as a motor driver and as a power charger would be a good product.
2. **Miniature redundant aileron actuators:** The vibrations, wind gusts, possible ice formation will be risky to actuator failure. Hence redundant drive actuators in miniature size have to be developed for aileron drive.
3. **Solar panel heat redistribution:** The solar panels will have raw heating due to low efficiency, this heat should be used to maintain safe temperatures for the batteries, electronics, sensors, etc. Design on a miniature scale is going to be a novelty.
4. **Miniature wing for extreme conditions:** Proper material selection and wing design, with simulations at extreme temperatures, humidity and vibrations has to be performed. These will have to be tested out in a wind tunnel type of facility.

Startup Opportunities:
Short term: Manufacturing of propellers and brushless electronic speed controllers are not done in India, and this is a major import item from China. As part of the

Make-in-India initiative and to avoid dependency on monopoly suppliers, we can design and manufacture this locally at similar pricing as global.

Long Term: As part of Startup India initiative and TIH activity, the glider technology will be transitioned to a startup in the third or fourth year, by which we expect to be at TRL-3. The market and employment opportunity is immense, as manufacturing, maintenance and operations of a fleet of self-launching/landing micro satellites will generate a lot of business, cater to very essential needs (communication and surveillance) and boost research in aircraft design in India.

Summary:

The launch and operations of low earth orbit (LEO) satellites involves several unrecoverable and unserviceable aspects. Significant percentage of rockets are not reusable, the launch costs are high and the launched satellites are rarely serviceable or upgradeable. The communication satellites help in establishing GPS, communications, broadcasting and meteorology, but are already becoming increasingly crowded and initiating a major international debate on space debris generated due to inactive satellites. Even if reusable launch vehicles and space servicing is realized, the operational costs of such missions would be higher (rockets and fuel) and wouldn't solve the space debris issue to a major extent. New emerging technologies such as long endurance balloons and airplanes are ushering a new era of satellites. These satellites would operate at lower altitudes from 20-60Km altitude (outside commercial airspace), would be self launching and landing and hence enabling servicing and upgradation. Further, the rapid emergence of small communication and surveillance equipment enables even smaller aircrafts to act as good satellites, as the losses would be much lower at lower altitudes. Some of the examples are:

Balloons:

- Altaeros (http://www.altaeros.com/)
- Google Loon (https://loon.com/)

Solar winged aircrafts:

- Helios(https://www.nasa.gov/centers/dryden/history/pastprojects/Helios/index.html)
- Solara (https://www.aerospace-technology.com/projects/solara-50-atmospheric-satellite/)
- Airbus Zephyr (https://www.airbus.com/defence/uav/zephyr.html)
- Boeing Odysseus (https://www.aurora.aero/odysseus-high-altitude-pseudo-satellite-haps/)

The balloons have a challenge of maintaining a geostationary position or local orbit, which makes the challenge of providing communication a hopping phenomenon, also are the challenges to availability of free helium in a longer run. Solar winged aircrafts are a good option, but they rely heavily on solar power to maintain the long endurance, which has theoretical and practical limits on photovoltaics. Our idea is to move away from rigid structures and into flexible structures, enabling a kite/glider plus sky sail type of movement. This idea is derived from combining four major ideas, (i) flight of the albatross (like a kite/glider) which has intrigued several researchers all over the world [A1, A2, A3, A4, A5] and accomplishes it using dynamic soaring in horizontal shear gradient and (ii) three dimensional local orbiting by having only attitude control phase and capturing the wind energy as electricity in part of the orbit (iii) sailing of boats [A6, A7, A8, A9] which uses the sail to create a forward propulsion when sailing at an angle with the wind and lastly (iii) flapping of wings for redirectional forward thrusting instead of fully utilizing propellers [A10, A11]. The best optimum configuration combining all four ideas will be modeled and simulated. All these are hypothesized only in a steady state, which is why an active closed-loop control, aerodynamic parameter estimation and trajectory generation for stable periodic orbits are required to maintain a steady geostationary local orbit. Once these objectives are accomplished, the wind based self propulsion and stationkeeping will augment solar power in a major way.

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V. Design, Development and Control of a Multi-purpose Mobile Manipulator for Intelligent and Collaborative Manipulation Tasks

Investigators: Santhakumar Mohan, Vijay Muralidharan, Sneha Gajbhiye

Regulatory and Environmental Risks:
Since the project involves testing of the aforementioned control algorithms on ground based wheeled mobile robots with manipulator (arm) systems, there is no regulatory or environmental risk posed.

Technologies to be Developed:

- Detailed mechanical design and functional prototype of a modular mobile (vehicle) manipulator system for generalized and intelligent intervention tasks.
- Simplified and feasible motion control scheme for the mobile manipulation tasks.
- An interactive graphical simulator would be developed by considering the various operating conditions.
- Fully functional prototype for multiple task associated missions.

Startup Opportunities:
This work would lead to the design and development of a mobile manipulator system along with investigations on analysis and experiments on CPS from a motion control system and validation point of view. The research would lead to developing functional prototypes, interactive graphical simulators for the motion control designs and a possible hardware setup in CPS. Therefore, it will definitely provide a room to bring a firm which fabricates fully functional mobile manipulators based on the customer requirements. It leads to an autonomous mobile robot space and grabs a good market in the near future.

Summary and Objectives:
In the current scenario, industrial robots have made significant contributions toward automating the manufacturing processes. The efficient use of robotic systems shows a

significant improvement in productivity and quality, and reduction of production cost. However, most of these industry robots perform simple repetitive tasks, namely pick and place, machine loading and unloading, spray painting and spot welding, etc. On the other side, mobile manipulation is one of the integral parts of modern day manufacturing technology and playing as a giant in the economic sector. The autonomous mobile robot, a mobile robot with one or more manipulator arms, is attracting various service and field sectors which includes industry warehouses to agricultural fields. At present, automated mobile platforms have become a major part of human life since they are extensively used in industrial, domestic, agricultural, educational, research, defense, etc. Some of the most common examples are wheelchairs, service robots, rescue robots, medical robots, surveillance mobile robots, robots in warehouses, etc. that aim at facilitating human physical disabilities, robots in warehouses for inspection, monitoring crowds, product handling in factories, patrolling the border, etc. However, to be able to perform the tasks effectively and safely, the mobile robot must be robust enough and versatile to move quickly in any direction even in occluded space in a dynamic environment.

In addition, the most successful control systems on earth are biological ones. Robotic systems are being designed to mimic human behaviour such that their applications can make inroads in service sectors such as elderly care, smart home and smart super-market. The effective way to make a robotic system more human like is to embed human like intelligence in robotic systems as well. This mandates that the controller learns the system dynamics as well as the control actuation with minimum information about the system and environment.

A mobile manipulator with a robotic hand which has 9 DOF or more has not been rigorously studied in the learning based paradigm. This proposal will comprehensively investigate the empowerment of such robotic devices through learning. Thus in this proposal, a sincere endeavor will be made for scientific contributions both in learning theory and smart/intelligent robotic systems.

The objective of this project are as follows:

- To develop a detailed design, solid model (for all components) of a nine degrees of freedom (dof) (3-dof vehicle/mobile base + 6-dof manipulator arm) multi-purpose mobile manipulator and derive a detailed mathematical model for the proposed modular mobile manipulator.
- To develop a dynamic simulation model for the proposed mobile manipulator and analyze the overall system performance at different operating conditions.
- To develop a suitable semi-autonomous motion control scheme through a tele-operation mode for tracking, positioning and various mobile manipulation tasks.
- To develop optimal redundancy resolution controllers: The mobile manipulator

system will be represented as an input-affine system. Real-time optimal redundancy resolution strategies will be worked out using single network adaptive critic networks. Development of learning algorithms for critical convergence will be vital for this goal.

- To develop soft-computing based learning architecture that will be able to mimic a human trainer that will speed up the training.
- To investigate the feasibility and performance of the motion and force hybrid controller under different operating conditions and external disturbances.
- To develop a prototype and perform an experimental verification of the system performance.

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VI. Design and Development of an Intervention Class Underwater Robotic Vehicle with Tilting Thrusters for Marine Applications

Investigators: Santhakumar Mohan, Subrahmanyam Mula, Shaikshavali Chitraganti, Sneha Gajbhiye

Regulatory and Environmental Risks:
Since the project involves testing the feasibility of the proposed vehicle design and testing of the aforementioned control algorithms on an underwater vehicle (robot), there is no regulatory or environmental risk posed.

Technologies to be Developed:

- Detailed mechanical design and functional prototype of an underwater robotic system.
- Simplified and feasible motion control scheme for the autonomous underwater vehicle for the trajectory tracking task.
- An interactive graphical simulator would be developed by considering the various operating conditions.
- Fully functional prototype for underwater exploration.

Startup Opportunities:
This work would lead to the design and development of a new intervention class underwater robotic system (or vehicle). The mechanical design and the motion control design along with function prototype verification will provide a brighter way of making this vehicle development based on the customized design can bring opportunities to a startup. Further, the underwater vehicle control along with sensor integration and navigation will provide an opportunity to startup a service provider in this domain which is lacking at this point. Therefore, this project work will definitely provide a room to bring a firm which fabricates fully functional underwater robots based on the customer requirements. It leads to an intervention-class underwater vehicle domain and grabs a good offshore installation and inspection market in the near future.

Summary and Objectives:
The earth is covered with 70 percent of water, yet humans could explore only 05 percent of oceans and 01 percent of the ocean surface with great uncertainty. On the other hand, space technology advanced to a level where rovers could land on Mars and leave the footprints of man on the moon. This is due to many reasons, such as an unstructured,

hostile marine environment makes it difficult to understand and especially exploring these areas is expensive and time-consuming. In order to tackle these shortcomings, Human Occupied Vehicles (HOVs) and Remotely Operated Vehicles (ROVs) are developed and deployed to accomplish missions such as seabed surveys and profiling of oceans, submarine cable maintenance, offshore erections monitoring and maintenance (J. Yuh, 2000). The present scenario of the advanced underwater technology demands reliable and specialized vehicles for mission-specific applications and completely autonomous operation. Better autonomy increases the complexity in the vehicle control, navigation and guidance due to the nonlinear, time-varying and coupled dynamic behavior of the subsystems (Kim, 2015).

