Revised

Detailed Project Report (DPR) for the Technology Innovation Hub (TIH) for Cobotics at IIT Delhi

[Secition-8 Company: I-Hub Foundation for Cobotics]

Human-Robot Collaboration for Enhancing Human Capabilities, Reducing Risk and Improving Productivity

(Proposed Budget: Rs. 170 Crores)

by

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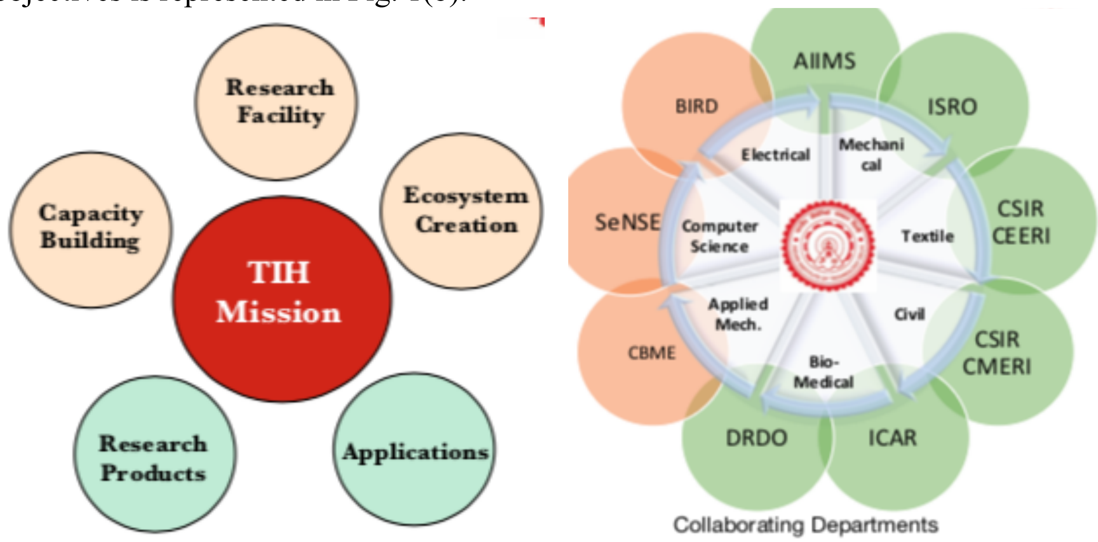
I-Hub Foundation for Cobotics (IHFC)
[Technology Innovation Hub at IIT Delhi]
Executive Summary

The 21st century has been an age of unprecedented advancement in sensing, computing, algorithm research and development. These advances have indirectly ushered a growth in robotics research and its adaptation in the real world. More robots are being used right now in the world than ever and with the COVID-19 crisis acting as a catalyst; this trend is only going to grow.

Extrapolating the trend of adoption, robots are going to play an essential role in society in the coming years, especially in sectors like manufacturing, defence, medicine and disaster management, to mention a few. Intelligent robotic teammates have the potential to expand human capabilities, reduce risk of harm, increase safety, productivity and ultimately the quality of life for our people. Therefore, the development of technology and products that enable the population to work alongside robots is the need of the hour.

With this aim, **I-Hub Foundation for Cobotics (IHFC)** was incorporated as a non-profit (Section-8) company at IIT Delhi in June 2020 with the funding of Rs. 170 crores (USD 20 millions) over a period of 5 years from the Department of Science Technology (DST), Ministry of Science and Technology, Govt. of India. The Director of IIT Delhi (Prof. V. Ramgopal Rao) is one of the board of directors who also chairs the Hub Governing Body comprising of eminent personalities from Government/Ministry, Industry and Academia. Its mission is depicted in Fig. 1(a), whereas the team drawn to achieve the mission objectives is represented in Fig. 1(b).



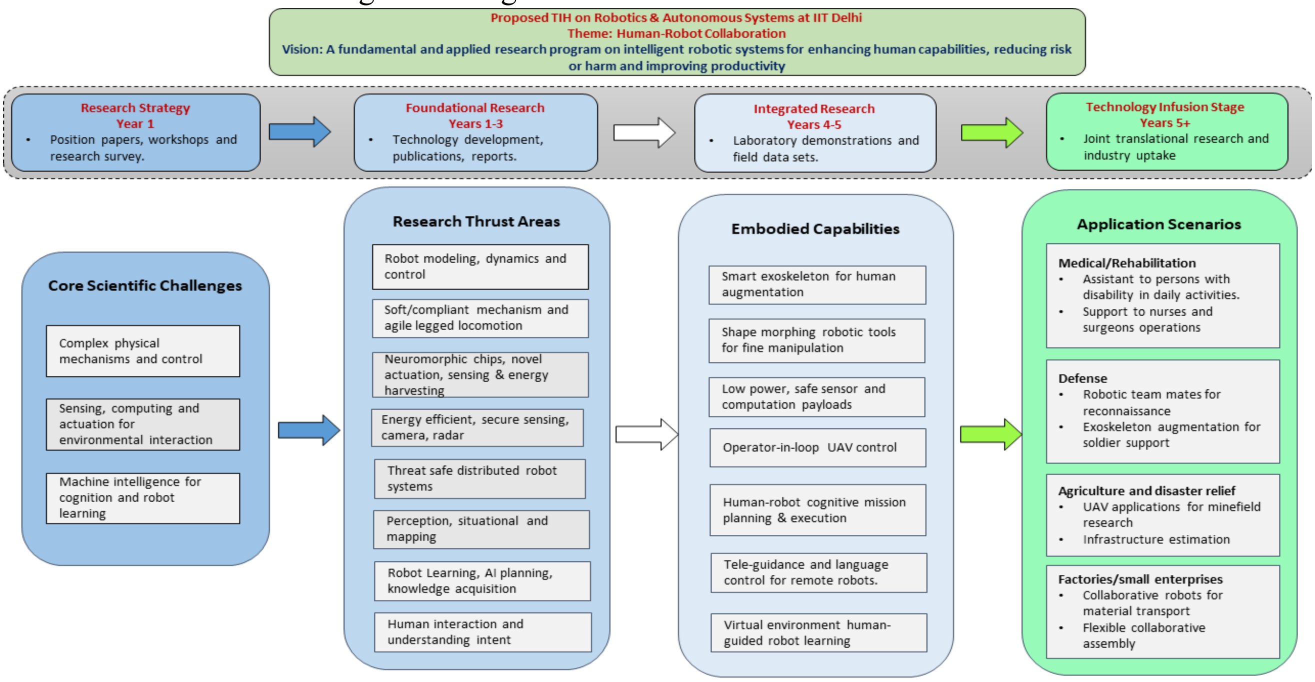
(a) Mission (b) National team

Figure 1 Mission and the team of the IHFC

The guiding theme for this venture is **Human-Robot Collaboration** for Enhancing Human Capabilities, Reducing Risk and Improving Productivity. A total of 100+ faculty from IIT Delhi, other IITs, IIITs, NITs, and universities around the world have agreed to be a part of this venture in addition to industries like TCS, Samsung and Wipro.

As depicted in Fig. 2, the vision of the IHFC is to focus on the research and development of novel technology in the area of robot analysis, design and control, communication, computer architectures, machine learning, artificial intelligence and the design of embedded systems and power topologies.

Figure 2: Program vision of the IHFC



IHFC is tasked with the commercialization of the developed technology into products for application into various target sectors like:

- <u>Medical Robotics</u>: Products and technologies enabling tele operated minimally invasive surgical system (wheeled mobile robots and mounted surgical manipulator)
- <u>Agriculture/Disaster Management</u>: Products and technologies enabling UAV application for minefield research, collaborative mobile robotic manipulator for agricultural assistance.
- <u>Defence</u>: Products and technologies enabling robotic teammates (legged like humanoid or wheeled etc.) for reconnaissance, Exoskeleton/wearable robotic augmentation device for soldier support.
- <u>Factories/MSMEs</u>: Products and technologies enabling collaborative mobile robots for material transport, Exoskeleton/wearable for augmentation of factory workers, flexible assembly lines.

IHFC is actively looking forward for collaborations with industry, start-ups, universities, and R&D organizations in India and abroad to create a market oriented research framework, co-develop technologies and taking them to the market.

<u>Contact us for further details:</u>

Prof. S.K. Saha - Project Director, IHFC (saha@mech.iitd.ac.in, saha@ihfc.co.in)
Mr. Ashutosh Dutt Sharma - CEO, IHFC (ashutosh@ihfc.co.in)

IHFC

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CERTIFICATE

Name of the TIH: I-Hub Foundation for Cobotics (IHFC)

Technology Vertical: Cobotics

1. This is to certify that the Detailed Project Report (DPR) on the Technology Vertical Cobotics 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 Delhi (IITD) (Host Institute name and address) functioning at its premises at Hauz Khas, New Delhi - 110016 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 04th December 2020 between Mission Office, DST, Indian Institute of Technology Delhi (IITD) and I-Hub Foundation for Cobotics (IHFC).

Date: 15-09-2021

Place: IITD, New Delhi

Prof. Subir Kumar Saha

Project Director, IHFC

Endorsement from the Head of the Institution

1. Certified that the Institute welcomes participation of Dr. Subir Kumar Saha as the Project Director(s)/Co- Principal Director for the Technology Innovation Hub (TIH) and that in the unforeseen event of discontinuance by the Project Director, the Indian Institute of Technology Delhi (IITD) will identify and place a suitable faculty as Project Director for fruitful completion of the TIH activities.

2. Certified that the Host Institute shall provide basic facilities, faculty support and such other administrative facilities as per Terms and Conditions of the award of TIH, will be extended to TIH.

3. As per Tri-partite Agreement, the Host Institute (HI) shall play its role and fulfil its responsibilities for the success of TIH.

Date: 15-09-2021

Place: IITD, New Delhi

Prof. V. Ramgopal Rao

Director, IIT-Delhi

Abstract

This document presents the Detailed Project Report (DPR) of the Technology Innovation Hub (TIH) for Cobotics at IIT Delhi which was registered on June 13, 2020 as a Section-8 (non-profit) company, i.e., **I-Hub Foundation for Cobotics (IHFC)**. This version of the DPR is prepared based on the observations made by the Mission office as per their letter dated Jan. 22, 2021, original DPR submitted to the DST on June 14, 2020, followed by a revised one on August 30, 2020, and the Tripartite Agreement signed on Dec. 10, 2020 between IHFC, IIT Delhi, and the funding agency, i.e., Department of Science and Technology (DST), Govt. of India. The TIH was originally approved by the DST in March 2020 followed by the sanction of Rs. 170 crores under the National Missions on Interdisciplinary Cyber-Physical Systems (NM-ICPS) programme as per their letter dated August 04, 2020. The theme of the IHFC is *Human-Robot Collaboration for Enhancing Human Capabilities, Reducing Risk and Improving Productivity*. It has the context and background, aims and objective, management, finance, strategy, legal and ethical aspects, etc., as per the 15 items specified by the DST, and the list of collaborators along with the brief summary of their proposals submitted to the IHFC at IIT Delhi.

Acknowledgement

The team of the Technology Innovation Hub (TIH) for Cobotics at IIT Delhi, which is a Section-8 (non-profit) company **I-Hub Foundation for Cobotics (IHFC)** under the leadership of Prof. V. Ramgopal Rao (Director, IIT Delhi), takes this opportunity to thank DST for considering IIT Delhi in the area of Cobotics, which is very apt for the theme on *Human-Robot Collaboration* that was originally submitted by IIT Delhi. The team also thank the DST for its sanction of Rs. 170 crores as per the letter dated August 04, 2020, and releasing the first instalment of Rs. 22.25 crores after the signing of the Tripartite Agreement in Dec. 2020. The team sincerely thank all 50+ faculty at IIT Delhi, and almost the similar number of collaborators from other IITs, IIITs, NITs, and universities around the World, namely, USA, Canada, Europe, Australia, Japan, and South Korea for their interest, consent, and submission of the projects. Industries like TCS, Wipro, Addverb and those from abroad like RoboSurg from Singapore, Hansan Robotics from Hongkong, and similar are acknowledged for their interest and possible commitment to co-develop products for the TIH, i.e., IHFC, at IIT Delhi. Finally, the start-up companies like Peer Robotics, GreenLeap Robotics, Botlab Dynamics, and others are acknowledged for their consent to convert technologies from the IHFC for commercial use.

The Board of Directors of IIT Delhi is thanked for their immediate approval of the Section-8 company, as required by the DST to open the Section-8 company, which was formed just in two months. The other administrative sections at IIT Delhi including the R&D unit are thanked for their help. Finally, the active participation and the guidance of the members of the Hub Governing Body (HGB) of the IHFC whose members are from reputed industries like TCS, Samsung, Milagrow Robotics, institutes like IITs, and the NM-ICPS Director are highly acknowledged.

Contents

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While preparing this DPR, the proposals from the collaborators from India and abroad (academic institutes/R&D organizations/industry) that were prepared in a prescribed format are included. The focus is of course the translation of knowledge into the products which is the emphasis of the National Missions on Interdisciplinary Cyber-Physical Systems (NM-ICPS). Following the incorporation of the IHFC company, a savings bank account was opened at SBI IIT Delhi where the first instalment of Rs. 22.25 crores were received after the signing of the Tripartite Agreement. See attached the Certificate of Incorporation in Appendix III, and the Bank Statement in Appendix IV.

The following 15 sections explain various aspects of the IHFC or the TIH for Cobotics at IIT Delhi.

1. Context and Background

(i) Description of the Hub

The Technology Innovation Hub (TIH) at IIT Delhi is focused towards a particular theme of the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS), i.e., Cobotics or Collaborative Robotics for Human-Robot Collaboration (HRC).

(ii) Context

Advances in sensing, computation and autonomy are enabling robots and autonomous systems to enter real-world domains such as manufacturing, defence, medical, agriculture, etc. where machines must work alongside and interact with humans. We are entering an era of "*manned + unmanned*" teaming where humans and robotic systems must work together towards common goals.
Intelligent robotic teammates, have the potential to expand human capabilities, reduce risk of harm, increase safety, productivity and ultimately the quality of life for our people. The competency in *Cobotics or Collaborative Robotic Cyber-Physical Systems* is crucial for our country such that robotic systems enhance the capabilities of our workforce rather than trigger replacement. Internationally, a number of research programs have turned attention to this area. Hence, it is vital for India to create capacity and advance capabilities in this area.
The proposed TIH for Cobotics at IIT Delhi is driven by the vision of moving the nation towards the cutting edge in this area of strategic importance. The hub at IIT Delhi is envisioned as a world-class technical resource with competencies in foundational research, complex system design and vibrant application-focused innovation.

(iii) Intellectual focus

The proposed hub envisions to contribute towards fundamental knowledge, technology development and innovative application development to realize effective human-robot collaboration. See Figure 1.

- The development of intelligent robots or machines for human assistance requires scientific advances in primarily three interconnected areas. They are listed under “Core Scientific Challenges”. The proposed research projects will be organized as “Research Thrust Areas” targeting specific scientific challenges.
- The research activities carried out under the research thrust areas will converge into “Embodied Capabilities” contributing towards advanced Cyber-physical systems unlocking new applications in a variety of domains.
- The proposed TIH will enable sustained evolution and realization of platform capabilities arising from scientific investigations into addressing technical barriers in realizing Cobotic Cyber-Physical Systems (CPS). The key components of the TIH program are discussed in this and subsequent sections.

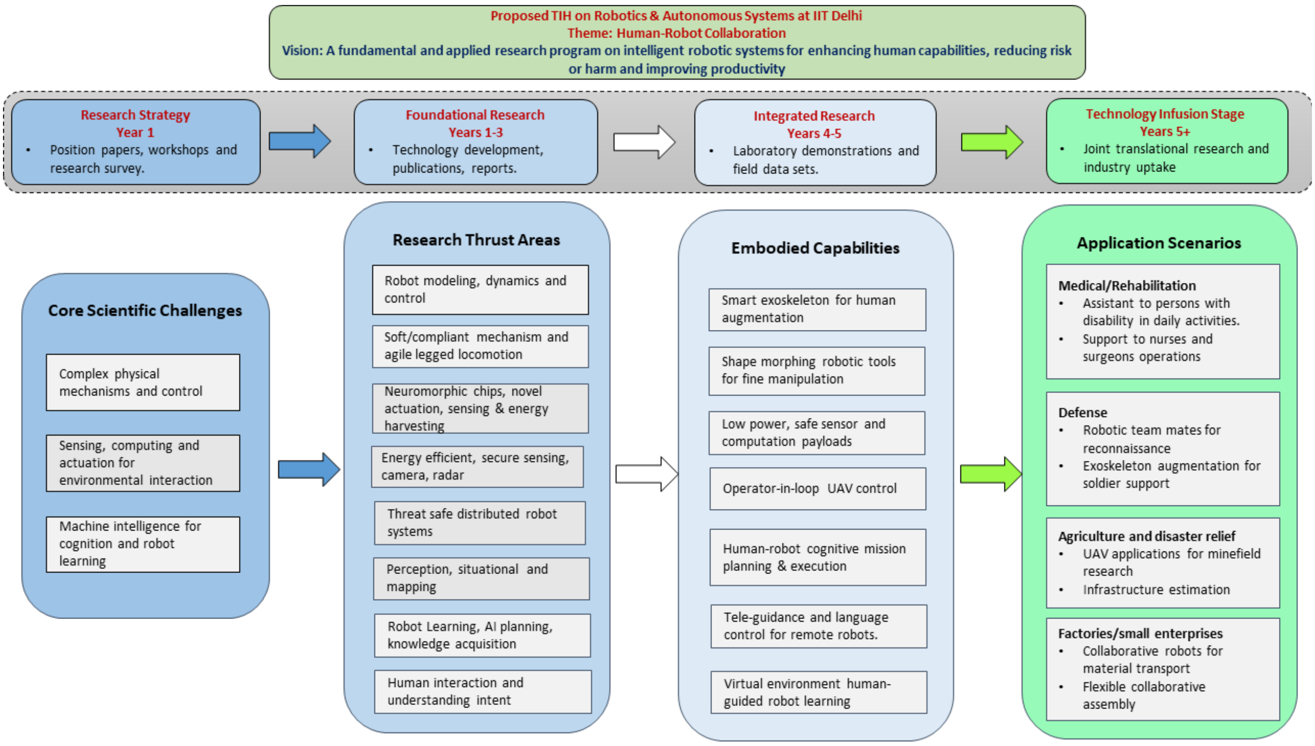


Figure 1: Program vision of the TIH for Cobotics at IIT Delhi

(iv) Proposed Activities

The spectrum of activities to be carried out in the proposed hub is as follows.

- **Inter-disciplinary Research Program:** The proposed hub will act as a research collaboration drawing faculty from multiple departments in the institute such as Mechanical Engineering, Applied Mechanics, Electrical Engineering, Computer Science and Engineering, Physics, Textile Engineering, Humanities and Social Sciences (HSS), and specialized centres like SENSE (Centre for Sensors, Instrumentation, Cyber-Physical System Engineering), CBME (Centre for Biomedical Engineering), Centre for Applied Research in Electronics (CARE), the Center of Excellence (CoE) on BIRD (Biologically Inspired Robots and Drones), and allied groups in the institute.

- **Establishment of Cobotic-CPS Laboratory Ecosystem:** The TIH program will lead to the establishment of modern laboratory facilities to support intra- and extra-mural research critical for carrying out high-end work. The facilities will be made available as a national resource centre in the area of Cobotics to all associated researchers who are either its collaborator or use the facility on payment basis.
- **Infusion of Academic Programs:** The hub proposes to establish new opportunities for B. Tech., M. Tech., MSc, MS(R), PDF, Ph. D students and scholars with the aim of creating future leaders in the area. Also, interfacing with the programmes like M. Sc in Cognitive Sciences by the Dept. of HSS is under discussion.
- **Focal point of Knowledge/skills:** The hub wants to grow towards a major focal point of some targeted technological capabilities like exoskeleton for soldier support and medical rehabilitation, algorithms for human-robot teaming in defence and industries, imaging and control algorithms for robot-assisted minimally invasive medical surgeries, etc. in the next couple of years.
- **Interface with Industry and Agencies:** One of the other mandates of the hub is to create an industrial and start-up ecosystem, where the hub can act as an accelerator for burgeoning deep tech startups in collaborative robotics fields. The hub will interface with national agencies like CSIR labs, industries like Wipro, Fourier Intelligence, etc., start-ups like Peer Robotics, Botlab Dynamics, etc. and international partners like Monash University, Laval University, etc. for idea exchange and joint research.

(v) Progress towards advanced Cobotic CPS Systems: The TIH Research and Development Roadmap is illustrated in Figure 1.

- Technical advances in scientific areas will be addressed by research activities organized in thrust areas culminating in new capabilities and evaluation (Year 1-3).
- Progress in multiple research thrusts will be collated and realized on robotic platforms leading to Embodied Capabilities (Years 4-5).
- The embodied capabilities would represent several sub-systems working together in laboratory-scale demonstrations and enable interface with agencies, industries, and other organizations for embarking on translational research and technology infusion (Years 5+).

(vi) Short and Long-term research and translation goals: Our team will address scientific challenges in thrust areas contributing towards capabilities embodied in realistic robotics research platforms. Our knowledge-sharing and translational strategy is continual and multi-fold as illustrated in Figure 1.

- First, research will focus on foundational knowledge, models and systems that will fill key technical gaps in applications and scenarios derived from downstream application scenarios. Second, our development activities have arisen from close interaction with industry and national agencies. Finally, our engagement with partners will be continual. For example, we will organize scientific symposia to share the state of the art and envision research in scientific areas in collaboration with agencies and industries. This will assist partners in keeping abreast with the current technical progress in their area of relevance. Please refer to "Research Thrust Areas" of Figure 1.
- We will share key outcomes from research under technical areas giving partners visibility into new emerging results and system prototype development. In the later part of the program, we will organize a capability/skill showcase demonstrating capabilities on research platforms bringing together research in multiple thrust areas. Such a showcase is intended to allow partners to conceptualize and initiate joint research, translational research, and technology infusions activities. Please refer to "Embodied Capabilities" of Figure 1. The above highlights the catalytic role of the

hub as providing a platform to build foundational capabilities drawn from multiple research strands; allowing multiple partners to absorb the know-how in domain-specific ways.

- In the long term, the generated know-how and competencies will contribute to key components for enabling eventual applications. Our guiding principle will be to improve the quality of life for the common people, to serve India's strategic interests, and to enhance competitiveness of our industries/agencies. Next, we target application scenarios in the following domains: (i) Medical and assistive/rehabilitation, (ii) Defence and strategic national interest, (iii) Agriculture and disaster relief, and (iv) Factories and small enterprises. This is indicated under "Application Scenarios" of Figure 1. We will also target skill demonstrations and real-prototype development in laboratory/controlled environments as listed in the previous section.

2. Problems to be Addressed (Grand Problem)

Human–robot collaboration is a new frontier for robotics, and the human–robot synergy will constitute a relevant factor in industry for improving production lines in terms of performances and flexibility. This will only be achieved with systems that are fundamentally safe for human operators, intuitive to use, and easy to set up. In a country like India where work-force is one of its biggest assets, Cobots and not Robots is the need of the hour to make it even more competitive in global arena.

At present, the know-how and technical knowledge in Cobotic Systems is in its infancy with very few applications and practical demonstrations. Current systems largely perform repetitive and short-horizon tasks in environments mostly isolated from human partners. Specifically, the capabilities of contemporary Cobotic systems are limited in the scope, nature and complexity of tasks that they can perform. Further, their ability to work alongside (e.g., manipulators in factories), attached with (e.g., exoskeletons, soft robotic tools), and in synergy with humans (e.g., aerial, mobile platforms in large areas) is fairly restricted.

The development of future Cobotic CPS systems for human assistance requires scientific advances in primarily three areas.

- **Scientific Challenge I:** The development of complex physical mechanisms and control for performing dexterous real-world tasks.
- **Scientific Challenge II:** The realization of high-fidelity sensing, energy-efficient computing and smart actuators for environment interaction.
- **Scientific Challenge III:** The development of computational models for machine intelligence for cognition, planning and learning from experience.

The identification of needs and focus areas stems from academic discourse, industry inputs, national/international perspective and past experience of the institute in this area. Apart from technical gap areas, there is an urgent need to build human resource capacity in this area in the country. Training of students and researchers is necessary to advance knowledge and build capabilities requiring a concerted effort. Finally, development of CPSs is a challenging task requiring multiple capabilities to converge in a concentrated manner. Hence, it is important to build linkages between institutions and industry partners and establish multi-dimensional teams to develop and realize complex systems.