The offshore oil & gas industry is a complex innumerable of advanced equipment, structures, and workforce. With a proper knowledge of offshore oil and gas rig environments, the applications of industrial robotics and automation are less abstract. Before any real vision of the potential roles robotics and automation in offshore oil processes can emerge, those processes must be enumerated appropriately. The underwater manipulator, as an important piece of equipment for underwater vehicles, plays a crucial role in underwater applications. Underwater Vehicle-Manipulator System (UVMS) is an underwater vehicle system mounted one or more manipulators to complete certain underwater tasks. With the increased interest in the development of undersea intervention technology in the fields of offshore oil and gas industries, many approaches have been presented to improve undersea intervention capability of UVMS (Antonelli, 2006; Cui and Sarkar, 2001; Marani et al., 2009; Yuh, 1995). Currently, the state of art of the underwater manipulator is represented by remotely operated vehicles with manipulators through master/slave schemes by human pilots (Cui and Sarkar, 2001). This human-piloted scheme causes several operational difficulties, inaccurate trajectory tracking and force control, time delay in the man-machine control loop, and fatigue and performance of the human operator (Cui and Sarkar, 2001). Some of the above mentioned difficulties can be overcome by the use of autonomous manipulation, which considers the nonlinear and coupled dynamics between the underwater vehicle and manipulator systems. In fact, the UVMS operations typically involve manipulation tasks in the presence of parameter uncertainties, sensor noises and external disturbances (e.g., underwater current). This requires the system control to be more robust in terms of compensating external disturbances and sensor noises, and feedback control is performed using the information on the system states that can be obtained partially from the available measurement sensors and the parameter states that are generally not available explicitly. The UVMS consists of an underwater vehicle (UV) and one or more manipulators (i.e. n dimensional) and becomes a kinematically redundant system when it has more degrees of freedom (DOF) than is required to perform a task in its space (i.e. m dimensional). This actuation redundancy due to the extra DOFs provided by the vehicle and the onboard manipulator, allows the system to achieve increased flexibility for the execution of sophisticated underwater tasks. In general, the vehicle and the manipulator of the UVMS used to be controlled individually rather than as a whole without using the redundancy in the system (Yuh, 1995; De Wit et al., 2000; Antonelli et al., 2004; Yatoh et al., 2008; Santhakumar and Kim, 2012; Taria et al., 2012; Xu et al., 2012; Santhakumar, 2013a; Antonelli, 2014; Pandurang et al., 2017a; Pandurang et al., 2017b;). However, these redundant DOFs of the UVMS can be used by considering the UVM system as a whole for planning more flexible and energy-efficient trajectories. For example, using the system redundancy, the motion of the vehicle and the manipulator can be coordinated simultaneously, and in addition, its extra DOFs can be used to assign additional motion without violating the end-effector's (task space) functions since the velocity of the end-effector in the null space (i.e. n-m) of the Jacobian (transformation matrix) will not affect the task space velocity. This fact is commonly referred to as self-motion since it does not induce any motion in the task space and thus can be used to improve the UVMS performance such as minimizing energy requirements, satisfying motion constraints, etc.

In Indian scenario, National Institute of Technology (NIOT) had developed a deep water work class Remotely Operated Vehicle (ROV) ROSUB 6000 which was suitable for exploration in deep waters. It was successfully operated at a maximum depth at 5,289 metres in the Central Indian Ocean Basin. It also contributed to the exploration of deep ocean minerals such as gas hydrates, polymetallic nodules and hydrothermal sulphides, which occur at water depths ranging between 1,000 and 6,000 metres, said a communication from the institute. This vehicle is mounted with two 3-DOF manipulators for intervention operations. Another miniaturised ROV was developed for exploration and inspection up to 500-metre water depths, caters to the needs of the research community and industry. It was also deployed for scientific research in Antarctica as a part of the 34th Indian Scientific Expedition to Antarctica during Jan-Apr 2015. It was deployed in the Lake Priyadarshini near the Indian permanent station Maitri and in the New Indian barrier ice shelf regions. This vehicle is mounted with a 1-DOF manipulator. Though ROVs with similar depth rating and capabilities are available in the international market, many of them were not suitable for polar conditions. Similarly, AUVs in India with intervention capabilities are not reported so far.

Design, develop and fabricate an underwater robot with four tilting thrusters to achieve six degrees of freedom to perform complex intervention tasks through autonomous/semi-autonomous mode which targets

- an intelligent motion controller using redundancy resolution schemes.
- to perform complex tasks such as underwater pipeline inspection (inside and outside), drilling, manipulating 3D objects, cutting, sample collection, etc., in 3D space.
- to perform obstacle/collision avoidance and improve its motion and force control performance during its operation.

The objective of this project are as follows:

- Detailed design of a six DOF multi-purpose vehicle and derive a detailed mathematical model.
- Simulation model for the vehicle and analyze the overall system performance at different operating conditions.
- A suitable autonomous/intelligent motion control scheme for tracking, positioning and various deep-sea operations such as inspection, valve opening, drilling, etc.
- To investigate the feasibility and performance of the motion and force hybrid controller under different operating conditions and external disturbances.
- To develop a behaviour based fault tolerant control for the actuator faults (thruster faults)
- To develop a prototype and perform an experimental verification of the system performance.
- To validate the proposed multipurpose underwater vehicle under different deep-sea operating conditions.

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VII. Aerial Dexterous Manipulators, Grasping and Transportation

Investigators: Sneha Gajbhiye, Vijay Muralidharan, Santhakumar Mohan, Shaikshavali Chitraganti

Regulatory and environmental risk:

The current regulatory policy from the Directorate General of Civil Aviation (DGCA) regarding the use of drones classifies based on their total weight with cargo and batteries for commercial/personal flying. Rotorcraft with a dexterous manipulator and end-effector (RM) assembly falls in the Small (from 2kg to 25kg) category. Under this policy, to fly outdoor requires clearance at the institute level on Digital Sky Platform from the Unmanned Traffic Management (UTM) system. The initial testing of the Rotorcraft-Manipulator-Load system will be performed in an indoor motion capture environment with proper safety gears on rotorcraft blades to protect any damages on rotorcraft and to the remote pilot due to direct or indirect strikes. Since the work involves indoor testing of the control algorithms, there is no regulatory or environmental risk present.

Technologies to be developed:

- Rotorcraft with dexterous manipulator and end-effector (RM) assembly to capture a heavy payload object (3-5 kg weight) would be developed to demonstrate grasping and deploying of load in the range of a few meters.
- To build an autonomous aerial transportation system that not only results in easy maneuvering keeping the desired formation but also preserves robustness while in-flight load variations.
- The novelty of the proposed project is based on the strong theoretical foundation of ideas which will result in new motion algorithms and observer designs for motion estimation. Keeping the coordination in theory and implementation, we will test the resulting control algorithms exhaustively.

Startup opportunities:

This project leads to the design and development of drone with dexterous manipulator with target payloads has immense industrial and commercial applications. The research would lead to the fabrication of the prototype and design of control algorithms for grasping, navigation, and deployment of payload. This design and development of the assembly will provide startup opportunities for developing low-cost drones with target payloads based on customer requirements.

Summary:

Rotorcraft UAVs have great three-dimensional agility and mobility like vertical take-off and stay hovering. Due to which they overcome other unmanned aerial vehicles and ground vehicles in many applications. In the last decade, significant progress has been made in research and development of rotorcrafts involving physical contact and interaction tasks with the environment, such as cargo transport, load deployment, sampling, aerial grasping or even aerial manipulation mainly using rotary-wing platforms. They can accomplish unapproachable sites/terrains due to their agility; they can also deploy as an emergency rescue on the natural disaster sites. They are also seen in pandemic situations and in agriculture applications by improving field efficiency and decreasing task completion time.

While the aerial manipulation has several applications and potential, it has its own challenges. The grasping of an object by flying rotorcraft raises several problems due to both the unstable dynamics of the vehicle and the coupling effects given by the presence of the object. Similarly, a mounted manipulator provides even more issues since its dynamics depend on the actual configuration of the whole state of the system. [MQSK11] addresses the static equilibrium problem of a grasped payload at a desired pose, as well as the consequent stability analysis.

Maintaining hover over a target object and aligning with it accurately enough to capture is challenging due to aerodynamic disturbances encountered in low altitude flight. The aircraft manipulator must be tolerant to accidental end-effector contact with obstacles and must reliably grasp objects without transmitting destabilizing forces in the airframe [PBD11, B92, KO08]. Initially, fixed claws are incorporated under the low capacity rotorcraft platform allowing the system to carry lightweight and small size objects [G14, TWHAI15]. However, during hovering the uncertainty in end-effector position maneuver and restricted motion of claws made accurate grasping difficult. To face this problem, solutions like magnetic devices, hook as an end-effector, or using articulated claws do exist [B92,YL14,KSSLMO13]. Although these options have the advantage of extending the range of applications to the robotic system, there is significant increase in onboard weight, which is difficult to afford by conventional UAVs. This fact has led to the use of multi-jointed manipulators [JMHOC13] which proved critical in terms of restricted joint actuation power rating, weight of the joints and limited payload lifting capacity.

When working with rotorcraft in most cases the experiments are performed in indoor testbeds equipped with multi-camera real time motion capture systems, which provide very accurate attitude and position estimation. Usually, the small size rotorcraft are used in these indoor testbeds, which have a limited workspace. Due to small size of rotorcraft, manipulator load and the object load is small, limiting the applications range and the manipulation ability. In this project we proposed to design and develop a large payload outdoor aerial manipulator and using motion capture system for initial calibrations and testing for initial flight maneuvering.

Objectives:

To design and develop Rotorcraft and dexterous Manipulator with end-effector (RM) assembly to capture an object (3-5 kg weight) for the purpose of transportation services. The task includes grasping the object by the end-effector, transporting the object and deploying safely to the desired position. This includes cooperating with other rotorcraft manipulators to grasp the heavy payload. Once the load is placed the RM returns back to the starting position and the cycle repeats. The objective has following tasks:

- To develop a system model through mathematical modeling by considering Rotorcraft-Manipulator-Load (RML) as a multibody-system with the attitude of RML as fully actuated. This is achieved by decomposing the pose (total attitude of RML and load position of the end-effector) of the RM system into two decoupled dynamics.
- Fabrication of a dexterous manipulator with actuations and sensors onboard.
- Design of rotorcraft and manipulator assembly with GPS and estimation sensors for outdoor positioning and onboard computer for autonomous operation.
- Synthesizing and implementing hybrid control laws for end-effector trajectory tracking. The controller acts in three stages depending on the center-of-mass of the RML system, that is, load take-off control, stabilization and deployment on the desired location. While synthesizing and implementing, the rotorcrafts are able to estimate change in mass/inertia/parameters and adapt it for better tracking performance. We will also investigate the feasibility and performance of the motion and force hybrid controller under different operating conditions and external disturbances.

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VIII. Real-time Monitoring and Control of Road Bridge Structure

Investigators: Sanjukta Chakraborty Shaikshavali C, Santhakumar Mohan, Sneha Gajbhiye

Regulatory and Environmental Risks: None

Technologies to be developed:

- Development of suitable control strategy for the real time identified parameters of the structural system
- Development of the testing protocol considering the proposed algorithm for a real life application of the developed technology.

Startup Opportunities:
The proposed technology helps in extending the bridge life by increasing the reliability of the structure. It is often observed that the aged over bridges are prone to abrupt failure because of their degradation in load carrying capacity and at the same time increase in the daily traffic load. Such developments have immense efficacy for such structures and preventing failures. The same strategy can be used for other types of structures subjected to degradation due to age like buildings, stadiums, and different types of tall structures.