Next, we discuss certain application areas that have motivated our research priorities discussed in this document.

a) **Application Scenario I: Medical and Rehabilitation Robotics <u>(Priority 1)</u>**

Context: Medical Robotics will fall in two sectors, namely rehabilitation and surgical robotics: a) An affordable rehabilitation device is the current need in a populous country like India. The hub plan to develop capability in affordable rehabilitation space in collaboration with specialty hospitals like Indian Spinal Injury Centre, AIIMS, New Delhi, and similar; b) Tele-operated medical robotics holds the future of minimally invasive complex surgical procedures. A robotic surgical tool is not meant to replace a surgeon, rather it is going to be a sophisticated tool given to a surgical expert to carry out the procedure in a minimally invasive, error-free manner. Advantages are less hospital stay for the patient, quick heal, less human-related surgical error, etc. The illustrations are shown in Figure 2.

[Image courtesy: SS Innovations, Google Images]

Figure 2: Application scenarios in medical and rehabilitation robotics

Capabilities: We want to develop the following capabilities i) Exoskeleton for human augmentation, ii) Brain-machine Interface, iii) Tele guidance and Language control for remote robots, iv) Shape morphing manipulation. These capabilities will arise from research in the thrust area of soft/compliant robotics. Other capabilities that need to be integrated for successfully building a medical robot are: mobile robotic platform; Algorithm for synchronization and control; Localization; Tele-operation communication protocol; Surgical manipulator and tools; Precision manufacturing; Computer vision; Haptics; and Biomechanical modelling.

Application use-cases: The following use-cases are considered.

- **Augmentation devices**: Smart exoskeleton for rehabilitation of spinal cord injured patients. Old age geriatric support. Deployment in the production line of industry where manual operation still needed to be done.
- **Surgical robotics**: Tele-operation also brings a number of advantages like experts can now operate without physically going to the operation. This might be tremendously useful also in defence scenarios, where injured soldiers can be treated remotely through teleoperated surgical robots.

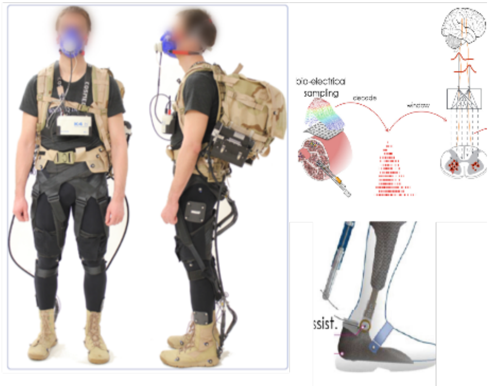
Technology Translation: The robotic augmentation devices for rehabilitation purpose will be developed in collaboration with the Indian Spinal Injury Centre (ISIC). ISIC will provide medical expertise, as well as in-field patient requirements. For the surgical robotics domain, IIT Delhi has partnered with Robosurg Med-Tech Pvt. Ltd. a US-China-India-Singapore based medical robotics company whose own surgical robotic platform is ready to be launched. Also, the institute is in talks with Intuitive Surgical Inc., USA for their Da Vinci research platform-centered university collaboration.

b) Application Scenario II: Human-Robotic Teaming for Defence and Strategic Missions

Context: There is a need for robotic systems that provide augmented intelligence for human soldiers with the goal of removing the human from harm's way, improving safety as well as operational effectiveness and mission tempo. This is particularly relevant for missions in uncertain or hazardous domains with limited prior situational awareness. Figure 3 illustrates this scenario.

Capabilities: We aim at developing the following capabilities: (i) AI-Enabled Intelligent Robotic Team-mates for Indian Soldiers, (ii) Exoskeleton for augmenting soldier capabilities. These capabilities will arise from research thrust areas of perception, situational awareness, human interaction, AI/Machine learning, robot learning, sensing, soft/wearable suits. The output product is envisioned as a prototype intelligence architecture/software that allows semantic understanding of the environment, ability to interpret high-level goals and execute behaviours on a standard research platform.

Robot team mate securing and facilitating platoon movement. securing the soldier in case of injury during mission.



Lower-limb exo-suits for defense personnel for augmenting physical abilities.

[Image courtesy: Google images]

Figure 3: Application scenarios in Human-Robotic teaming for defense and strategic missions

Application use-cases: Some use-cases are explained below.

- **Robotic team mate to reduce risk to human soldiers:** An intelligent robotic system that can interpret high-level mission instructions from a human, perform semantic reasoning and execute actions. Such a robotic system can assist in military logistics, inspecting unknown areas prior to platoon arrival, securing the soldier in case of injury during mission, unmanned-cordon guarding a manned-platoon during movement etc.
- **Augmentation of soldier capabilities:** Lower-limb exo-suits to protect and enhance physical soldier capabilities during strenuous missions. Brain-machine interface for suite control. Applications for soldiers posted in difficult northern terrain need performance-boosting full-body wearable exoskeleton, shape-changing camouflaging jacket or bioinspired soft robotic artillery.

Technology Translation: The development of robotic systems that can serve as team mates to soldiers in a variety of missions has been recognized in India. It will have increased safety and effectiveness for human soldiers in military and strategic operations. DRDO is embarking upon a national program on System and Technologies for Advanced Robotics (STAR) to create robotic soldier team mates to assist human soldiers. In particular, the STAR program has laid out the vision for robotic assistance in logistics, reconnaissance, and mobility in complex terrains. The ability of intelligent robotic team mates has applications in other allied strategic areas. These include inspection and monitoring of strategic assets. For example, human-guided/teleoperated inspection for tactical assets such as Navy aircraft carriers, bridges, etc. Similarly, human collaborative robotic and autonomous systems are crucial for India's Space Program due to the inherent risk in human exploration, for example, long-range operation and maintenance of space assets.

(c) Application Scenario III: Agriculture and Disaster Relief

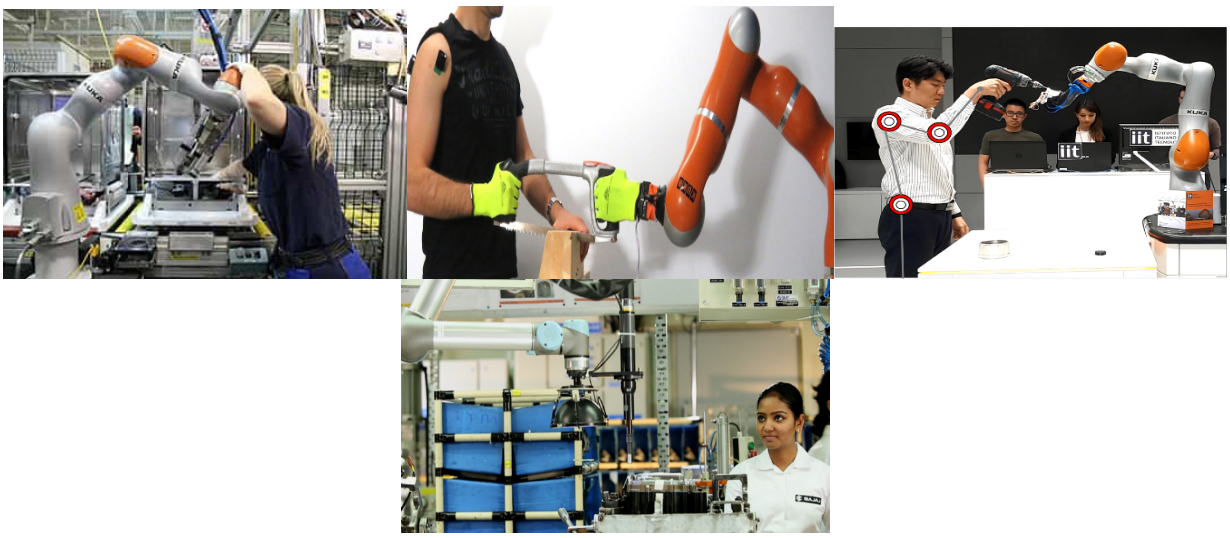
Context: The agricultural sector is rapidly becoming a high-tech application arena of robotics. Need for greater yield to cater for the burgeoning population growth, precision harvesting to circumvent the increasing urbanization, socio-economic implications and diminishing manual labour in the farming sector all have necessitated the increased application of robotics and automation. Some examples are shown in Figure 4.

[Image courtesy: Google images]
Figure 4: Robotics applications in agriculture

Capabilities: We aim at developing capabilities of operators in the loop for UAVs and shape morphing robotic manipulation tools for precision agriculture. These capabilities will arise from research thrust areas of Robot modeling, dynamics and control, perception, situational awareness, human interaction, AI/machine learning, robot learning, sensing, soft/compliant mechanism. The output product is envisioned as a prototype intelligence architecture/software that allows to substitute repetitive monotonous human involvement, quick assessment of soil moisture content, fertilizer requirement and other decisions influencing information for farming and better yield.
Application use-cases: Some use-cases are elaborated below.

- Harvesting and picking, weed control, Drone-based autonomous mowing, pruning, seeding, spraying and thinning, Phenotyping, sorting and packing, etc.
- Soft robotic grippers can be used in conjunction with finite DOF robot arms for agricultural harvest.

Technology Translation: IIT Delhi is going to collaborate with WIPRO in the technology translation stage to transfer capability to the industry to in-field product deployment.
(d) Application Scenario IV: Factories and Small enterprises (Priority 2)
Context: The manufacturing industry is moving towards the next generation of assembly, which is conducted based on safe and reliable robots working in the same workplace alongside humans. The machine does not replace humans but complements his capabilities and relieves him of hazardous tasks. Human-Robot Collaboration (HRC) is a challenge for industry today. Some illustrations of HRC in factories are given in Figure 5.



[Image courtesy: Google images]

Figure 5: Application scenarios in factories and small enterprises

Capabilities: We aim at developing collaborative mobile robots and mobile manipulators which could be used in warehouses for transporting goods, in factories for collaborative assemblies, in hospitals and homes as service robots, etc. These capabilities will arise from research thrust areas of Robot modelling, dynamics and control, perception, situational awareness, human interaction, AI/Machine learning, robot learning, sensing, soft/compliant mechanism. The output product is envisioned as a prototype intelligence architecture/software that is used to augment human workers' capabilities to increase the throughput with a reduction in cognitive load. At the same time, it will also improve the safety of the workplace and is highly efficient in hazardous work environments.
Application use-cases: Few use-cases are explained next.

- The Human-robot collaborative assembly task or load transport task will be demonstrated with cobots mounted on the mobile platforms. In this prototype, we will leverage Reinforcement Learning (RL) based approaches for modelling the human-robot interaction dynamics. Also, a framework will be developed for a user to teach a robot collaborative skills from demonstrations.
- Intelligent mobile robots will be developed with various payload capabilities to be used in warehouses that can navigate in human-shared spaces.
- Different robotic systems like fixed-base industrial robots, mobile robots and similar intelligent machines will be networked with the Internet of Things (IoT) protocols to know the status of flow of materials in a factory or the health of the robotic devices for preventive maintenance.

Technology Translation: IIT Delhi will collaborate with Peer Robotics (a spin-off from IIT Delhi) in the technology translation stage to transfer capability to the industry to in-field product deployment.

3. Aims and Objectives

The TIH for Cobotics at IIT Delhi aims at primarily contributing towards scientific and technology development goals. These are outlined in Part I below. Further, we seek to undertake the broad objectives of developing an enabling national-level ecosystem to support advanced R&D and networking between a community of dedicated researchers. These objectives are laid out in Part II.

Part I: Scientific Aims and Objectives

a) Knowledge Generation

We propose to undertake collaborative R&D activities in key thrust areas targeting new capabilities. The initial set of thrust areas include:

- Dexterous manipulation and agile legged locomotion
- Robot modelling, dynamics and control
- Soft/ compliant robot mechanisms
- Perception and localization
- Human modelling and understanding intent
- Planning, reasoning and knowledge acquisition
- Learning and artificial intelligence
- Sensors, neuromorphic chips and quantum technologies
- Domain-focused needs in aerial, humanoid, exoskeletons, mobile manipulation
- Ethics and cognitive science aspects
- human-robot interaction
- human-automation

(b) Technology/Capability Development

The TIH aims at the realization of new technical capabilities arising from research carried out in thrust areas. The initial focus will be on the following capabilities:

- Smart exoskeleton for human augmentation and rehabilitation
- Shape morphing robotic tools for dexterous manipulation
- Novel actuation, sensing and control system design
- Intelligent Architecture for cognitive planning and learning
- Human guided robot teaching system
- Tele-guidance and human-machine/language interface for remote robot
- Operator in loop UAV control for disaster management and agriculture application
- Energy-efficient and harvesting sensors
- Low-power neuromorphic processing
- Secured Communication

The resulting technical capabilities will contribute towards experimentation/realization of advanced Cobotic CPS systems. The experimentation will progress from simulated, standard physical research platforms or physical platforms developed in the program. We envision contribution towards three types of Cobotic CPS systems:

- CPS type I: Exoskeleton like wearable and soft/hard co-robotic tools operated by a human partner.
- CPS type II: Human-in-loop aerial/manipulation/mobile Cobotic CPS platforms
- CPS type III: Novel sensing, processing and optimization payloads for Cobots.

(c) Knowledge Translation and Applications

The generated know-how and competencies will contribute key components for enabling eventual applications. As mentioned above, our guiding principle will be to improve the quality of life for the common people, to serve India's strategic interests, and to enhance competitiveness of our industries/agencies. The proposed research is motivated by applications in the medical, rehabilitation, manufacturing, agriculture and in strategic areas. Specific activities include:

- Establishment of an interface to engage industry and national agencies
- Development of collaborative projects and technology infusion
- Industry-focused innovation and application creation
- Incubation of innovative ideas as potential start-ups
- Support via technical advisory and mentorship
- Exploration of applications of basic technologies and know-how to support neglected societal needs.

Part II: Capacity Building and Ecosystem Creation

a) National Ecosystem Creation

The TIH aims at establishing linkages with other national institutes, agencies, institutions in a hub and spoke model. The TIH plans to bring together the best Indian academia has to provide and make a seamless collaborative platform with the respective industries in a number of application areas. We envision the infusion of new ideas via workshops and joint research initiatives. In the long run, the TIH will enable the emergence of a community of networked researchers in this field in India. Proposed activities include:

- Inter-departmental and inter-institutional partnerships, alliances and joint activities

- Visits, interactions and exchange activities
- Workshops, tutorials and awareness activities

b) Education and Skill Development

The TIH aims at the involvement of students and research staff in research and development. Further, we plan introduction of new course materials and programs in this area. Specific activities include:

- Support to Research staff, Post-doctoral Fellows, Students (Ph.D., M. Tech, B. Tech, MS(R), MSc). Support of M. Tech/Interdisciplinary undergraduate program.
- Introduction and support towards courses, academic programs, and teaching modules. Support for innovative student projects.
- Outreach to students from disadvantaged backgrounds to provide exposure to advanced technologies.

c) Advanced Research Facility

The TIH aims at establishing an enabling laboratory ecosystem to support research, education and development activities. The research facility will be crucial for supporting cutting edge work and realization of advanced capabilities, experiments and demonstrations.

- **Existing facilities:** IIT Delhi will provide CRF (Central Research Facility); NRF (Nano Research Facility); Mechatronics lab, Programme for Autonomous Robotics lab in the Department of Mechanical Engineering; Control lab, Multi-media lab, Swarm Intelligence Lab in the Department of Electrical Engineering. Department of Computer Science and Engineering labs will support this activity in the area of intelligence, perception and learning/AI-based robotics. High-performance Computing Facility with GPU support will also be made available for specific project components that require large amounts of data-driven learning.
- **Future facilities:** Along with the above facilities, the TIH at IIT Delhi plans to establish new laboratories which include CPS platforms, sensors, equipment, testing, fabrication, experimentation, etc. We plan to develop the following facilities: GAIT analysis facility; Surgical robotics research lab; Drones robotics platform for agricultural research; Integrated circuit characterization capability; Material characterization facilities; Additive manufacturing facility, Cognitive science lab etc. It will also work together with SATHI (Sophisticated Analytical and Technical Help Institute) sponsored by the DST to IIT Delhi in order to synergize the research facilities of the TIH.

4. Strategy

Successful organization development depends on the clarity of its vision-driven foundational strategies. In this aspect. The overall roadmap of the TIH for Cobotics has been built upon the following strategic point, as indicated in Figure 6:

Strategy 1: Emphasizing on capability building

Strategy 2: Core interdisciplinary framework

Strategy 3: Strong national and international collaboration and industry connect

Strategy 4: Leveraging on the past and present experience on robotics, autonomous systems, and collaborative robotics-related research.

Strategy 5: Playing a role in nation-building through start-up ecosystems and human resource development

Strategy 6: Self-sustaining revenue model

Our strategies will contribute towards both scientific outputs and establishment of a national level ecosystem.

STRATEGY 1: Emphasis on embodied capabilities and platform technology development

One of the basic hallmarks of the TIH for Cobotics is giving more emphasis on Embodied in-house capability building. The pictorial representation of this architecture is given in Figure 6. This mode of operation has been adopted against operating as a mere collection of a number of research projects defined over the next five years. Embodied capabilities can be applied in building multiple platform technologies and products in different application domains. The embodied capabilities have been further classified into multiple research thrust areas where targeted research problems were defined. It was envisioned that embodied capabilities will lead to development of tangible technologies in the technology infusion or translational phase. The idea behind this framework is as follows:

1. **Purposeful Industry-academia engagement**: To utilize the best capabilities of both academia and industry. Traditionally, it has been seen that academia is good at concept, knowledge, skill and know-how development, and industry, on the other hand, specializes on more product-oriented design and development. The present TIH's mandate is to bring this two diverse expertise under the same umbrella. The technological translation phase is where respective industries from different application domains will shake hands with groups inside the TIH with developed embodied capabilities to translate into realizable technology.

2. **Sustainable "Organic" growth model**: The second aspect of this mode of operation is to give the TIH a evolving and sustainable growth model for the future without changing the overall framework. New embodied capabilities can come under the TIH in future as more diverse groups of projects are brought in, at the same time older capabilities can be dropped or dissolved as needed. New applications can also emerge and be dropped as required in future. This mode of operation is much more organic in nature and guarantees long term sustainability. For example, in the current five years plan we have not considered collaborative robotics applications in the space robotics area. In future, space will be an important domain to add under applications scenarios, and ISRO and other space-related start-ups can be brought in for space robotics-related technology translation.

3. **Accessible one stop solution for technological capabilities**: The TIH has been envisioned to work as an accelerator to relatively matured start-ups and industries. It plans to be a one-stop solution for technological capabilities and advanced know-how for different "sectoral" industries (medical, agro, MSME, defense). At the same time, state of art facilities are planned to be developed for targeted industry-oriented technology development and solutions. Proximity to an institution of national importance like IIT Delhi, it will act as a knowledge factory for the industries in the coming days. IIT Delhi already has the Forum for Technology and Technology Transfer (FITT) in its campus, which acts as its industry interface and incubator for the startups for various Govt. funding agencies like BIRAC, DST, DBT, etc. The TIH plans to append it lead it to a larger scale adopting the role of an accelerator, in collaboration with FITT.

Figure 6: Strategy for the proposed TIH for Cobotics at IIT Delhi

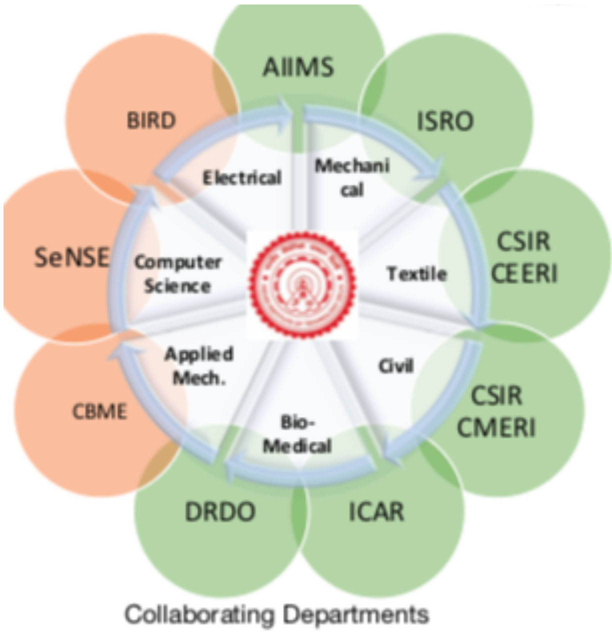


Figure 7: Multi-disciplinary approach

STRATEGY 2: Core Interdisciplinary Framework

As shown in Figure 7, the Hub and Spoke model will be adopted which is based on an interdisciplinary skill-based association with internal and external organizations. The TIH for Cobotics has successfully been able to bring together interdepartmental skillsets existing in the IIT Delhi campus as well as many renowned institutes and national labs. One of the strengths of the TIH at IIT Delhi is that it is not driven by one single department. Faculty with robotics-related specializations and skillsets from multiple departments have been roped in to formulate the overall research team. In cases where the skill sets were absent in IIT Delhi campus, the TIH has looked beyond and has been able to successfully engage various other Institutes in the country. The list of partners and collaborating departments from IIT Delhi in this proposal is provided in Appendix I.

STRATEGY 3: Building on strong national and international collaboration and industry connect

One of the other characteristics of the TIH for Cobotics is its wide national and international network. In particular, enormous emphasis has been given to build a wider network of industry connections. Technology translation in partnership with specialized industries is going to define the future of the TIH for Cobotics.

Following engagements have been initiated to ensure relevant industry collaboration (both national and international)

a. We have members from TCS, Samsung and Milagrow Robotics in our Hub Governing Body (HGB). We are in discussion with them to collaborate and forge meaningful partnership with their organisations to achieve the identified objectives.

b. We have set-up a network of partners to have an access of start-up eco-system in this domain. We are tying with them to collaborate on relevant research projects to ensure there is a market connect in the research projects we undertake.

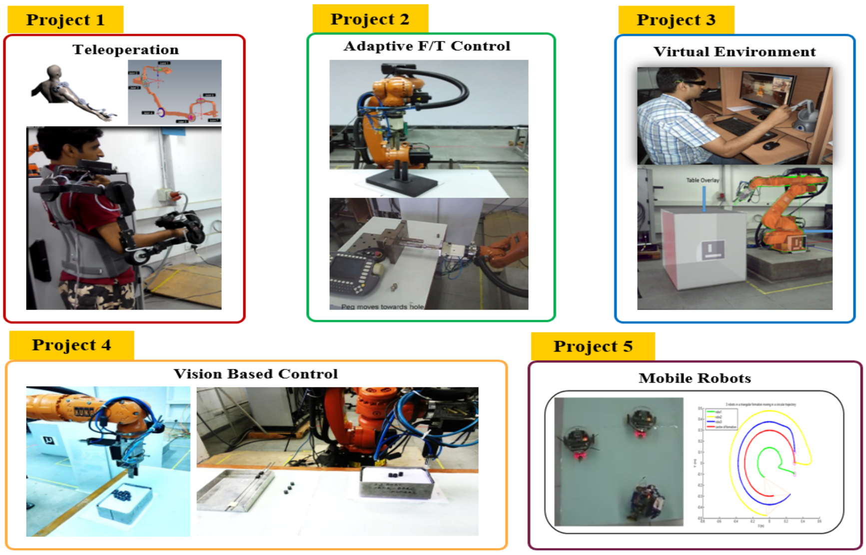
c. Initiated business development activities to get consulting projects and hence ensure that real time market problems are identified for research and output delivered back in a time bound manner. For example, we are working with GreenLeap Robotics for making a low-cost solar panel cleaning robot for SoftBank Energy. We are also working with Addverb Technologies to create algorithms for indigenously designed Cobot.

d. Working with the Inter Ministerial Co-ordination Committee (IMCC) set-up by DST in association with NITI Aayog to forge strong connects with PSUs and Ministries and thereby working on identified socio-economic problem.

STRATEGY 4: Leveraging on the past, ongoing research and development experience in Robotics research to build the future roadmap

We would categorize the collaborative activity in the following three categories: *Past, Present and Future*, as described below.

Figure 8: Robotic simulators for Simulator Development Division, Secunderabad



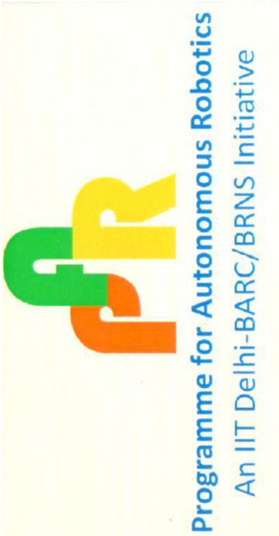


Figure 9: BRNS-funded projects at IIT Delhi under the Programme for Autonomous Robotics

Past:

1. Simulator Development Division (SDD), Secunderabad (2007-2016): Two funded projects were successfully completed.

a. To conceptualize a walking simulator for the army jawans to be trained without really going to the field. The system called OASIS was built at IIT Delhi before it was transferred to SDD.

b. To design a motion simulator of a truck which is basically a parallel robotic device. It was a funded project. The system was designed and fabricated by an outside company. The technology was transferred. See Figure 8.

2. BARC, Mumbai (2010-2016): In a funded Programme for Autonomous Robotics (PAR), five sub-projects with very specific objectives were completed before they were implemented and demonstrated to the scientists of BARC. See Figure 9. The knowledge was completely shared with BARC.