Summary and Objectives:
In recent times, there are many cases of sudden collapse of road bridges that came to an end of their service life. The bridges underwent a sudden failure because of the rapid degradation towards the end of their service life and due to simultaneous increase in the traffic load. This implies the importance of a constant health monitoring of the aged over road bridges throughout their intended lifetime to specify the reliability of the structure [1]--[6]. In the present time, there are bridges subjected to regular monitoring. However, the challenge lies in integrating the data for the accurate assessment of the modified structural parameters and providing the reliability of the structure. Furthermore, the bridge structures are exposed to a wide spectrum of excitation environments such as the regular traffic loads along with uncertain events like wind or earthquake. Adaptive closed loop control design based on the existing structural parameters enhances the structural responses and can be accomplished by additional active or semi-active devices such as MR dampers [7]. However, in case of an abrupt change in the structural property, optimum design of controller is also modified. Past studies on smart structural systems shows that in such cases the classical control design

philosophy is unable to perform satisfactorily and even affects the system adversely by amplifying its responses [8]--[12]. Thus, one can understand that the development of an adaptive real time control strategy based on the modified structural parameters as assessed in real time from the monitored data is having huge significance in avoiding the sudden failure of old bridge structures in service. In this study, a coupled control based on the real time monitoring of structural parameters is proposed. At first a measured vibration output based technique to identify the modified structural parameters is implemented. Measured outputs as considered in terms of the structural frequencies and the mode shapes, provide an estimate of the degraded structural properties and also additionally helps in identifying the damage locations inside the structure. Further, based on the online structural parameters identification, the optimum design of the controller is considered. Classical control in case of any abrupt change in the structural parameter provides poor response enhancement and sometime instability. Therefore, a real time identification and control using neural networks based on the system classification technique is considered in the study. The objectives of this project are

- Real time assessment of structural parameters based on monitored data.
- Development of a real time optimal control strategy for the bridge structure based on the real time identified parameters for systems exposed to a wide spectrum of excitation environment.
- Comparative assessment of some of the popular existing classical control mechanisms with respect to the proposed control law.
- Optimizing the location of the output sensors to achieve the best parametric identification along with the observability.
- Experimental model testing for proposed coupled strategy

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IX. Surrogate Safety Measures for Predictive Intervention for Safety on Inconsistent Roads with Heterogeneous Traffic

Investigators: B. K. Bhavathrathan

Regulatory and Environmental Risks: None

Technologies to be developed:
- A new SSM considering traffic heterogeneity.
- Sensitivity analysis of SSM thresholds by predictive intervention feedback into the simulations.

Startup Opportunities: None

Summary and Objectives:
Intelligent collaborative systems can proactively intervene to prevent crashes, either by warning road users of potential crashes ahead of time, or in case of autonomous vehicles, by performing with lateral or longitudinal driving action. Such warnings could be targeted warnings delivered to on-board devices, wearable devices, etc. or broadcast warnings from infrastructure mounted devices. Regardless of the delivery mode, they require computation of crash risk for every moving entity on the road. Surrogate safety measures (SSM) can be used for computing such crash risks based on trajectories predicted ahead of time. However, research gaps exist in the context of inconsistent roads with heterogeneous traffic (IRHT).

Firstly, since a single universal SSM applicable to all classes is yet to be identified, the relevance of different SSMs would be different for different locations and road-user classes. Therefore, appropriate SSMs are to be identified based on the location and the road-user class. Also, thresholds for the SSMs would vary based on location and road-user class. Hence, the threshold levels are also to be established and preloaded to the intelligent systems which can then intervene such that the false-alarm ratio is minimized.

The objective of this research is to identify appropriate SSMs based on location and road-user class, and to establish thresholds for employment in intelligent collaborative systems targeting predictive intervention for safety on inconsistent roads with heterogeneous traffic. The following steps are envisaged as the broad research methodology:

1. Review of various existing SSMs and available methods for the comparison of SSMs.
2. Calibrate microscopic traffic parameters for different traffic conditions on typical IRHT segments.
3. Compute SSMs based on simulated trajectories of different traffic conditions on typical IRHT segments.
4. Compare SSMs with simulated driving behavior to prioritize SSMs on different locations based on similarity indices with respect to driving behavior.
5. Investigate the relevance and propose a new SSM considering traffic heterogeneity.
6. Sensitivity analysis of SSM thresholds by predictive intervention feedback into the simulations.

4.3 Details of Special External Projects

A few project proposals for special external projects are as follows:

I. High power density switched reluctance motor and drives

Investigators: Ramkrishna Pasumarthy (IITM), Vijay Muralidharan (IITPKD), Arun Mahindrakar (IITM), Bharath Bhikkaji (IITM)

Regulatory and Environmental Risks:

The project involves high power electronic circuits which can cause electromagnetic radiations and harmonic emissions on the conducting lines. These phenomena are subject to regulations to avoid harm to the humans and the power grid. Safety standards such as IEC 61508, CISPR 11 (EN 55011), IEC 61000 (harmonic emissions/susceptibility, ESD, surge, voltage dips, etc.) will be studied and suitable tests will be carried out to improve/ensure device compliance.

Technologies to be Developed:

Switched reluctance motors in the power levels of 2-20 Kilowatt will be developed, with 1-2 key power ratings depending on the market requirements. Smaller trucks, bikes and auto rickshaws have a power level in the range 2-20 Kilowatt. In addition, we can also look at heating, ventilation and air conditioning (HVAC) requirements in the 2-20 Kilowatt range. Switched reluctance motors can also be used as generators, and the power levels we are targeting will give rise to micro wind turbines.

The switched reluctance motors or generators require continuous control and power electronics to function as motor/generator. So designing of lower cost power electronic drives and control of the electronics and the motor generator will be the next vertical of technology. Use of most recent developments in high voltage, high current and high switching speed MOSFETs will also be explored to create a power converter system which will work on high voltage and relatively low current to reduce the resistive power losses.

Startup Opportunities:

The motors, generators and power electronics will be licensed to electric vehicle startups/industries, HVAC industries, and windmill designers.

Summary:

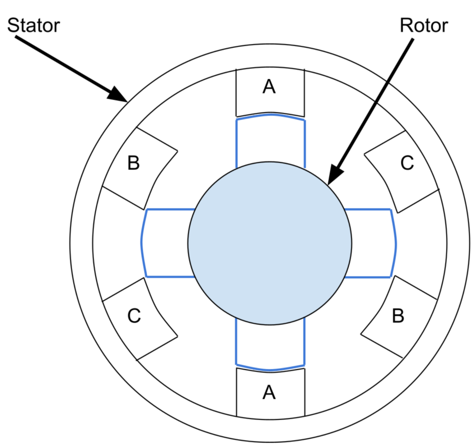

Figure 1: Schematic of a 6/4 SRM

A switched reluctance motor (SRM) works on the principle of alignment of ferromagnetic material (iron, steel, etc.) towards an applied magnetic field. Shown is an example switched reluctance motor in Figure 1. The stator has 6 poles, each of which will be carrying a coil to apply a magnetic field, the opposite coils are combined as a single electrical phase indicated by A,B,C. The rotor has 4 protruding poles and is entirely composed of a ferromagnetic material. Assume initial alignment of the rotor as shown in the picture, if we apply a field on phase B, then we will have a clockwise rotation, as the rotor pole nearest to phase B will be attracted. The rotation happens to ensure that the magnetic field takes the least magnetic resistance (reluctance) path. Now, if through a control algorithm, magnetic field is applied alternatively to the phases, then continuous rotation and torque can be created in the rotor. This describes the operation of the motor in brief. More details can be found in the book [6].

The SRM and drive development is of great significance in applications due to the following reasons:

- No use of permanent magnets and associated precious metal usage [11]
- Higher power density (Kilowatt / Kilogram) at high power levels [13,15,16]
- No cogging torque [6]. This helps in paralleling multiple motors for reliability [7]
- No shoot through in power electronics (the configuration differs significantly from other brushless motors) [3]
- Simple rotor construction, higher mechanical reliability [10,11,14]
- No resistive losses in rotor like induction motor
- To eliminate dependency on precious metals which are Chinese and South American imports predominantly. Further, extraction of such precious metals from the minerals creates a big carbon footprint and leaves several harmful byproducts
- Permanent magnets have to be maintained at much cooler temperatures than just a ferromagnetic metal to avoid reduction in field and demagnetization. So SRM can operate at higher temperatures without much cooling required.
- The switching of current between different phases requires very high power and high speed MOSFETs and IGBTs, which are seeing continuous developments. These developments can be effectively used to promote SRM
- The torque ripple, which is an SRM geometry based artifact and can be bright down with proper SRM geometry [4,6,9]. Through proper motor design, power electronics design and control design it can be brought to very low levels, thus a multidisciplinary problem. [1,2,3,5]
- Axial configurations can also be achieved easily [8,12] where the flux predominantly flows parallel to the axis of rotation.

- The system has some constraints on how control has to be done. This opens up opportunities for several tools of nonlinear analysis and control (controllability, observability, parameter identification, feedback linearization, etc.).

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II. Failsafe Biplane Tailsitter VTOL UAV for Medicine and Organ Transportation with High Degree of Safety and Reliability

Investigators: Abhishek (IITK), Mangal (IITK), Ravi Banavar (IITB), Chirag Jain (EndureAir Systems Pvt. Ltd.) and M. Rama Krishna (EndureAir Systems Pvt. Ltd.)

Regulatory and Environmental Risks:
The system operating in inhabited areas would have to be highly reliable and have to be equipped with adequate safety features to ensure its safe and reliable operations. To be able to operate in civilian airspace, the design would have to be compliant with DGCA's Digital Sky platform. Relevant software would be developed to achieve this.

Summary:
The proposed design consists of an octa-rotor biplane tailsitter concept, which is a novel concept consisting of eight rotors, four on each wing of biplane. During the entire duration of the flight, the wings remain parallel to the propeller axis and hence do not result in any download penalty due to rotor downwash hitting the wings, which is commonly experienced by tiltrotor type configurations. It is mechanically simpler as it doesn't require any tilting mechanism that is associated with tilrotors and tiltwings. Since, same powerplant is used for vertical as well as horizontal flights, it doesn't have any weight penalty of a quadplane.

The payload can be mounted inside the fuselage of the vehicle which has been designed for this purpose. This ensures the safe and secured transportation of the cargo, and it also ensures that payload is free from any atmospheric effects of wind which in some cases can cause unwanted swing for underslung payload, affecting the stability and performance of the UAV. After gaining safe altitude in hover mode, differential thrust is to control pitch attitude to change from hover mode to forward flight (airplane) mode by generating lift resulting in pitching moment about the centre of gravity of the vehicle. The VTOL vehicle being designed, attempts to selectively incorporate the advantages offered by both the fixed wing and rotary-wing type vehicles, as it can take off and land vertically and hover at a point which is a necessary requirement to deliver

the payload safely to any destination. During the forward flight mode, it can fly efficiently without any dead weight (like other VTOL configurations) and attain high speeds to cover large distances as per the mission requirements.

The key innovations offered by the proposed biplane tailsitter design are as follows:

a) Mechanical simplicity and distributed propulsion based efficient design compared to other VTOL configurations.
b) Compact footprint and low noise in comparison to other UAV configurations of similar weight class.
c) Dual redundant set of actuators to ensure very high reliability in normal continuous operations.
d) Modular design to ensure ease of transportation and storage.
e) Low maintenance downtime due to all electric modular design.

The objective is to develop an electric powered UAV that can lift 20 kg payload and transport it to 40-50 km under near sea level conditions. This high efficiency UAV is meant for aerial logistics and would be a multi-purpose system that has both societal and defense applications. Such a UAV can be used for transportation of essential / emergency medical supplies to places with poor road connectivity. It would be also used for organ transportation and provide emergency medical support at accident sites and deliver supplies to those affected by natural calamity. On defense side, Indian Army as well as Navy currently has an open requirement for "mule" drones for this exact configuration. A full functional market ready system would be designed and developed. This would have built in failsafe capability to ensure its safe op.

III. Energy Efficient Unmanned Helicopter UAV for Agriculture and Logistics

Investigators: Mangal Kothari (IITK), Abhishek (IITK) and Ravi Banavar (IITB), Chirag Jain (EndureAir Systems Pvt. Ltd.) and M. Rama Krishna (EndureAir Systems Pvt. Ltd.)

Regulatory and Environmental Risks:

The system operating in inhabited areas would have to be highly reliable and have to be equipped with adequate safety features to ensure its safe and reliable operations. To be able to operate in civilian airspace, the design would have to be compliant with DGCA's Digital Sky platform. Relevant software would be developed to achieve this.

Summary:

There is tremendous demand for agricultural UAV as precision agriculture is gaining acceptance. Such UAVs would have ability to carry at least 20 litres of pesticide and appropriate sensors to enable precision selective spraying on diseased plants. This would cause significant saving of pesticide and would make the entire process more environment friendly.

This UAV due to its payload weight can be reconfigured for a variety of applications ranging for long range logistics as well as for defence forces. With such weight category it could find applications in counter UAV segment also to enhance range of counter UAV detection as well to enable capture of rogue UAVs by using net throwing systems. The goal of the project would be to develop this multirole UAV platform that can be customized to meet requirements of a variety of customers

The objective is to develop a UAV that can lift 20 kg payload and fly for over 3 hrs. in near sea level conditions. This UAV is urgently required in agricultural sector for precision agriculture for selective pesticide spraying. This approach is energy saving, resource saving and environment friendly. Same system would be of immense use for dealing with locust attacks and for other spraying activities for disease control. In addition, being a helicopter, it can be used for multitude of applications, such as aerial logistics and wide range of applications for army and navy. Being able to takeoff and land vertically, such a platform can be used for search and rescue operations and operate from ship decks.

IV. High Efficiency Vertical Axis Wind Turbine for Household Application

Investigators: Abhishek (IITK) and Mangal Kothari (IITK)

Regulatory and Environmental Risks:
The system operating in inhabited areas would have to be highly reliable and have to be equipped with adequate safety features to ensure its safe and reliable operations.

Summary:
According to Wikipedia 80% of Indian villages have at least an electricity line, just 52.5% of rural households have access to electricity. In urban areas, the access to electricity is 93.1% in 2008. The overall electrification rate in India is 64.5% while 35.5% of the population still lives without access to electricity. As per Renewable 2015 report, globally almost 1.1 billion people have no access to electricity. This proposed wind

turbine tries to address the challenge of improving electricity access to rural and urban homes in an environment friendly yet frugal manner. India experiences an annual average wind velocity of less than 4.4 m/s at a height of 10 metres, making the reliance on wind energy difficult. At such low wind speeds, most existing horizontal axis wind turbines either fail to start or operate at diminished efficiencies of 20-25% or less. Wind power being an intermittent energy source is expected to have fluctuations in power generation due to variation in wind speeds. This makes the integration of large scale wind turbine plants to the grid a challenging task and has limited the use of wind based power in India.

The solution to some of these challenges lies in "small wind energy and hybrid systems". According to a recent study by World Institute of Sustainable Energy (WISE), the potential market for renewable energy based micro generation is estimated to be 83,000+ MW globally. A sizeable portion of this can be realized in India by developing micro generation potential through small high efficiency wind turbines and hybrid systems with low installation cost. This proposal discusses the development of commercial scale prototype of high efficiency vertical axis wind turbine system with variable amplitude dynamic blade pitching with the aim of increasing the penetration of wind energy and making it suitable for areas with low wind speeds. Such wind turbine systems would be collocated with the point of consumption and therefore obviate the need for connectivity to grid and eliminate transmission related costs and losses. Wind turbines would be installed in inhabited areas unlike the typical wind farms that are located far from population in areas with continuous and laminar wind profile. This requirement demands a novel and innovative design, as, the existing horizontal axis wind turbine designs perform poorly in environments with non-uniform wind profile typical of urban or rural settlements. Recent studies have indicated that the vertical axis wind turbine designs have significant performance benefits in such wind conditions. The wind turbine proposed is a vertical axis wind turbine with variable / dynamic pitch change. This variable pitch Vertical Axis Wind Turbine (VAWT) design makes use of unsteady aerodynamic effects to provide higher efficiency than the conventional Horizontal Axis Wind Turbines (HAWTs) and other fixed pitch vertical axis turbines. Because of vertical turbine shaft, it has smaller footprint and lower tip speed results in reducing mechanical and aerodynamic noise. The biggest advantage of this design is its ability to change the pitch angle of the blade to optimize the aerodynamic efficiency for wide range of wind speeds and turbine rotational speeds. This enables the turbine to become operational at very low wind speeds (as low as 1.5 m/s to 2 m/s), making it the ideal candidate for less windy regions of the nation. Further, in wind rich areas, such as North East, mountainous Himalayan region and coastal areas this frugal technology can make a significant impact due to its very high efficiency and low costs. The mechanism used for pitch change is simple and reliable four bar mechanism. The amplitude of the variable pitch system in the design can be adapted based on the sensed wind speed, by changing the length of one of the arms of the four bar linkage. The simplified design is expected to keep the maintenance cost to a bare minimum.

The objective of this proposal is to design and develop a high efficiency micro–Vertical Axis Wind Turbine (VAWT) of 1-2 kW power output with variable amplitude dynamics blade pitching for household application. The objective of this research is to systematically carry out the design and development of a novel Vertical Axis Wind Turbine (VAWT) with variable amplitude dynamic blade pitch change and built-in storm protection and power control device. A lab scale prototype of this type of turbine has already been developed and demonstrated and two patents have been filed (Patent Application No.904/DEL/2015 Dated: 31/03/2015 and Patent Application No. 201611003599, Dated: 02/02/2016) related to this design. The objective is to design and build a fully functional 1-2 kW output turbine which can be a product grade prototype ready for commercialization.

V. Spatial Parallel manipulator for Lower Limb rehabilitation

Investigators: Jayant Kumar Mohanta (IITJ), Santhakumar Mohan (IITPKD)

Summary:
Motor rehabilitation therapy needs continuous motion of the paralysed limb in order to regain the motor neural capability. Lower limb rehabilitation robots facilitate motion of the lower limbs i.e hip, knee and ankle joint to follow clinically recommended patterns. At present lower limb rehabilitation robots are able to deal in only in the sagittal plane. The reason for this is that it is quite complex to perform off-sagittal plane motion with bulky setups as present rehabilitation robots are bulky setups. Spatial parallel manipulators can help to solve this problem machine can perform the traditional robotic rehabilitation therapies with more versatility in treatment performed for rehabilitation; a schematic of the proposed system is shown in Figure 1.

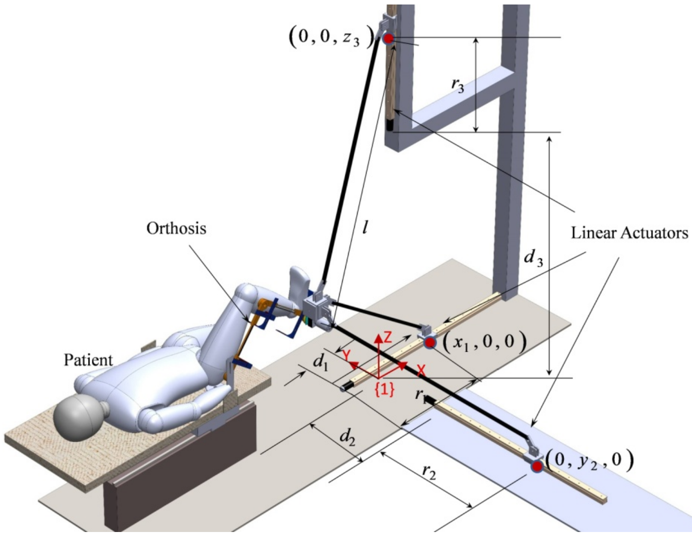


Figure 1: Schematic of the spatial parallel manipulator for Lower Limb Rehabilitation

Salient features and topics going to be covered in the project:

- Fabrication of spatial manipulator
- Kinematic and dynamic analysis of manipulator
- Dynamic control of the manipulator
- Lower limb rehabilitation therapeutic motion performance

Innovations :

- New lower limb orthosis for complying hip adduction-abduction, hip flexion-extension, knee flexion-extension and ankle flexion-extension.
- Addition of extra degree of freedom in Lower limb treatments.
- Proposition for hip adduction and abduction motions in lower limbs.
- Modularity in configuration and usability for other trainable limb rehabilitation processes.

VI. Design and Development of Multi-medium Robot for Aerial, Terrestrial, and Underwater Applications

Investigators: Asokan T. (IITM) and Santhakumar Mohan (IITPKD)

Summary:

Robots are generally classified based on their application or their medium of operation. There are mobile ground robots (UGV) for terrestrial applications, underwater robots (UUV) for submerged applications like offshore surveying, accessing and exploring marine ecological environment, and aerial robots (UAV) for application in aerial reconnaissance, survey etc. While these vehicles are terrain specific i.e. have their

performance optimised in their own specific environments but they cannot meet the demands and requirements of a multi medium operation. Applications like disaster management, water sampling, survey of sewerage and gas pipelines, ship hull survey, mapping of remote regions etc. require the robots to operate in cross domain environments. An aerial vehicle which can manoeuvre in air and also has the ability to dive underwater to rescue or assist drowning individuals or people in distress has much higher utility. Similarly, a terrestrial robot which can drive either autonomously or manually till the region of interest and fly to provide a visual aerial coverage of the region of interest will have a greater utility and operational range in comparison to a conventional UAV.

In this context there is a huge need for cross domain robots capable of performing in multifarious environments where seamless transfer from ground to air or water to air can be done. Current demands require a new design of cross domain transitioning vehicle which can combine the speed, agility, and manoeuvrability of an aerial vehicle with the stealth and subsurface sensing capabilities of an underwater vehicle and endurance of terrestrial robot.

Research and Development Objectives

The objective here is to design a robotic vehicle for terrestrial, aerial and underwater applications. Any such design is judged by the capability to perform, which is eventually decided by the mission criteria or design criteria. The main criteria considered for the design are:

1. Compactness: making it compact means making it more agile, able to navigate through tight spaces while minimizing the risks on the environment.
2. Versatility- which will make it able to perform on multiple environments making the distinction of UGV, USV, UAV existing for decades vanish.
3. Safety- to use in urban and cross-country environments without causing damage to the users or environments.

The research and development work has been divided into the following modules:

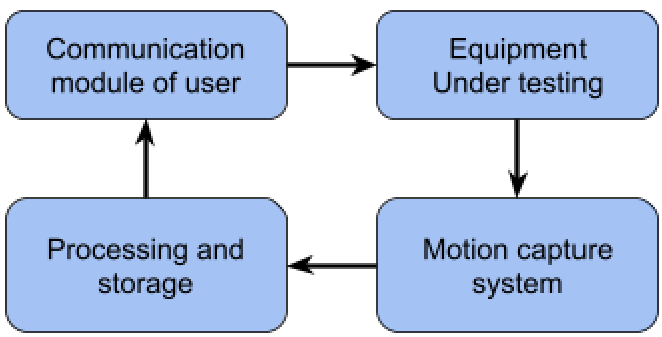
1. Study the different kinds of robots currently in use for aerial, ground, and underwater applications
2. Identify functional requirements of a multi-medium robot.
3. Conceptual design and synthesis of a novel robot configuration.
4. Kinematic and dynamic modelling and simulation studies.
5. Controller design using hybrid control strategy.
6. Prototyping and testing.