3. Tata Consultancy Services (2018-2019): In another funded project, the knowledge generated in the BARC project was extended to the Industrial Robot (Brabo) developed by Tata Automation Limited (TAL). The results of kinematic identification and calibration of Brabo were handed over to TAL.

Present:

1. Tata Consultancy Services (TCS): In another funded project, drone-based manipulation for aerial inspection is under development.

2. Wearable Soft Robotics for Upper Limb Muscle Power Augmentation with Brain-Machine Interface - A proof of concept study, DRDO DEBEL-IITD JATC.

Figure 10: National and international collaborators of IIT Delhi

Future:

1. Robosurg Med-Tech Pvt. Ltd.: It is a US-China-India-Singapore based medical robotics company who has been developing surgical robots to replace Da Vinci. The company has already developed robot hardware in China but wants IIT Delhi's support to develop control software.

2. Peer Robotics: It is a start-up company on collaborative robots which evolved from the robots used at IIT Delhi for the robotics competition organized by Doordarshan.
3. Botlab Dynamics: It is an already established Drone company in the campus. They want design inputs from IIT Delhi faculty and students.
4. Indian Spinal Injury Centre: It has been interacting with several faculty of the institute for collaborative activities
5. DRDO labs like DEBEL, CAIR: For defence exoskeleton project, IIT Delhi faculty were contacted to evolve a new project to be funded by a Ministry of Defense (MoD).

Figure 10 depicts our national and international collaborators for the TIH for Cobotics at IIT Delhi. In the long term, the generated know-how and competencies will contribute to key components for enabling eventual applications. The capabilities will however not be limited only to the products mentioned in Figure 1 but the capabilities were so conceived such that they would have far-reaching implications in the next 10-20 years.

STRATEGY 5: Playing a role in nation-building through start-up ecosystems and "skilled" human resource development

TIH in Cobotics strategies to build its "policy vision" rooted in the philosophy of "Nation building". Activities, programmes of TIH should focus on contributing towards India's economy, technological superiority and its scientific influence in the global map. In this regard, TIH's main focus would be creating technologically competent skilled workforce and provide them an entrepreneurial ecosystem to thrive in future.

1. Innovation, Entrepreneurship and Start-up Ecosystem: The following will be the contours of the innovation ecosystem:

- Foundational research carried out in this program will create new capabilities enabling robots to operate effectively with humans. These will create new industry opportunities, improve competitiveness of industry and infuse technology in partner agencies.
- The hub will facilitate vibrant industry-need focused development that will address current technology gaps, development processes and lower barriers such as cost etc. Such activities will link closely with the current industry ecosystem.
- The program will support funding for transferring technologies to agencies and industry funding de-risking programs for igniting start-ups (FiRE), joint research programs to transfer know-how and technical assistance to startups.
- The hub will also interface with social organizations for utilization of components of frontier technologies for societal applications.
- A key aspect of the hub will be to create a link between researchers, industry and students. This will have a far-reaching impact on R&D and its eventual application.

2. HRD and Skill Development: Students and research staff will be closely involved in project activities. Ph.D. and masters level students will be engaged in collaborative research with opportunities to travel for research activities and review meetings. We plan to hold at least one national conference or scientific meeting (including international speakers) in topical areas for reviewing the state of the art and conceptualizing new directions. The proposed program will support a new M. Tech. program in the area and boost Ph.D scholarship. We intend to support the new M.Sc in Cognitive Sciences by IIT Delhi starting from 2020. We will introduce new courses, create materials accordingly and programs in this area with inputs from industry. We will outreach to students from disadvantaged backgrounds to provide exposure to advanced technologies. We plan to start a M. Tech or dual-degree programme at IIT Delhi with specialization in Cobotics or similar name under the newly formed CoE BIRD. This will be basically the strengthening of the existing specialization in robotics (IDSR).

3. Translational Research Manpower Creating under the TIH: The TIH will be supporting knowledge generation and industry transfer. An important phase in this journey is translational research and development. This is a crucial component and often called the valley of death that prevents ideas from becoming usable. Under the TIH Cobotics, the development of embodied capabilities is closely aligned with recognizing and supporting translational work.

We envision post-PhD students, research students, undergraduate students (through design credits) to support repeated use and adaptation of capabilities after their concept is proven. This will support field trial, adaptation to new data sets and domains, and interfacing with academic needs. In the long run, the generated know-how and experience gained by the research staff and students in the program is likely to build capacity to undertake future translational research projects as a step towards real-world use. The ability to take up such projects will assist in raining resources for the TIH beyond the program duration.

4. Deferred Placement and Post-Graduation Translational Incubation: The development of translational research capacity and manpower will enable retaining focus of graduate students to knowledge generation and at the same time creating stronger interface usability requirements of the real world where core problems can be distilled. Further, this will also create role models engaging students who would like to push and test their ideas in the real world ultimately de-risking their own ventures. There are possibilities to explore similar examples in other universities. For example, NREC is associated with CMU, USA. Note that IIT Delhi is also providing scholarship support to graduating B. Tech. students with attractive stipends to pursue activities in the institute after graduation. TIH plans to implement concepts like "*deferred placement*", "*translational skill development incubation*" for its graduating human resource, which means that after graduation trained students, project assistants can extend their association on a part time employment basis for working towards product realization from their earlier degree research. During this phase, they can also concentrate on industry interface, start-up ventures etc.

STRATEGY 6: Self-sustaining revenue model

For any organization to sustain for a long time, it is absolutely necessary to develop its own revenue generation model. The current TIH proposal for five years has been planned mainly to develop core competencies in terms of know-how and framework which are very generic in nature and have long-term utility. However, keeping in mind the country's need, several specific projects in the area of Medical robotics, Defence, Agriculture and Disaster Management, and Factory Automation are planned so that the applicability of the know-how generated/technological framework can be demonstrated, at the same time a revenue generating financial model can be formulated for sustenance of TIH beyond the time of DST's project based funding.

To generate the revenue, the following activities are planned (in the order of short-term to long-term):

a) Hold equity in relevant start-ups arising out of IITs via TIH as a Section-8 company and divest this equity at the right time so as to maximize the profits earned while avoiding the risk of holding equity for a prolonged period of time.
b) Encourage more students and faculty to launch and lead start-ups through favourable policies on the campus, thus creating an additional revenue mechanism for the institutions.
c) After students complete M. Tech. and Ph.D. degrees, TIH must provide a "deferred placement" or translational skill development incubation phase to them so that they can try out start-ups, work towards product realization from their earlier degree research, or concentrate on industry interface.

d) Develop appropriate leave rules and funding models to encourage faculty to become entrepreneurs, thus enhancing the entrepreneurship ecosystem of IIT Delhi.
e) Conducting training programmes for the academic communities and industries from 3rd year onwards on payment basis.
f) Generate, course materials out of the above programmes and sell them.
g) Starting M. Tech and research programmes on self-sponsored mode.
h) Organize conferences/workshops (at least once in a year) by inviting international speakers in collaboration with the Robotics Society in India and similar other organizations to earn some share.
i) Providing consultancy services to industries (both national and international): Already few are in the pipeline. One of them is joint development of surgical robotics in collaboration with Robosurg Med-Tech Pvt. Ltd.
j) Pushing for technology transfer at the end of 3rd year based on royalty basis. One of them is targeted with Botlab Dynamics for teaming of drones.
k) Attracting more sponsored research from Govt. bodies like the Ministry of Social Justice and Empowerment, Ministry of Agriculture & Farmers' Welfare, Ministry of Micro, Small and Medium Enterprises, etc. and private companies.
l) Corporate membership to provide some of the services free against an annual fee.

Some of the salient points in revenue generation strategy need elaborate discussion:

1) **Revenue from licensing of Intellectual Property (IP):** Though IITs are slowly ramping up their patent portfolios, the revenue from IP licensing is a negligible fraction of the overall revenue. However, filing of patents is important for growth of the entrepreneurship ecosystem on the campuses. Without IP protection, no technology start-up would ever be able to raise funds from the investors. Creation of strong professional teams for drafting quality patents and monetizing the IP through dedicated Technology Transfer Offices is indeed very essential to develop a strong research environment and culture. It may be mentioned here that this activity, unless coupled with the start-ups and equity investments, may eventually not contribute any significant amounts to the institute revenue considering the costs involved in managing the patents.
2) **Equity Investments in Student/Faculty Start-ups on the campus:** Institutions through a TIH like Section- 8 entity must hold equity in start-ups arising out of the campuses and divest this equity when the time is right. Schemes to encourage more student and faculty led start-ups and supporting the start-up activities through favourable policies on the campus can create an additional revenue mechanism for the institutions. Deferred placement schemes for students to try out start-ups, coming up with appropriate leave rules and funding models to encourage faculty to turn entrepreneurs, can help enhance the entrepreneurship ecosystem on our campuses.
3) **Overheads from Research and Consultancy Projects**: The TIH must be provided sufficient overheads for the research projects that they undertake. In the absence of this, it is difficult to scale up the research activities in the institutions and maintain the research infrastructure. Large projects without sufficient overheads are fast becoming a burden on the institutions. MHRD needs to take up this matter with other funding agencies and impress upon them the need for providing overheads. Another source of revenue is taking up consultancy projects in collaboration with private industries and Govt. sectors, where TIH can employ its human resource for innovative practical technological solutions on a case to case basis. For example, many small industries have reached out to IIT Delhi for automation technology implementation in their manufacturing, which can be handled by TIH like organization.
4) **Online Educational Programs/Executive Programs/Skill development course:** IITs through TIH like organization may consider getting into market-driven online/in-house education/certification/executive programs in areas of current demand and join hands with private players for enhancing their outreach. This can create avenues for additional revenue. After

compensating the faculty members suitably, the balance funds can be used to build the endowment fund or for other specific purposes. Appropriate policies for engaging private players for scale-up of these on-line/executive programs need to be developed at the institute Senate/Board level.

5) **Better utilization of campus and central research facilities:** TIH may also rent out developed facilities on the campus which are used infrequently. In this regard, TIH plan to propose a financial model to use its central facilities (CRF) on a payment basis for the external agencies/start-ups etc.

5. Target Beneficiaries

It is hard to imagine any sector which will not be benefited from collaborative, guided automation in the near future. Based on available current expertise, collaborative footprint, past experience, available resources the TIH has grouped the proposed project proposals for the next five years into the following application domains.

- Medical and Rehabilitation
- Strategic areas such as defence
- Agriculture and Disaster relief
- Factories and Small enterprises

Based on the above classifications, the target beneficiaries can be identified as Indian society at large and various organizations associated with the above application domains who involve technology for their functioning. Role of collaborative robotics is ever increasing in medical, defence, agricultural, and small and medium scale industries. It has a role to play in the country's future economic growth as well. Through numerous internal and external projects, the TIH envisioned to contribute towards the following cyber physical system development

- CPS-I: Exoskeleton like wearables and soft/hard co-robotic manipulator tools operated by a human partner
- CPS-II: Human-in-loop aerial/manipulation/mobile Cobotic CPS platforms
- CPS-III: Novel sensing, processing and optimization payloads for Cobots

It is appropriate to discuss beneficiaries under the broader classifications of targeted CPSs and application domain.

CPS-I: Exoskeleton like wearables and soft/hard co-robotic manipulator tools operated by a human partner

Exoskeleton-like wearable robotics can be of two types: augmentative and rehabilitative. Augmentative devices, which can work as strength or power booster can benefit security forces on the ground, soldiers in the battlefield, firefighters in the defence and security-related scenarios and army and security agencies would be the target beneficiaries. Augmentation type wearables will also benefit factories and small enterprises (MSME) where assembly line work needs repetitive manual intervention. It can benefit farmers in agricultural work. It can benefit people involved in disaster and rescue related operations. Augmentative devices can also benefit elders in the society from their geriatric related weakness and disabilities. Exoskeleton as a rehabilitative device will mostly benefit stroke patients who have lost their motor control activities.

Hard/soft co-robotic manipulator tools can benefit multiple sectors across the four application domains perceived in this project for the TIH. Tele-operated minimally invasive surgical robotics in surgery can have deep societal implications. India has a huge shortage of skilled medical professionals. Currently, high skilled surgical procedures are restricted to some speciality hospitals in the urban locality. Naturally, the majority of the population are deprived of quality healthcare at the time of need. Remotely operated, minimally invasive surgical equipment can make quality healthcare accessible to the masses. Manipulators can also find applications in agricultural fields, disaster relief, and small and medium industry's assembly line activity.