4.4 TIH-ICS Laboratories

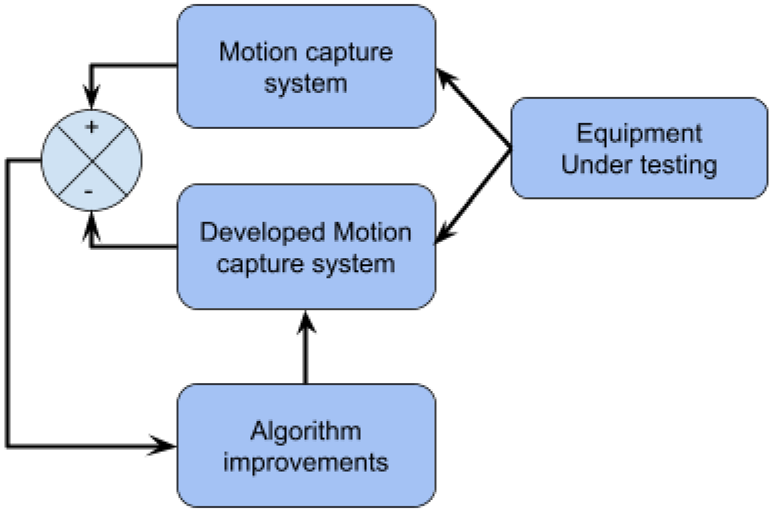
TIH Laboratories will play a foundational role in the development of CPS-ICS technology and products. These labs will enable students, researchers, entrepreneurs and startups to experiment and prototype in several domains of CPS-ICS.

➢ Motion Capture Laboratory

Motion capture lab will contain camera and laser based sensors to capture the position of multiple solid objects in three dimensions and provide data to the user on a computer. All vertical takeoff and landing drones, mobile robots, human motion capturing can happen in this laboratory. This lab will play a proactive role in disseminating information to the public on the method in which data capture happens, and how it is provided to the end users. A few standard interfacing options will also be provided on the motion capture computer to connect to wireless communication modules (to be brought by the user). Using the communication module, a closed loop control can be achieved for the necessary application as follows



Another interesting venture we plan out is to develop and validate a lower cost motion capture system using the larger one. Across India, it is observed that motion capture systems are imported from two or three international companies, and that too, at exorbitant costs. This vicious cycle needs to be broken by developing indigenous motion capture systems. This would also generate local business and impart such skills to the Indian job seekers.

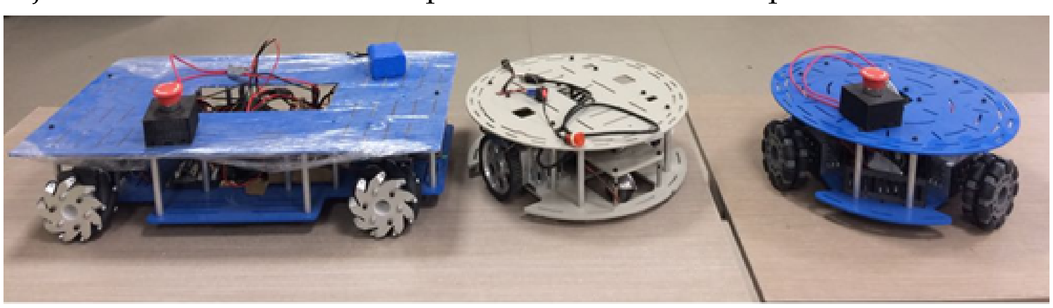


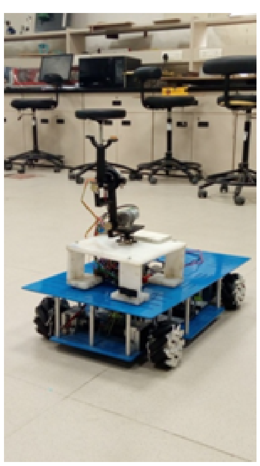
➢ Service, Assistive, Field and Exploration (SAFE) Robotics Lab

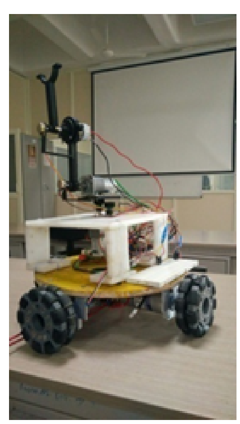
There are several wheeled robotics that will comprehensively form the wheeled robots development lab, this will fall under the research laboratory. A list of the wheeled robots from the projects:

- Network of autonomous mobile robots
- Mobile robots with robotic manipulators

The wheeled robots are one of the technologies which will be reaching TRL-5 faster than other projects. Hence this lab will help accelerate such development.







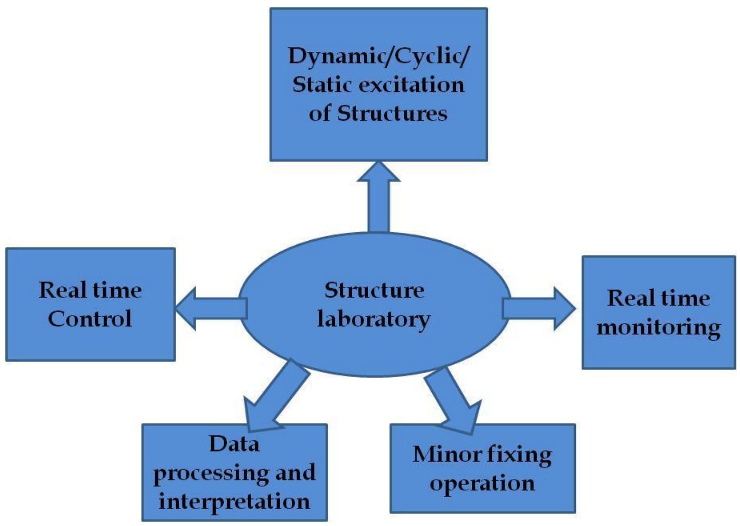

➢ AI and CPS Lab for Smart Agriculture

This lab is proposed to set up an unique data collection and processing infrastructure for collecting raw and processed data from farm equipment, field sensors, UAVs, and weather stations. Using the data, we envision to build decision support tools towards advanced spatiotemporal image, and video analysis, automation in identifying crop stress etc. for assisting farmers to manage and optimize use of the agricultural resources in real time. Building a indigeneous prototype for low cost weather stations and UAV farmland surveillance computing stack is the other goal of this lab. We will also engage into inhouse development of sensors to measure a variety of essential soil properties.

Towards achieving the intelligent agricultural infrastructure, on the one hand, the lab will consist of high end workstations, simulation softwares, test UAVs, embedded and FPGA boards, oscilloscopes, peripheral devices, sensors, RGB, thermal and hyperspectral cameras. On the other hand the lab will be complemented by a dedicated server room, which will assist to set up the unique data ecosystem for sustainable smart agriculture.

➢ Structures Laboratory

The primary purpose of the Structural laboratory is to provide an environment to accomplish experimental investigation on the model/prototype flexible real life structures or component structures under various static, cyclic or dynamic loading conditions. Various passive, active or semi-active control strategies can be developed and implemented for the response enhancement of these structural systems that are often exposed to uncertain environmental conditions. In particular, the structural laboratory for the TIH-ICS project includes the development of real time monitoring and control of the scaled model of real life prototype structures. It will have the facility to significantly excite the structure dynamically and sense the vibration by using suitable sensors and monitor the structural vibration in real time. Based on the monitored vibration data, a real time control system is to be generated which includes sophisticated data acquisition and response control devices. Apart from the real time monitoring and control, there should be places where the experimentally observed data can be analyzed and processed either to justify the analytical development or to develop an analytical model based on the experimentally observed data. Apart from the structural control and structural health monitoring, the laboratory will have a facility of small fixing and modifying small scale flexible structural components suitably for the experimental purpose.



➢ Underwater Robotics Laboratory

The underwater robotics lab mission will be to enhance and extend the institute's existing technological strength in underwater robotics and motion control areas, with demonstrated potential for the nation's economy. The lab will conduct interdisciplinary research on vehicle design, controller development, modification, and evaluation; on development of various marine robots and robotic solutions for different deepsea tasks; and on vehicle manipulator systems. The lab builds on the world-leading and international excellence performance in the field of marine robotics and motion control. The main areas of research carried out by the lab are:

- The application of mathematical modelling and computational modelling.
- The investigation and understanding of the interaction between controllers and robotic systems,with an emphasis on intelligence
- The use of computational and robotics modelling methods to investigate system behaviours and searching for improvements
- The application of these models into the real-world robotic and interactive/intervention applications

All these research outputs and developed prototypes will be tested in the lab and are expected to be transferred to start-ups and industry.

4.5 Environmental Impact

Environmental Impact Assessment for internal projects has been performed and can be found in the detailed proposal of the respective projects. For external-facing projects, the investigators will be asked to do Environmental Impact Assessment as a part of the project submission process. They are also expected to propose measures to mitigate the adverse impact, if any.

4.6 Legal Framework

The legal framework of executing technology development, but not limited to:

- Memorandum of Understanding (MoU) are start points of agreements between IPTIF and host institutions of project investigators.
- MoU between IPTIF, Government organizations and other Technology Hubs.
- Licensing or Transfer of IP agreements will be between IPTIF, host institutions of project investigators, and project investigators.
- Monetization on IP agreements will be between IPTIF, host institutions of project investigators, and project investigators.
- Institute/Organization endorsement between IPTIF and host institutions of project investigators.
- CSR agreements between private company and IPTIF

Suitable consultants will be onboarded to execute these as per applicable legal regulations.

4.7 Outcomes

40 technologies and 29 products are expected to be developed and licenced. In addition to this, 40 researchers/engineers will be inducted under the CPS research base over a span of five years.

4.8 Risk Analysis

The technology/product development is a high risk activity, as the risk of failure is quite high. Some of the reasons the technology or product fails is due to the smaller ecosystem available on emphasizing patenting, licensing, etc. One of the ways to mitigate this risk is to plan for more targets than what is expected as outcomes, the planned targets are taken from Table 4.1 and the target outcomes are taken from Table 4.5. The increase in CPS research base is projected for planned targets as 1 person/50L of investment, as we are aware that good project engineers is how most projects would be implemented. Furthermore, even if the product/technology hasn't been successful, the engineer will still be more proficient in CPS based technologies through their journey. We can observe from the following comparison table that even with a 60% success rate, all the mission targets would be met.

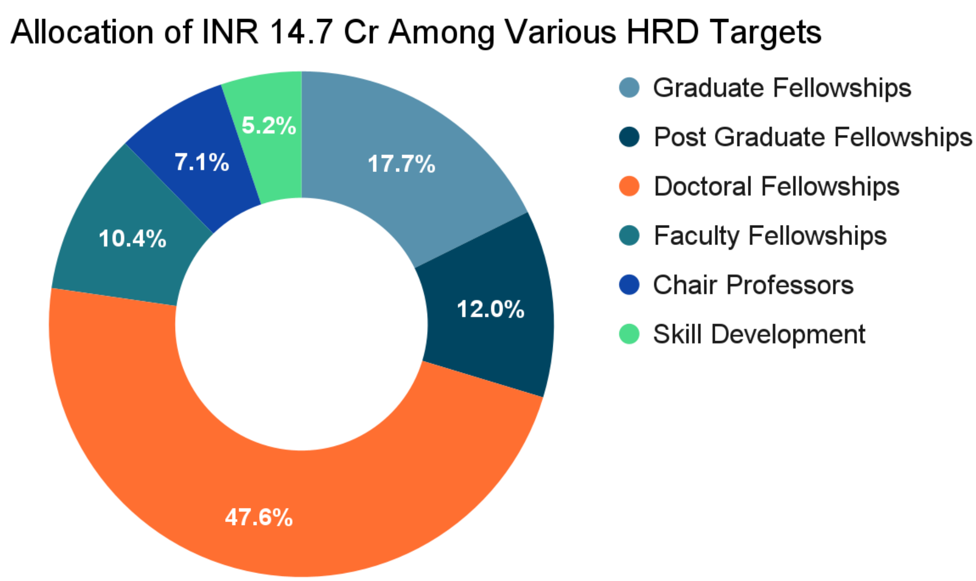
Table 4.5: Planned targets vs. Target outcomes

Planned Targets							
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Total	**Technology**	**0**	**2**	**7**	**17**	**9**	**35**
	Product	**0**	**1**	**4**	**9**	**8**	**22**
	Increase in CPS research base	**2**	**32**	**30**	**18**	**18**	**100**
Target Outcomes							
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Total	**Technology**	**0**	**2**	**4**	**7**	**6**	**19**
	Product	**0**	**1**	**3**	**3**	**5**	**12**
	Increase in CPS research base	**8**	**23**	**21**	**10**	**0**	**62**

Another aspect of risk is on the sustainability of IPTIF after the five year funding period, one of the modes being equity/loan agreements from funded startups. We also propose that external projects will be given higher priority to organizations who are able to take the grant money on an equity basis. Entrepreneurs and startups who are looking out to develop products and are looking for funding on an equity basis can easily apply to develop these products. This way, there will be more investment pooled into entrepreneurship activity from the technology development activity.

5 Human Resource Development

IPTIF will be actively involved in human resource development at different levels of expertise and experience. We believe that this will in turn allow us to leverage their support in improving the research, job market and sustained business in the local ecosystem. To achieve our HRD target, about **INR 14.7 crores** has been budgeted over a period of 5 years. This budget has been distributed over various activities such as fellowships at the graduate, post-graduate, doctoral levels. Moreover, faculty fellowships and chair professorships are planned to recognize excellence in the field of CPS and further support the mentorship initiatives of IPTIF. Several skilled training activities are planned for dedicated skill training programs implemented at IPTIF as well as through ITI institutes of repute.



5.1 Graduate Fellowship

The fellowship will present bright and motivated undergraduate students of our country an opportunity to nurture their spirit of research and entrepreneurship in CPS-ICS.

5.1.1 Strategy

- 210 fellowships will be awarded over a period of 5 years with 42 fellowships per year.
- *Each graduate fellowship will be for a period of at-most 10 months with a fellowship stipend of INR 10,000/- per month.*

- *In addition to this, an amount of INR 10,00,000/- has been set aside to meet the needs of students who are pursuing hardware projects.*
- Undergraduate students studying in India are eligible for this fellowship.
- Preference will be given to students who are pursuing projects in the area of *Intelligent Collaborative Systems (ICS)*.

5.1.2 Outcomes

We believe this fellowship will create a cohort of future graduate students who can promote diversity within the engineering and science student body, especially in CPS-ICS.

5.2 Post-graduate Fellowship

This fellowship will be provided to post-graduate students enrolled in a 2-year M. Tech program, at IIT Palakkad (HI), that is aligned with the CPS-ICS theme. Post-graduate students are enrolled in such a program only for 2 years. In such a brief period of time, it will be difficult for them to holistically contribute to ongoing technology development projects. Hence, it is better if they can pursue an CPS-ICS themed independent project.

5.1.1 Strategy

- 13 fellowships will be awarded in the 2^{nd}, 3^{rd} and 4^{th} year each; a total of 39 fellowships.
- *Each fellowship is for a period of at-most 24 months with a fellowship stipend of INR 15,000/- per month.*
- *In addition to this, each student is eligible for a contingency amount of at-most INR 2,00,000/-.*

5.1.2 Outcomes

We believe that this fellowship will allow IPTIF to generate more CPS-ICS technologies, as each post-graduate project can be regarded as a new product/technology.

5.3 Doctoral Fellowship

Doctoral fellowship will be awarded to individuals who are pursuing full-time Ph.D. in the area of CPS-ICS. This fellowship will attract bright candidates who would otherwise have discontinued higher education and research.

5.3.1 Strategy

A total of 30 fellowships will be awarded in the first year.

- *Each fellowship is for a period of at-most 60 months with a consolidated fellowship amount of INR 31,000/- (plus applicable HRA) per month for the first 2 years, and INR 35,000/- (plus applicable HRA) per month for the remaining years.*
- *In addition to this, each student is eligible for a contingency amount of at-most INR 2,00,000/-.*
- Ph.D. students studying in India are eligible for this fellowship.
- Only students who are pursuing research in the area of *Intelligent Collaborative Systems (ICS)* will be supported through this fellowship.
- *Each Ph.D student supported by this fellowship is expected to deliver at-least 2 publications/IPR.*

5.3.2 Outcomes

These Ph.D. students would have worked on cutting-edge research in CPS-ICS for 5 years and can be considered as a high quality addition to the CPS research base. The publication targets that are part of the technology development vertical will also be met through this fellowship. Expected outcomes of this fellowship are

	Year 1	Year 2	Year 3	Year 4	Year 5
Publication/IPR	2	6	7	7	8

5.4 Faculty Fellowship

Faculty fellowships will be awarded by IPTIF to recognize and encourage young faculty in the field of CPS-ICS.

5.4.1 Strategy

- 3 fellowships will be awarded in the 2nd year.
- *Each fellowship is for a period of at-most 36 months with a consolidated fellowship amount of INR 1,25,000/- per month.*
- *In addition to this, each fellow is eligible for a contingency amount of at-most INR 2,00,000/-.*
- *Each faculty supported by this fellowship is expected to deliver at-least 1 publication/IPR.*

5.4.2 Outcomes

We believe that this fellowship will allow IPTIF to make high quality additions to the CPS research base. Expected outcomes of this fellowship are

	Year 1	Year 2	Year 3	Year 4	Year 5
Publication/IPR	0	0	1	1	1

5.5 Chair Professorship

Chair professorships will be instituted by IPTIF to recognize excellence in the field of CPS-ICS and further support the mentorship initiatives at the level of academia and industry.

5.5.1 Strategy

- 3 fellowships will be awarded in the 2nd year.
- *A fellowship is for a period of at-most 36 months with a consolidated honorarium of INR 80,000/- per month.*
- *In addition to this, each fellow is eligible for a contingency amount of at-most INR 2,00,000/-.*
- *Each faculty supported by this fellowship is expected to deliver at-least 1 publication/IPR.*

5.5.2 Outcomes

Expected outcomes of this fellowship are

	Year 1	Year 2	Year 3	Year 4	Year 5
Publication/IPR	0	0	1	1	1

5.6 Skill Development

India graduates thousands of ITI traders, Diploma holders and engineers every year but when it comes to employability in suitable industry, only 20% of them are employable. Often, the industries and employers take on the task of training these recruits through in-house programs for the tasks that they are required to perform. According to a survey, only 25% of the Indian workforce has undergone a skill development program, and India requires a greater number of such skilled workforce in the years to come. The main objective of the skill development programme of IPTIF is to provide adequate training in professional (technical) and market-relevant skills to over 380 individuals (preferably ITI, Diploma and fresh degree holders) by the end of 2025. It also aims to create opportunities for the development of talent within the country, in specific local regions of the hum and improve the overall scope and space for CPS-ICS sectors. Our plan is to offer different certification based skill training with two different time durations focussed on knowledge-based courses/programs in the following areas

1. Machining and Fabrication
2. Electrical and Electronics Design
3. MATLAB/Python (Control) Programming
4. Robotics
5. Hardware Design
6. Embedded Systems Design
7. AI of Things (AIoT)

5.6.1 Strategy

A total of INR 0.76 Cr is budgeted for this activity. The programs will designed in such a way that participants can do this certification during their regular courses in the either of the following mode:

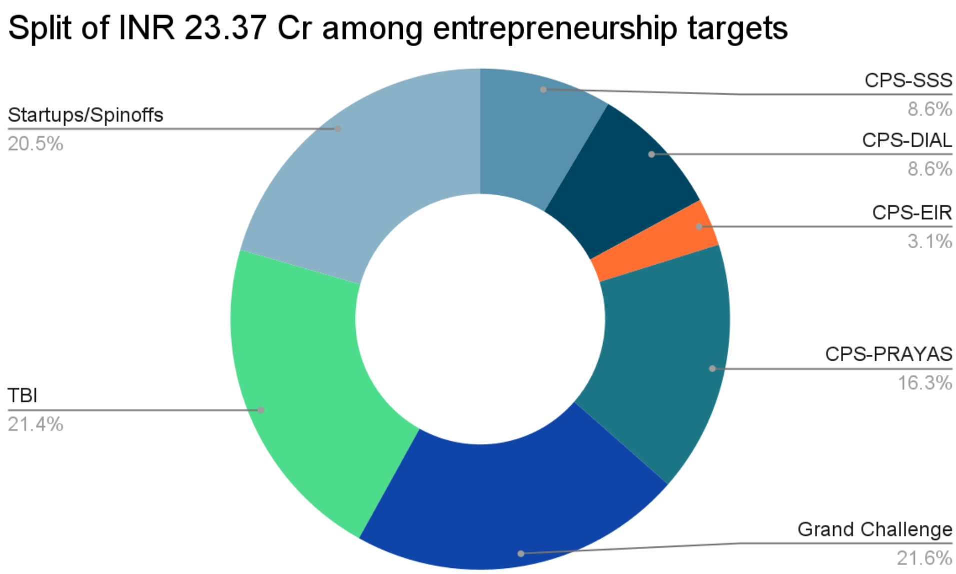
- **Crash course mode**: 20 lecture hours along with 15 hrs of hands-on sessions during the weekends
- **Comprehensive mode**: A month long intensive course with 30 hrs lectures hours and 24 hrs of hands-on sessions.

5.6.2 Outcomes

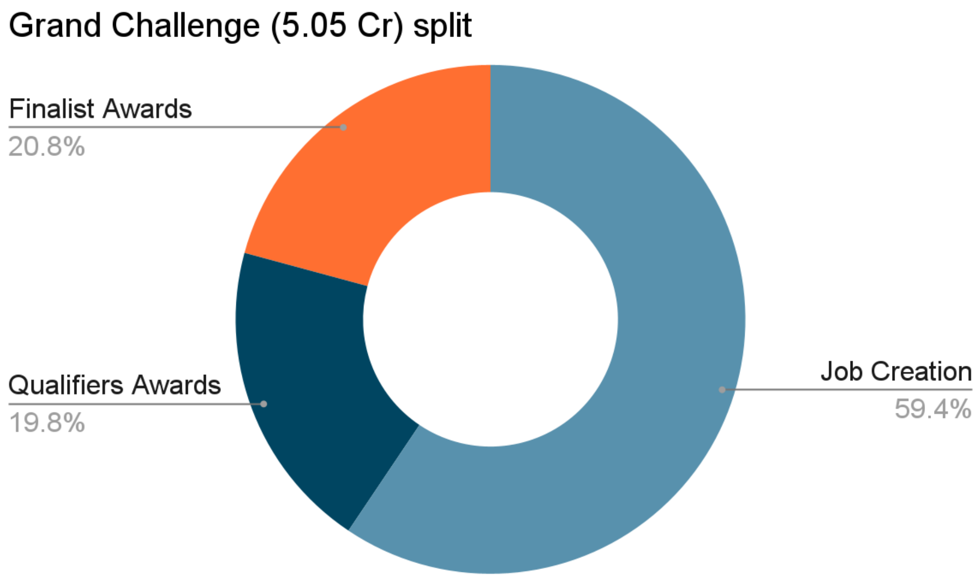
Over 380 individuals will be trained and certified through the various projects and skill development programs of IPTIF over a period of five years. Skill development is an important part of human resource development. We also foresee that it will also act as a revenue source for IPTIF in the long run.