CPS-II: Human-in-loop aerial/manipulation/mobile Cobotic CPS platforms

Human-in-loop mobile robotic platforms in aerial, legged or wheeled form-factor can benefit soldiers in the battlefield as robotic team mates, security forces for law and order management, National Disaster Relief Force (NDRF) for relief and rescue operation during natural calamities. Drones/aerial robotics can benefit the farmer community in the agricultural sector for crop management, soil moisture measurement, pesticide sprinkling etc. The medical sector in particular hospitals can benefit from mobile robotic platforms for patient management, remote caregiving during virus outbreaks like the recent COVID-19 pandemic.

CPS-III: Novel sensing, intelligent processing and optimization payloads for Cobots

Sensing, data processing and intelligent communication will dictate the "collaborative" part of any cobots. Human guided knowledge acquisition through energy-efficient and secure sensing, camera and radar, virtual teaching, and robot task execution will benefit every application, every community who will use cobots in defence, minimally invasive surgeries or rehabilitative purposes in medical applications, in agricultural field for crop management or in industrial assembly, packaging applications, etc.

6. Legal Framework

At its core, a good business structure requires a prudent legal foundation. The chosen legal system should ideally enable one's business to grow with minimal intervention. Hence, the aspect of setting up a legal framework for smooth running of the business is very very important. Since the incorporation of the Section-8 company, which is defined a non-profit entity engaged in social work for the benefit of the country, at IIT Delhi under the name "I-Hub Foundation for Cobotics" is underway with the help of a Chartered Accountant (CA) for which the objectives, etc. were mostly specified by the requirement of the DST, Govt. of India under their programme NM-ICPS, they are not discussed much in this DPR.
However, some of the other aspects are highlighted here for the success and growth of the TIH as a self-sufficient entity even beyond 5 years.

- The decision-making system of the business, as it is elaborated in the section of structure to run the TIH.
- The roles and responsibilities of the founders, collaborators within and outside India, both academics/researchers and industry people.
- It is advisable to identify various issues for the running of the TIH, discuss, and record all decisions in writing.
- How to add capitals to the TIH should also be discussed. A legal agreement should be drawn in simple terms capturing the key details with the stakeholders.

The legal permissions, approval, etc. required for the functioning of the TIH for its day to day activities as well as wide-ranging research and product developments ranging from factory automation to agriculture to medical robotics and defence robots are mentioned below:

1. **Obtain the Required Registrations and Licenses:** In most cases, your business will be required to file statements with the government from time to time. The following are the various registrations and licenses which may be required by the TIH:

- Import Export Code (IEC) for import or export

- Employees' Provident Fund Organization
- Value-Added Tax (VAT)
- Shop and Establishment License for physical premises
- Permanent Account Number (PAN) for income tax
- Taxation Account Number (TAN) for withholding of tax
- Service Tax Number if your business involves providing services
- Professional Tax Registration
- Employees' Insurance (ESIC)

Further, the TIH may be required to obtain specific licenses, such as a FSSAI license for food manufacturers, storage, transporters, distributors, etc. related to the devices that may be developed at the TIH at IIT Delhi and sold for validation purposes.

2. **Trademark:** As the TIH grows, so does its goodwill. It is therefore necessary to protect the trade name, logo, tag line, and key phrases from misuse. Trademark is a combination of words and pictures which is registered with the government as belonging to the TIH. Trademark gives the protection against misappropriation of value that would be created in the TIH through branding and advertising. Under the process of the existing law, registering a trademark typically takes about two to three years; however, one can start using the term "TM" next to its name from the date on which the application for the same is filed. The filing of the trademark is planned at an early stage, say, within a year, before starting the branding activities.

3. **Organise Accounting and Taxation Systems:** A well-designed accounting system is among the most important parts of your business. Without it, you would not be able to keep a track of the various transactions conducted by your business - the assets it owns, to whom it owes money and amounts receivable from its customers. A strong accounting system could be the dashboard of the TIH's finances, helping the directors to understand the answers to various questions such as:

- How could the TIH scale up its operations and how should it finance this growth?
- In what areas could course corrections be made to ensure a healthier financial position?
- Are things going as per the TIH plan or are there any course corrections that one needs to make?
- What discounts and credit periods can the TIH afford to offer to its customers who are basically collaborators and start-up companies with the funding from the TIH?
- How could one prepare and analyse meaningful 'what-if' scenarios for taking strategic and tactical decisions?

Failure to have a well-designed and robust accountancy function robs you of the opportunity to review rich data and draw meaningful inferences for decision making. As a corollary, a capable accounting team will be formed to gain the advantage of foresight for the TIH.

4. **Create Business Policies:** Building an industry-leading venture needs support of stakeholders - clients, vendors and employees. Having coherent documented systems allows the organisation to present a clear framework of relationships. Clients (i.e., the collaborators of the TIH) will appreciate the missions, values and functioning methodology of the TIH. Possible start-ups/industries must be aware of how to acquire a technology from the TIH for Cobotics, and its performance/quality. Employees of the TIH, and most importantly the collaborators (both from IIT Delhi and outside) must know the TIH's expectations and operational framework. Well-structured policies facilitate the evolution of the best principles of corporate governance at the venture. Some of the policies that are relevant for the TIH, as drawn from the business world, are as under.

Operational Policies

- Marketing Policy (advertising guidelines, commission structure, client satisfaction parameters)
- Website Terms and Conditions
- Human Resource Separation Policy (retirement, resignation, termination, notice, handover, full and final, etc.)
- IT Policy (level of access, restricted sites, backups, checkups, etc.)
- Use of Official Assets Policy (use of company's laptops, vehicles, guesthouses, etc.)

- Human Resource Policy (Recruitment, training, travel, reporting, attendance, reimbursement, leave, disciplinary)
- Rewards Policy (appraisals, increments, promotions, benefits, etc.)
- Code of Conduct (corporate culture, sexual harassment, conflict of interest, whistle-blower, etc.)
- Sales Policy (invoicing, discounts, payments, product return, interest on delayed payments, after-sales, etc.)

Website Policies
- Privacy Policy
- Terms of Use Policy
- Disclaimer of Liability

Employee-related Policies
- Termination Letter
- Increment Letter
- Employee Offer Letter
- Non-Disclosure Agreement
- Notice for Default
- Relieving Letter

Business Systems
- Audit Committee and its policies
- Compensation Committee and its policies
- Recruitment Process and its policies

Some generic issues will be kept in mind for the said TIH are as follows:
a. Budget more for legal expenditure and time than one may think as the technologies are new which need to be IP protected, possibly, internationally.
b. Have the right attorney for each task so that tasks are done smoothly.
c. Never ever break any laws as the cost of legal battle is expensive and will be detrimental for the country's image for such international collaborative activities.
d. While waiting for the legal permissions/approval use the time wisely to build the business.

7. Environmental Impact

Based on the impacts on the environment, the projects proposed in the TIH can be broadly classified into two categories, namely, a) Projects with only positive impacts, and b) Projects with both positive and negative impacts. The key outcomes of the projects that were used to form the categories are listed in Table 1. No major negative impact on the environment is anticipated from the projects proposed in the TIH for Cobotics at IIT Delhi. On the contrary, the positive impacts of the projects seem to provide long term benefits. Projects that involve wearable robotics such as Exoskeletons and Exosuits have a history of using toxic and non-biodegradable materials in their output products. But this issue has been properly addressed by the teams with the use of environmentally friendly components.

8. Technology

The main vision of the TIH at IIT Delhi suggests that the projects will mainly be focusing upon the enhancing the human-robot interaction in the industrial as well as the medical research fields in order to enhance human capabilities to achieve the precision and reliability which seems deficient in humans. It also focuses on reducing the risk or harm the humans are facing whether it be a person working in the production line or a soldier guarding the international borders for maintaining peace and, finally the perspective will be to improve the productivity of the humans. Considering the scenario of utilizing cobots in a production line where initially all the tasks on the floor were performed by humans. The scenario can be considered as a microprocessor making company where the main tasks are assembly, soldering and packaging. So, after the deployment of cobots, similar to Figure 11, in the production line, it will enhance the capabilities of the workers who are soldering or assembling different parts to be soldered. As each one is capable of processing more parts with better precession of the tasks performed. The risk factor is also reduced as the workers just have to monitor the robots doing the tasks rather than performing the task of shouldering themselves as well as it improves productivity by increasing the throughput at each station of the production line.

After the identification of the "**Core Scientific challenges**" for the TIH to focus upon, all the projects are evaluated on the basis of all the three factors as mentioned above in detail. The Basic of qualification of the project as suitable for the objective of cyber-physical systems are:

- Enhancing Human Capabilities,
- Reducing Risk, and
- Improving Productivity

Once the idea of Humans-Robot collaboration is opted out after being capable to fulfil all the criteria, the core scientific challenges are figured out for making the attempts for addressing the applications and deployment part. Fig. 12 describes the steps involved in selecting as well as the factors of selecting the technologies involved in the project.

Table 1: Impacts and corresponding outcomes

Nature of Impact	Outcomes
Positive	• Reduction in use of disinfectants. • Real-time monitoring of crops, plants and soil moisture. • Improved human endurance and support in decision making. • Reduction in energy consumption. • Eco-friendly electric vehicles and smart transport. • Reduction in waste production. • Reduction the effects of cyber uncertainties. • Real-time environmental hazard monitoring such as mine field detection, radiation and pollution mapping. • The low-power neuromorphic design will lead to sustainable green electronics and low energy footprint compared to conventional computing.
Negative	• Increased harm from robotic materials and electronic components

[Courtesy: International federation of Robotics; https://ifr.org/case-studies/collaborative-robots/]
Figure 11: Robots working together

(Courtesy: https://www.verasolutions.org/10-criteria-to-evaluate-when-choosing-a-new-technology/)
Figure 12: Ten criteria to evaluate when choosing a new technology

Following the top-down approach for the development of any successful invention. After recognition of the theme on which the TIH has to focus the respective core scientific challenges are identified for the projects. It proves to be interdisciplinary as the challenges will be confronted by the approach of Mechanical, Computer Science, Design, Electrical as well as specialized departments like: SENSE. So, the confronting ideas are proposed by all the department members involved with the mission. Beginning from the very basic designing and prototyping of simple as well as complex physical mechanisms as well as their controls. The sensor implementations as well as effective computations also need to be taken care of. Finally, for the system to have dominance over the conventional systems the involvement of machine intelligence is needed for cognition and robot learning for letting the system make rational decisions independently on its own after deployment.

Evaluation of technology options

According to the Vera solutions, as shown in Figure 12, a technical consultancy firm, the evaluation of a technology in comparison to other solutions available in the same field can be done on the basis of evaluating them in 10 above-mentioned criteria. These are basically used for the companies to compare different solutions available to them when they want to invest in some latest technology. But the same can also be used to compare the options available for research purposes.

Basis of choice of technology for the proposed project

For the definitions of the project to be suitable for the objective of cyber-physical systems, the following factors, as depicted in Figure 13, are also considered for the choice of particular projects.

Figure 13: Factors for choosing a technology

The problem and application of this project are directly linked with the people involved in the agricultural sector of society. The Human-Robot interaction will result in enhancing the capability of the farmers as well as the enhancement of productivity as the result. The challenge considered is to develop a robotic system which will be assisting the people associated with the agricultural background for the estimation of the agricultural environment as well as the ground condition for considering the productivity of the land.

For the same task, it can be achieved by land-based unmanned vehicles also not considering the different options the feasibility and efficiency for the UAV based solutions. So the UAV based alternative was selected for the purpose of further research and development.