6 Entrepreneurship and Startups

Entrepreneurship and startups are important for innovation, technological growth and job creation. A major emphasis of the startup activity would be to promote Make-in-India as much as possible, and to help develop/setup industries ***eliminate our dependence on global monopolies***. These industries will augment the supply chain of the integrated product level startups working on lower cost products for India. The region of Coimbatore, closest to IIT Palakkad, is one of the major manufacturing hubs of India, and this will be leveraged to realize such products. Several schemes under this vertical are allocated a total budget of **INR 23.37 Cr**, and the split is as shown below.



Grand challenges are one of our most important entrepreneurial activities, which will infuse entrepreneurial enthusiasm and foster rapid talent development, further enabling them to get jobs. The following budget split will be used to meet the targets.



The targets set for IPTIF in entrepreneurship and startups are:

Table 6.1: TIH-ICS Entrepreneurship Targets

	Entrepreneurship Development	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Target**
(a)	Technology Business Incubator (TBI)	1					1
(b)	Start-up and Spin-off companies	4	8	8	8	4	32
(c)	GCC - Grand challenges and competitions	1	1	1			3
(d)	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)		1				1
(e)	CPS- Entrepreneur in Residence (EIR)	5	5	5	5		20
(f)	Dedicated Innovation		1				1

	Accelerator (DIAL)						
(g)	CPS - Seed Support System (CPS-SSS)			1			1
(h)	Job Creation			7500	250		7750

6.1 Target Beneficiaries

- **Grand Challenge and Competitions:** Every Indian citizen who intends to equip themselves with technological knowledge in CPS-ICS, upskill themselves and be career ready.
- **CPS Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)**: Very early stage startup idea(s) to be handheld from genesis to market readiness stage.
- **CPS Startups and Spin-off Companies**: Team incubation for a year (non equity), with additional top ups on equity basis. These founders are anticipated to be young entrepreneurs with basic ideation who are in need of incubation to create a proof of concept.
- **CPS Entrepreneurship in Residence (EIR)**: To provide founder mentorship and enable startup creation. Candidates are expected to have some experience with startups, but are now interested in having their own startups.
- **CPS Seed Support System (SSS)**: Additional funding for well performing existing/new startups both within hub and external
- **CPS Dedicated Innovation Accelerator (DIAL):** Support packages for promising startups by experienced entrepreneurs.

6.2 Legal Framework

The legal framework of executing entrepreneurship and startup targets include, but not limited to:

- Memorandum of Understanding (MoU): MoUs are start points of agreements between IIT Palakkad TBI (TECHIN) and IPTIF, between host institution and IPTIF, between industry and IPTIF , etc.
- Non Disclosure Agreement (NDA): NDA will be signed in all intellectual property (IP) sharing matters by the involved parties.

- Loan or Equity agreements: This will mainly be between IPTIF and startups, which will be helped by TECHIN.
- Licensing or Transfer of IP agreements: This will be between IPTIF and any industry/startup.
- Monetization on IP agreements: This will be between IPTIF, inventors, industry/startups and HI (wherever applicable).
- Grant letter/agreements: This will be between IPTIF and startups who are receiving the non-returnable type of investments.
- Corporate / Venture Capitalist funding agreements: This will be between investors and IPTIF.

Suitable consultants will be onboarded to execute these as per applicable legal regulations.

6.3 Strategy

6.3.1 Technology Business Incubator

Startups and startup ideas will be evaluated and incubated through the internal expertise, expertise of the industrial collaborators and the TBI of IIT Palakkad - TECHIN (Technology Innovation Foundation IIT Palakkad). Operational costs are budgeted for TECHIN, which would be used to avail the following services for meeting the targets

- Creating call for proposals, handling of application process, evaluation of applicants and applications, shortlisting potential entrepreneurs and startups, disbursal of money (transferred from IPTIF to TECHIN) for the following schemes:
    - CPS startup and spin-offs
    - CPS PRAYAS
    - CPS DIAL
    - CPS SSS
    - CPS EIR
- Incubation space, industry connects, legal help, workshops and hackathons, etc.
- Technology and business mentorship, product development facilities (in association with IPTIF), connect with development mentors both in academia and industry (relevant and feasible connects).
- Platform for venture capitalists, investors and startups to meet and benefit out of each other.

6.3.2 Start-up and Spin-off Companies

The startup incubation will be INR 15 lakhs per startup for a period of 1 year. Under this scheme, the teams that we foresee are recent graduates who have fertilized a good idea in their mind, and would now want to try materializing it into a prototype. In case these individuals are not experienced professionals, they would be receiving fabrication laboratory support and mentorship from TIH-ICS hub.

6.3.3 Grand Challenges and Competitions (GCC)

Grand challenges are a significantly large activity spanning multiple years and involves effort from multiple individuals along with startups, industries and educational institutions. A few well-known global challenges are the ones by DARPA and Hyperloop. We envision one such multidisciplinary grand challenge in the interdisciplinary areas of robotics, communication, embedded systems, algorithms, machine learning. A total of **INR 5.05 Cr** is allocated for the grand challenge, and additional funds (if feasible) will be obtained from private sponsors who are keen in promoting such large grand challenges in the Indian ecosystem.

We plan to conduct 3 Grand challenges; one each in the first 3 years of the hub. The problem formulated would have challenges from our focus areas, in particular our impact problems. Participants themselves should be at a stage where their efforts towards the challenge will fortify their skills which can in turn lead to their career growth, preferably in the form of a startup. Each grand challenge will have 3 rounds. They are as follows

Preliminary Round

- Teams will be shortlisted from a large applicant pool.
- This procedure would take about 4 months, including the open of call, closure of call and review of applications.
- ***Each shortlisted team would be given a grant towards the idea / crude POC of their proposed solution.***
- ***They are expected to complete building their solution within 2 months.***
- ***Each team member will also be asked to create a PPF account (INR 500 each).***
- Through the first round, candidates will equip themselves with skills relevant to their careers and a majority of them will go ahead successfully attaining one.

- The call for the challenge will be planned at such a time to ensure undergraduates / postgraduates have their final year project period fully available in the duration of the challenge.

Final Round

- A handful of teams will be shortlisted from those who successfully complete the pre-final round.
- ***Each team will be given financial support to improve their POC.***
- ***They will be given 4 month to improve their proof of concept.*** The prototype at the end of this round should be at TRL-4 or TRL-5, and such analysis should also be indicated in their reports. A detailed business plan, team structure, tie up with incubators, possible angel or VC investors and any more relevant information should be provided.
- ***At the end of this round, at-most 3 teams will be selected to form companies. Each of the 3 selected finalists will receive financial support to form a company incubated by TECHIN. They are expected to use this money to evolve their prototype into a product and explore investment opportunities.***

Table 6.2: A summary of the planned grand challenges.

		Prelims	**Final**	**Winners**
Grand Challenge 1 **Starts in the first year; focus on Intelligent Solutions for Energy**	**No. of teams**	100	10	3
	Max. financial support per team	INR 75,000/-	INR 2,00,000/-	INR 10,00,000/-
	Review and shortlisting duration	1 month	1 month	
	Round Duration	2 months	4 months	-
	Budget	0.75 Cr	0.2 Cr	0.3 Cr
Grand Challenge 2 **Starts in the second year; focus on Autonomou**	**No. of teams**	100	10	3
	Max. financial support per team	INR 75,000/-	INR 2,00,000/-	INR 10,00,000/-
	Review and shortlisting	1 month	1 month	

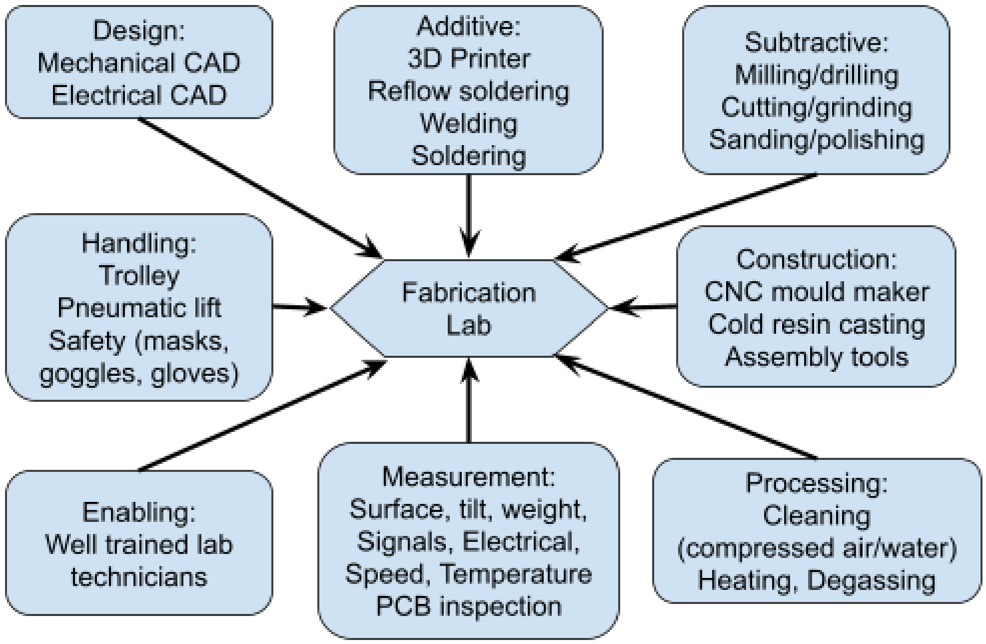
s Systems for Safety	**duration**			
	Round Duration	2 months	4 months	-
	Budget	0.75 Cr	0.2 Cr	0.3 Cr
Grand Challenge 3 **Starts in the third year; focus problems in Safety and Energy**	**No. of teams**	200	20	3
	Max. financial support per team	INR 75,000/-	INR 3,00,000/-	INR 15,00,000/-
	Review and shortlisting duration	1 month	1 month	
	Round Duration	2 months	4 months	-
	Budget	0.75 Cr	0.6 Cr	0.45 Cr

Overall, in each round, the funding increases in a progessive manner, and provides an opportunity for the teams to onboard more team members, and also serves as a motivator to establish a startup. Through this mode, we would have ensured the job creation target under the entrepreneurship header. A similar approach is under progress by MeitY (Ministry of Electronics and Information Technology), Government of India through several grand challenges to promote startup and job creation, an example being the Swadeshi Microprocessor challenge.

6.3.4 Promotion and Acceleration of Young and Aspiring Technology Entrepreneurs (PRAYAS)

A high potential early stage startup will also be provided a standalone higher level of funding under the PRAYAS scheme. This startup could be identified either from within the hub or by inviting external proposals. The difference between seed support system and PRAYAS scheme would be the experience of the founders expected. These strategies would be discussed later with the TBI and applications would be invited under suitable schemes for founders with different levels of experience. The nature and quantum of financial support will be as per mission DPR. Further, to support this scheme, a state-of-the-art fabrication lab will be setup at the hub.

This fabrication laboratory will house an extensive array of tools and equipment that will enable a fast prototype development, while keeping at bay types of equipment which are available as services in a quick and cheap mode. An example could be PCB fabrication services, where turnaround times of a week are a norm now, at a very economical cost. The fabrication lab will have the following components:



A major challenge most prototype developers face in institutions and external workshops is the scarcity of trained staff to operate fabrication equipment. Learning to handle all equipment can be taxing or individuals, and often results in situations where the equipment incurs significant repairs. Long waiting times are also common in institutions and in common markets. In such a situation, students and researchers have to resort to a mediocre quality prototyping. Such kind of disadvantageous cycle needs to be avoided for TIH-ICS to enable fast technology development. The proposed fabrication lab will be divided into the following capabilities:

1. **Design:** The design space and computers loaded with design softwares will be needed for all the startup companies that will be incubated. Individuals employed in such startups may not have access to the best design softwares and computers, and will need to be trained on these aspects as well. Another reason to have design space/computers is to also serve as control of all the other computer controlled machinery.

2. **Additive manufacturing:** The additive manufacturing in a colloquial sense implies 3D printing, but it encompasses anything that adds up material to base objects, such

as soldering, welding, etc. The soldering aspect is dealt with in multiple fronts: firstly PCBs involving very small surface mount ICs and BGA (ball grid array - having pins on bottom of chip) are almost impossible to solder by hand, in this case the PCBs are coated with solder paste and ICs are placed on top of them and heated in reflow station. Another soldering requirement is for regular components, for which conventional soldering stations suffice, and lastly, there are special cases involving large cables and big metal surfaces where the heat loss is rapid, here again high power soldering is required. 3D printers will also be made available for all prototyping.

3. **Subtractive manufacturing:** The major subtracting manufacturing requirement of CNC machining will be met by IIT Palakkad. Other tools such as laser cutting, metal cutting, drilling, vertical milling, grinding, sanding and polishing will be made available.

4. **Construction:** Regular assembly tools are available in most places, and cannot be considered as lacking anywhere. The more deviated requirement is the need to cast plastic structures that cannot be 3D-printed. Epoxy resins of various varieties which harden at room temperature will be made available. They can be mixed, degassed (removal of air bubbles) and poured into wood or plastic molds made out of the auto CNC routers.

5. **Processing and Handling:** In many cases proper air or water jet based cleaning is not available for manufactured materials, since processing or post-processing is not considered in the prototyping phase. But as a good practice to avoid any issues in prototypes, it is best to clean manufactured items before assembly. Processing of materials that require exposure to vacuum is also considered. Heating is also a common process in case of fiber reinforced plastics bonded by epoxy resins, and the facility will be included.

6. **Measurements**: In the assessment of prototype functionality, several measurements have to be done depending on the domain involved. Common measurements include PCB inspection under microscope, surface flatness of machined parts (to the level required), lengths, temperature, tilt, etc. Since several projects would include aerial vehicles, speed measurements are also essential. A majority of the measurements will happen in PCB and electronics hardware, where voltages, currents and signals have to be analyzed. Power supplies and oscilloscopes will be made available for electronics development and debugging.

		Year 1	Year 2	Year 3	Year 4	Year 5
Fab lab CAPEX	**Non-recurring**	1.0 Cr				
Fab lab OPEX	**Recurring**		0.4 Cr	0.4 Cr	0.4 Cr	0.4 Cr

6.3.5 CPS - Entrepreneur in Residence (EIR)

EIR program is equivalent to the entrepreneurship programs run by Entrepreneur First (EF), Startupbootcamp (SBC), etc. that invite founder aspirants with some experience to attend a training plus mentorship program. Through this program, the participants discuss their ideas with their cohort (participants in the batch), and try to form a company by finding partnerships who would be the founding members. The nature and quantum of financial support will be as per mission DPR

6.3.6 Dedicated Innovation Accelerator (DIAL)

The dedicated innovation accelerator program would be mentored and supported by the TECHIN. This could be considered as the logical next step of teams which perform well in the general startup fundings. Out of the several startups funded in the general scheme, though DIAL, additional capital would be infused into the ones that are performing very well. The nature of financial support will be as per mission DPR. A total of 2 Cr is set aside for this scheme.

6.3.7 CPS - Seed Support System (CPS-SSS)

Seed support system is in place to provide funding for early stage ideas that have proof of concept ready. The general goal is to provide additional boost to well-performing CPS startups and spin-off companies that are part of any TIH, in particular TIH-ICS. Performance of these startups will already be known since they're part of well-established TIH. This support can also be opened up for startups that have a strong proof of concept but not associated with any TIH. The nature of financial support will be as per mission DPR. A total of 2 Cr is set aside for this scheme.

6.4 Outcomes

- TECHIN - the TBI of IIT Palakkad will support and enable IPTIF to accomplish the goals of entrepreneurship and startup targets. This will enable TECHIN to be established as one the major TBI in the country.
- A majority of the funded startups are able to build proof of concepts, form connections with industry and venture capitalists, able to sustain themselves and grow.
- The grand challenge will create a major and rapid upskilling of youngsters, and such upskilling will ensure job opportunities for them. The participation in grand challenges involves collaborative efforts, fast learning/execution, project planning and team management, all of which will help these aspirants in becoming good engineers, managers and entrepreneurs.
- Under PRAYAS, early stage ideas will come into proof of concept, and preferably move into TRL-3 or TRL-4 levels, and move onto subsequent funding rounds and commercialization.
- An ecosystem that will enable entrepreneurs to find like-minded individuals who are interested in created startups..
- Connecting well performing startups to funding VCs and enabling them to grow.
- Startups and spin-off companies have refined their proof of concept and achieved higher TRL levels.

6.5 Risk Analysis

The foreseeable risks, and suggested mitigation are:
- Non-compliance with equity/loan/monetization agreements: Legal and financial action as decided by CEO and board of directors. If possible, suggest bank guarantees and compensatory bond arrangements.
- Misutilization of funds: Legal and financial action as decided by CEO and board of directors. If possible, suggest bank guarantees and compensatory bond arrangements.
- Non-adherence to NDA and Licensing: Legal and financial action as decided by CEO and board of directors.

7 International Collaborations

Hosting distinguished academic visitors, both at the national and international level frequently, to impart academic vibrancy and international visibility to the TIH-ICS, would be the last but not the least of its mandates. This objective would also bring in national and international visibility to the TIH, much needed in today's highly interconnected scientific world. The call for proposal announcements will be made in focused areas and the interested Indian institutions will be enabled to form shared projects with foreign institutions. Such international commitments will ensure an increase in CPS exposure of the institutions in India and initiate long term tie-ups among the partnering institutions. A few potential international collaborators and their area of expertise in ICS is presented below.

Sl. No.	Name	Affiliation	Area of Expertise in ICS
1	Rachid El-Azouzi	Laboratoire Informatique d'Avignon, University of Avignon, France	Game Theory, Queuing Theory
2	Janos Tapolcai	Budapest University of Technology and Economics, Hungary	Failure Localization in Optical Networks
3	Eitan Altman	INRIA, Sophia Antipolis, France	Optimal Control, Stochastic Games
4	Jinwhan Kim	Korean Advanced Institute of Science and Technology, Republic of Korea	Robotics, Machine Learning and Optimization, Reinforcement Learning, Autonomous Navigation
5	TaeWon Seo	Hanyang University, Republic of Korea	Robotics, Control, Optimization
6	Yukio Takeda	Tokyo Institute of Technology, Japan	Robotics, Healthcare Robots
7	Burkhard Corves	RWTH Aachen, Germany	Robotics, Artificial Intelligence, Optimization, Control
8	Philippe Wenger	Ecole Centrale de Nantes, France	Robotics, Optimization, Control, Motion planning

9	Weidong Zhang	Shanghai Jiao Tong University, China	Process Control, Unmanned Systems, Cooperative Control
10	Sethu Vijayakumar	University of Edinburgh, UK	Robot Learning, Artificial Intelligence, Optimal Control, Machine Learning
11	Thiusius Rajeeth Savarimuthu	University of Southern Denmark	Medical Robotics, Image Processing, Autonomous Navigation
12	Francesco Paci	Greenwaves Technologies, France	Computer Vision, Cyber Physical Systems
13	Xiaodong Ji	Tsinghua University	Structural Vibration Control and Health Monitoring
14	Roland Toth	Control systems group, Dept EE, TU Eindhoven, Netherlands	Data-driven Model-based Control
15	Samir Aberkane	Research Centre for Automatic Control (CRAN), Univ of Lorraine, France	Control, Game theory

7.1 Strategy

In order to facilitate speedy advance in knowledge development in the area of CPS-ICS, collaborations with researchers across the world at the forefront of innovations in the field will be sought. International collaborations are expected to lead to knowledge as well as technology exchange with additional benefits such as manpower training in CPS-ICS. International collaborations will be funded on the basis of a 50-50 cost sharing between TIH-ICS and funding agencies in their respective countries. A total of **INR 5 crores** has been budgeted under this head. A tentative call for proposals for international collaboration is shown in the following table.

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Max. projects		10			
Indicative Max. funding from Hub		17.5 lakhs per project	24.5 lakhs per project	8 lakhs per project	

Funding expected from foreign side		Should match the funding provided to the Indian side by the hub	

7.2 Legal Framework

The legal framework of executing technology development, but not limited to:

- Memorandum of Understanding (MoU) are start points of agreements between IPTIF and foreign funding agencies.
- Licensing or Transfer of IP agreements will be between IPTIF, foreign funding agencies, and project investigators.
- Monetization on IP agreements will be between IPTIF, foreign funding agencies, and project investigators.

Suitable consultants will be onboarded to execute these as per applicable legal regulations.

7.3 Outcomes

The following are the expected outcomes of international collaborations

- Possibility for Indian students/researchers to spend time in foreign institutions of repute.
- Hosting international experts in the domain of ICS at IPTIF, and disseminating knowledge through workshops/talks/seminars.
- At-least 10 researchers/engineers will be inducted into the CPS research base.

08 Conclusion

At its current juncture of scientific progress, India quickly needs to catch up with the notion of CPS in theoretical awareness, implementation, as well as its translation to many walks of social and industrial sectors in the country. The proposed TIH-ICS, whose goals have been elaborated in the previous sections, will precisely cater to a significant portion of this need. From autonomous drones to gliders to underwater vehicles that cater to applications ranging from civilian to defence to agricultural sectors, with robots and their many variants harnessed to both industrial and healthcare domains, with AI and ML ushered in to show its prowess in agriculture in a holistic manner, projects of TIH-ICS are posed to exhibit the synergy among intelligence, autonomy and collaborative systems.

Apart from the scientific temperament highlighted above, the need to address dissemination and expansion of CPS knowledge base, upskilling, technology development and internationalization is addressed in the DPR. Several key strategies are adopted to meet the mission requirements on technology, startups, job creation and entrepreneurship fronts. The finances have been allocated in an optimum manner to ensure successful implementation of the targets.

Activities of TIH-ICS have been planned in such a way so as to ensure outputs and inputs of relevant activities are interconnected. Among the targets, particular high numbers such as job creation, skill development and CPS research base increase has been given special consideration in budget allocation, timeline planning and mode of addressing. Several laboratories and projects are proposed to span across the CPS-ICS focus verticals and application areas, ensuring that we are able to produce technologies and knowledge which will serve towards sustainable development of the TIH-ICS and our country.

In alignment with the Startup-India, Make-in-India, Design-in-India, and Atma Nirbhar Bharat ideologies, that are encouraged by our government, our proposed TIH would enable more jobs, improve self-reliance of businesses in our country, enable them to shrug off dependence on monopolies, and place India as a key technology-enabler to the world. The knowledge, skill development, human resources, technologies, and startups would be addressed on equal footing on global standards, merging the gap between India and the rest of the world.