9. Management

The plan for the administration of the TIH is shown in Figure 14. It is divided into four layers. They are explained below:

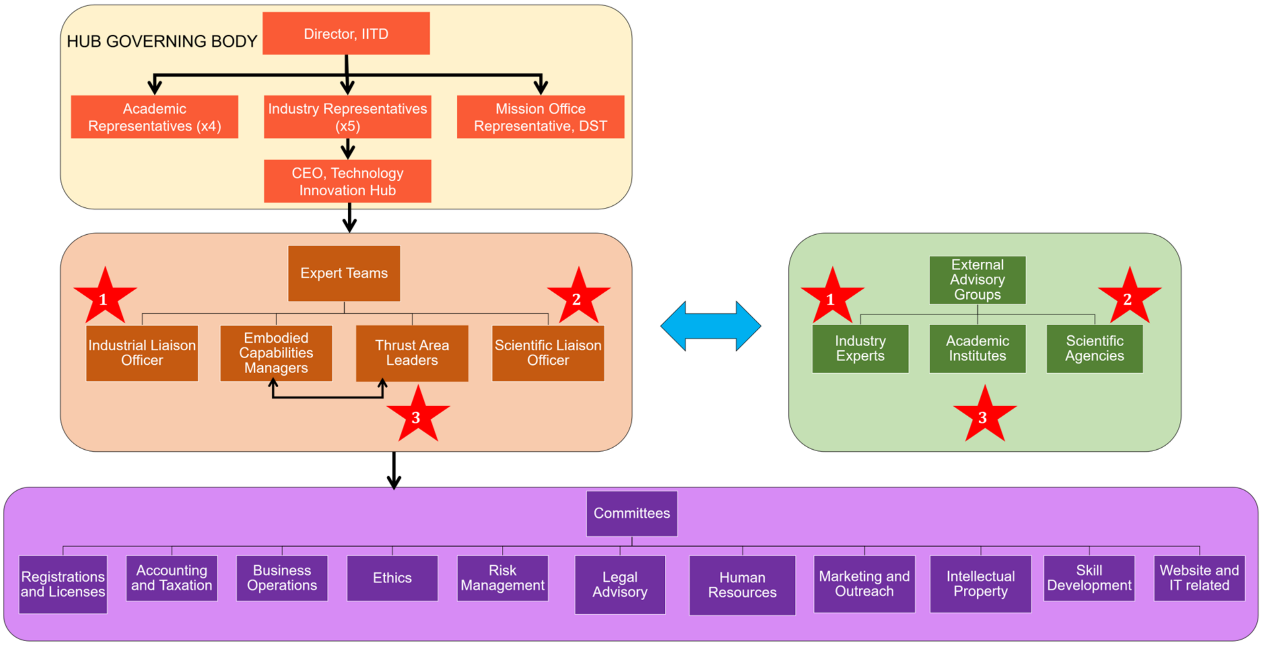


Figure 14: Management plan of TIH in RAS at IIT Delhi

1. The Director of IIT will be the **Chairman** of the Hub Governing Body for the TIH activities at IIT Delhi.
2. **Hub Governing Body**: At the next level, it will consist of academic representatives, industry representatives, and the representative of DST. They will be given responsibilities as coordinators and heads for synchronizing the hub activities at embodied capabilities level. A Chief Executive Officer (CEO) will be designated to direct all the projects in the TIH at the member-secretary level.
3. **Expert-Teams** (Medical Robotics, Defence, Agriculture, and Disaster Management, and Factories/Small enterprises): As in the application scenarios of Figure 1, this layer stage will involve handshaking between the project principal investigators and industry experts, academic institutes and various scientific agencies. Inputs will be exchanged bilaterally through representatives from each participating body. In Figure 14, we explicitly depict which members of expert teams will interact with which members of the external advisory group using numerals. For example, the industrial liaison officer will interact with the industry experts depicted by the numeral '1' inside the red star; similarly for the stars marked '2' and '3'.
4. **Committees**: Based on the inputs received from the previous layer, the final layer will involve various committees that will recommend and take necessary action on issues like legal matters including IP, human resources, environment, risk, ethics, etc.

10. Finance

The details of budgetary requirement are given below, whereas the income aspects are explained in Strategy 6 (Self-sustaining Revenue Model).

BUDGET SUMMARY

Budget Head	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Total Recurring Cost	13.25	14.00	16.00	14.00	13.12	70.37
Total Non-Recurring Cost	9.00	30.00	35.00	15.00	10.63	99.63

Total Cost (Recurring + Non-Recurring)	22.25	44.00	51.00	29.00	23.75	170.00

Year Wise Budget Summary

(Amount in Crores)

Budget Head	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Manpower (Re)	6.95	7.88	9.01	8.03	7.72	39.58
Travel (Re)	0.84	1.01	1.15	0.91	0.51	4.42
Technology Development (Re)	1.26	1.42	1.62	1.45	1.39	7.13
HRD and Skill Development (Re)	0.63	0.71	0.81	0.72	0.69	3.57
Innovation, Entrepreneurship and Start-up Ecosystem (Re)	1.26	1.42	1.62	1.45	1.39	7.13
International Collaboration (Re)	1.26	0.35	0.41	0.22	0.24	2.48
Consumables (Re)	1.07	1.21	1.38	1.23	1.18	6.06
Equipment (NR)	8.38	27.27	30.19			65.84
Capex Items (NR)	0.62	2.73	4.81	15.00	10.63	33.79
Grand Total	22.25	44.00	51.00	29.00	23.75	170.00

(Re) – Recurring; (NR) – Non -recurring

11. Time Frame

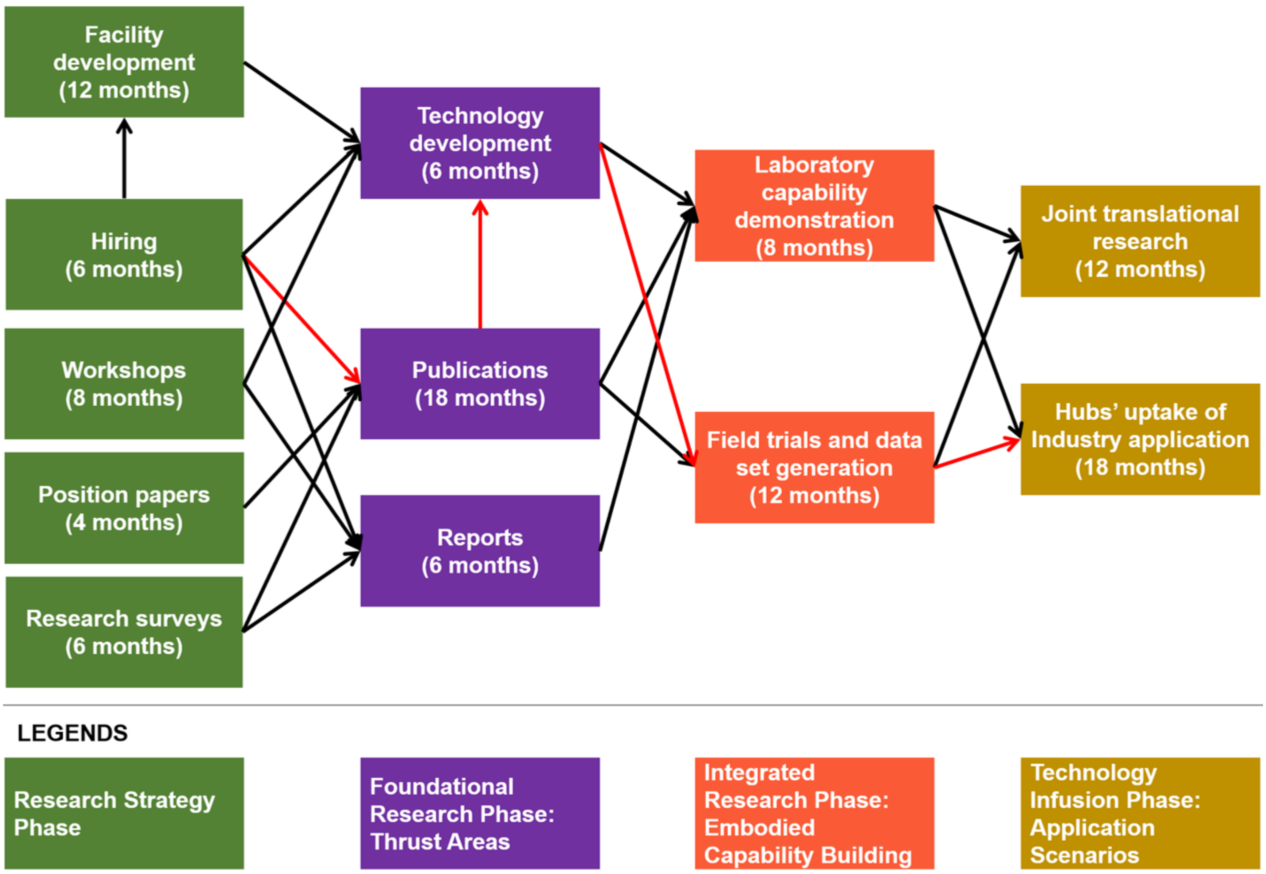
The proposed zero dates for the commencement of TIH activities is December 10, 2020. From the red-coloured critical path of the network diagram shown in Figure 15, one can observe that the entire proposed plan shall be completed within five years under the current tentative plan. In the first two years, the research strategy to be taken forward shall be decided and foundational research work would have been accomplished. In the next three years, we shall aim at building the embodied capabilities while integrating the developed research deliverables with the relevant real-world industrial applications.

12. Cost Benefit Analysis

In the framework of TIH for Cobotics we are aiming to develop home-grown transformative technologies to create a tangible eco-system to combat multi-disciplinary grand challenge problems to address national needs. The proposed research and development takes a significant step in the direction of enabling qualitative and quantitative improvements in scientific breakthroughs, innovations, higher education in science, technology and engineering disciplines. Here we would like to elaborate on some of the short and long term benefits from our envisioned ecosystem.

Activity	Year 1	Year 2	Year 3	Year 4	Year 5
Research Strategy Phase i) Facility development, ii) Position papers, iii) Workshops, iv) Hiring, v) Research surveys					
Foundational Research Phase **Thrust Areas:** i) Technology development, ii) Publications, iii) Reports					
Integrated Research Phase **Embodied Capability Building:** Laboratory capability demonstration and field data sets.					
Technology Infusion Phase **Application Scenarios**: Joint translational research, Industry, and sectoral application hubs uptake					

(a) Gantt Chart



(b) PERT/CPM diagram

Figure 15: Critical path analysis of activities to be undertaken at the TIH for Cobotics at IIT Delhi

(a) Present robotic systems possess very limited capabilities of understanding and executing semantic tasks. Hence, systems require near continuous low-level guidance and mostly require dedicated and trained operators. The ability to execute high-level tasks in a human-like way would enable untrained users to naturally interact with robotic systems. The resulting teaming will allow greater task-tempo and efficiency.

(b) In the long run, the ability to execute multi-stage reasoning-based tasks will enable robots to undertake missions in environments that are hazardous and may not be known a priori. This ability has the potential to remove the human from harm's way or reduce risk for eventual human arrival.

(c) Energy-efficient sensor networks typically deal with sensor transmission scheduling in the MAC layer, where data sampling of a particular sensor is ignored. However, sensor energy consumption can be greatly reduced if we can intelligently sample the sensor observations while taking into account the actual or estimated statistics of the process that is being tracked. This will improve lifetime of the sensor nodes over the existing literature on opportunistic transmission scheduling, and both can be integrated and further optimized. This will improve battery lifetime of sensor networks in agriculture, and also any robot equipped with sensors. This will also help in a more accurate estimation of the physical process.

(d) Security of cameras against deception attack is a well-studied problem in the AI/ML literature, but such defence schemes do not perform well against all attack algorithms. Also, none of the proposed attack and defence algorithms in the literature provide a theoretical performance guarantee of theoretical explanation of the observed performance. In this, TIH will theoretically develop defence against adversarial images, by using statistical properties of the images. The developed theory will guide us towards the design of universal defence schemes against adversarial images, which will protect the autonomous robots/drones/vehicles against deception attacks.

(e) Though there is game-theoretic analysis of jamming in radar literature, performance analysis and resource allocation for a radar over a time horizon via dynamic games, in the context of specific application such as target detection or tracking has not been addressed in the literature. Thus, the proposed work on radar will bring mm-Wave radar systems closer to practicality, in presence of an intelligent jammer. These radars will be mounted on robots/drones/vehicles, and the outcome of proposed research will protect them from jamming, especially in critical applications such as target detection and tracking in robotic warfare, or disaster management, or autonomous vehicles.

(f) Intended users of the semiconductor-based quantum communication proposal are various govt agencies and industries working in the domain of quantum computing for cyber physical systems in India and abroad. This user group currently has severely restricted (through cloud) or no access to quantum computers. Any effort from within the TIH in this area will significantly enhance the chances of a made in India quantum computer. Due to the strategic nature of this technology, it is highly restricted by countries owning it and there is little or no chance that it is sold and imported as a commodity item within the next one or two decade or so. Hence, our only chance to have a quantum computer is by making it here. Thus, it is not possible to do a cost benefit analysis for this technology as currently there are no alternatives.

(g) Applications of autonomous Sensor Networks and Internet of Things (IoT) are continuously growing in size and demand a portable solution for its energy requirements. The battery-based solutions limit the size of sensor nodes and also require these batteries to be replaced periodically. This increases the operational cost of the overall system. While on the other hand, energy harvester devices can harvest the ambient energy and thus does not require periodical maintenance. However, the existing energy harvesting solutions have limited efficiency and very few of them attempt to combine several energy sources and thus provide limited output power. The aim of this research is to find the optimal way of combining several energy harvesting techniques without increasing the size of energy harvesting devices significantly. Another objective of this research is to increase the overall efficiency of these energy harvesting devices and thus maximize the cost benefits.

(h) Existing commercially available exoskeletons are hard in their build-up, exorbitantly costly and out of reach for the common people. The idea of soft ExoSuit brings forth two fundamental changes:

cheap and easy fabrication, and cost effectiveness. If successful, the proposed ExoSuit can lead the path for mainstream usage of ExoSuit.

(g) A Da Vinci system, which is a tele-operated flexible continuum manipulator, currently costs around Rs. 30 Cr. The main cost comes from its patented technology of tendon driven manipulators, and their replacement almost after each surgery. A machine that can be made affordable, will make it accessible to many hospitals across the country. An alternative approach for manipulator fabrication and integration with the main frame of Da Vinci. Also, the prospect of 5G communication coming soon makes teleoperation practically feasible. It might be the first step in Indian scenario to make quality healthcare accessible to the masses. The usage of tele operated robotic surgical tools will reduce the per unit surgical cost significantly.

(h) The semiconductor based hard sensors will be useful for any robotic activity requiring determination of position or motion of any component with precision. In general, these sensors will find applications in efficient cobots. Moreover, data from such sensors will be useful for application of augmented reality in robotics. The Flexible magnetic field sensors, targeted for soft robotics are beneficial for typical application in the field of medical and health care.

(i) By simultaneous localization and soil moisture mapping the cost per unit area of data dissemination as advisory will be less as compared to fixed and immobile systems (eddy flux towers, COSMOS systems). The present state of technology for soil moisture estimation is either very costly or spatial resolution is not so effective for small holding application. For larger applications, the satellite data product can be downscaled to a finer resolution and bias-corrected using the real time data from this system for an application to typical land surface models used in climate change studies. Because of its mobility, a certain frequency (period spanning from 2 to 7 days) of data advisory, the area coverage of the proposed unit is extremely beneficial in terms of cost.

(j) The cost of fabricating a soft robot is reportedly much less than that compared to rigid robots. The consequential ease-of-usage would make end users to easily procure the proposed data-driven soft robots for their specified needs, hopefully leading to large demand and decrease in cost further.

(k) The Neuromorphic Computing Market is expected to witness sustained growth over the forecast period (2020-2024). Over the past four years, the Neuromorphic Computing market has managed to maintain the average annual growth rate of 0.430969081105 from ~ Rs. 15 crore in 2014 to ~ Rs. 90 crore in 2020. Market analysts believe that in the next few years, Neuromorphic Computing market size will be further expanded, and we expect that by 2024, the market size of the Neuromorphic Computing will reach ~ Rs. 2100 crore. Given these facts it becomes imperative for the country to develop relevant IP and products exploiting this new technology and become a major contributor in the market share for this industry. While the initial budget for prototype development of low power Neuromorphic perception units as mentioned in the proposal might be capital intensive, given the wide applicability of such designs leading to revenue based on IPR as well as potential benefits in terms of increased energy efficiency would be able to balance the initial costs.

(l) We hope, by exploring quantum optimization of problems relevant to robotics, will provide indispensable inputs for manufacturing smart robots. The development of the planned neutral atom quantum computing architecture itself is going to be a technological milestone for the country. Some of the world's most challenging problems, which could be addressed on a near term quantum computer, involves advanced drug design, quantum chemistry, smart material design, machine learning and network optimization. These problems can be solved on a quantum computer, only if appropriate quantum algorithms are developed and implemented on the quantum hardware. Designing optimized algorithms and to know how to implement them on the quantum computer hardware requires rigorous testing of quantum algorithms on quantum computers. To the best of our knowledge, such a facility does not exist in India. As a consequence, many of the quantum algorithm developers implement and test their developments in some foreign facility. As a term and condition to use such foreign facilities, the developers have to share their code to those foreign institutions. Once those institutions are rich enough in terms of intellectual resources, they normally commercialize their highly optimized products and make thousands of crores business even with those initial algorithm developers. If we build a quantum computing hardware in the framework of the TIH for Cobotics, it will not only be beneficial for optimization problems relevant to robotics, it will help all developers of the country to test their algorithms without losing intellectual property to any foreign institution. At the same time a quantum computer, made in India, will become at least as powerful as the foreign nations. This will have a long term significant effect in generating revenue from the fast growing quantum industry and internal security benefits in the domain of cyber physical systems for the whole country.

(m) In the field of hospitals, collaborative robots will allow doctors and nurses to focus on more cognitive tasks while taking over the assisting tasks like material handling or regular check-ups. Allowing healthcare professionals to deal with growing numbers of patients. In warehouses and manufacturing lines the same technology will assist in setting up an efficient and reliable supply chain while reducing physical workload off the field workers.

Where existing robotics systems can solve part of the puzzle, the multi-modal collaborative robots will be able to provide more versatile solutions with seamless integration between numerous domains.

13. Risk Analysis

Risk in the project can be defined as the estimated extent of uncertainty. There will be elements of risk and uncertainty in any project such as alternatives that have not been thought of, events that have not been seen and information that has not been available. Uncertainty does not have to lead to delay and search for the height ground of certainty. Risk could imply new opportunities, collaboration and challenges. In order to minimise adverse effects and maximize positive opportunities risk management plays an important role. To increase the chance of success for every project, identification of risk, quantification, and response control process is essential at different stages of execution. TIH has proposed to constitute a Risk Review Board (RRB) with a balanced composition of (IP lawyer, Chartered accountant, Medical administrator, a bureaucrat, Govt policy expert and area specific academic and industry experts), whose main role will be to engage in dialogue with every project teams at different stages of execution to broadly classify existing risks into [1]

1. **Preventable risks:** These are mostly internal in nature within the TIH as an organization, and will be controllable easily within TIH itself by RRB. Examples are the risks from employees' and project teams' unauthorized, illegal, unethical, incorrect, or inappropriate actions and the risks from breakdowns in routine operational processes like, logistic implementation challenges, space constraints, fabrication delay, power shortage leading to project delay. Based on the TIH's overall theme they can further subclass under,

a. Project management and implementation risks

b. Revenue risks

c. Ethical risks

This risk category is best managed through active prevention: monitoring operational processes and guiding people's behaviors and decisions toward desired norms [1]. A periodic dialogue with project team leaders will be essential in this aspect.

Table 4: Possible risks with internal collaborators

Projects	Project management/ Implementation Risk	Legal and contractual Risk	Environ-mental Risk	Revenue Risks	Regulatory Risks	Ethical Risks	Any other type
Bridging the "Semantic Gap": Human Guided Knowledge	Yes						

Acquisition, Virtual Teaching and Robot Task Execution							
Energy-efficient and secure sensing, camera and radar	Yes						
Secured Communication through Quantum Device Technology	Yes						
Development of Autonomous Sensor Systems using Mechanical Energy Harvesting (MEH) Devices and Power Management IC (PMIC) for Robotics Application	Yes						
Cooperative Control and Estimation for a Team of Mobile Robots	Yes						
Design and Development of Bioinspired, Soft Robotic Smart Exosuit for Human Endurance Augmentation	Yes					Yes	
Smart Exoskeletons for Rehabilitation of Stroke Patients	Yes					Yes	
Development, Prototyping and Demonstration of Tele-Operated Flexible Continuum Manipulator Technology for Minimally Invasive Surgical (MIS) Robotic Applications	Yes					Yes	
Development of a magnetic field sensor for proximity detection in futuristic robotic applications	Yes						
Simultaneous Localization and Soil Moisture Mapping for Agriculture Applications	Yes						
Data-Driven Soft Robotics in Agriculture	Yes						
Algorithms and Datasets for Smart and Autonomous Machines (SAMs) with the capability to interact with humans	Yes						
Development of low power Neuromorphic Perception Unit (NPU) for Cobotics Applications	Yes						
Quantum Optimization on a Rydberg Dressed Neutral Atom Quantum Computer	Yes						

2. **Strategic risks:** Strategy risks are quite different from preventable risks because they are not inherently undesirable. A strategy with high expected returns generally requires the company to take on significant risks, and managing those risks is a key driver in capturing the potential gains. For example, the TIH is going to manage a bunch of technology development projects, and it might be required to share IPs internally or externally, subcontract startups for external expertise, faster development, share IP at right time of project execution etc all these in order for "leapfrog" technological advancement and encouraging higher-risk, higher-reward ventures . Mostly, legal and contractual risks fall within this category. A well crafted IP sharing policies, ownership and legal implications need to be framed. In this aspect, IIT Delhi already has FITT (Foundation of Industry Technology Transfer), who is doing technology transfer on a regular basis and will be roped in for crafting Cobotics related IP strategies. This can be further sub-classified as

a. Legal and contractual risks
b. IP related risks

3. **External risks:** Some risks arise from outside an organization and are beyond its influence or control. Sources of these risks include natural and political disasters, Govt. policies, and major macroeconomic shifts, etc. External risks require yet another approach. Because organizations cannot prevent such events from occurring, their management must focus on identification (they tend to be obvious in hindsight) and mitigation of their impact. For example, Drone related research has regulatory challenges, beyond visual sight flight needs Govt. approval and has to be in compliance with Govt.'s current policies. Minimally invasive surgical robotics will also have to go through Govt. regulatory hardle. Given the dynamic nature of the TIH's architecture, space robotics might be inducted in the TIH umbrella and will bring regulatory challenges along with it. TIH will hire an external team of policy experts on a consultancy basis to seek advice, guidance on a periodic basis about changing Govt. policies about technologies. This can be further classified as,

a. Environmental risk
b. Regulatory risk
c. Any other Govt. policy-related risk.

Table 5 Possible risks with some of the external collaborators

Projects	Project management/ Implementation Risk	Legal and contractual Risk	Environ-mental Risk	Revenue Risks	Regulatory Risks	Ethical Risks	Any other type
1. Design and development of an intelligent unmanned aerial vehicle applied to open cast minefield surveillance for real-time monitoring, hazards and vulnerability assessment.	Yes						
2. Design and Development of a Bionic Manipulator	Yes					Yes	
3. Development of passive leg exoskeleton for rehabilitation of stroke patients	Yes					Yes	

4. Wearable robots for human gait restoration and augmentation	Yes					Yes	
5. Design and Development Of Low-Cost Surgical Robot For Laparoscopy With Tele Robotic Option	Yes					Yes	
6. Emotion Recognition for Creating a Homeostatic balance between Human and Robot in a Cobotics Framework	Yes					Yes	
7. Brain Computer Interface (BCI) based Robotic Hand Exoskeletons for rehabilitation of stroke patients						Yes	
8. Development of a new fiducial markers board for autonomous calibration of mobile robot on-board visual sensors							
9. Collaboration for Mobile Manipulators	Yes						
10. Networked tele-robotics	Yes						
11. Design, Development and Control of Reconfigurable UAV systems for Smart Transport and Manipulation		Yes					
12. Technology Development of Human-oriented Robotics for Human and Robot Collaboration						Yes	
13. Development of indigenous robot & integration with RoboAnalyzer for MSME	Yes						
14. PedicleSim - Design and Development of Spinal Surgery Simulator						Yes	
15. Design and Development of an Autonomous Robotics System for Disease Identification in Farms/Plants			Yes				
16. Advanced Energy Management and Control of an Unmanned Hybrid Ground Vehicle		Yes	Yes				

17. Near Real Time Disease Monitoring System of rice-wheat cropping system using Artificial Intelligence and Geo-Spatial Technique		Yes	Yes				

For the collaborators of the TIH for Cobotics at IIT Delhi, possible risks are highlighted in Tables 4 and 5 for internal and external collaborators, respectively.

References

[1] Robert S. Kaplan and Anette Mikes, Managing Risks: A New Framework, Harvard Business Review, 2012.

14. Outcomes and Deliverables

The following would be the anticipated scientific output of the hub, as illustrated in Figure 1:

- **Knowledge creation:** Creation of new algorithms, models and designs to address technical challenges. Development of software, hardware prototypes. Analysis and experimental validation appearing as technical publications.
- **Demonstration:** Realization of new skills/capabilities on simulated, standard physical research platforms or physical platforms developed in the program. Capability or skill demonstration in research facilities organized as per thrust areas or specific application domains.
- **Knowledge Translation and Applications:** Establishment of an interface to engage industry and national agencies. Development of collaborative projects and technology infusion. Industry-focused innovation and application creation. Incubation of innovative ideas as potential start-ups. Support via technical advisory and mentorship. Exploration of applications of basic technologies and know-how to support neglected societal needs.
- **Advanced Research Facility:** Establishment of world-class laboratory facilities to support research, development and training serving as a showcase of frontier technologies.
- **Education and Skill Development:** Training of students and research staff who can emerge as future leaders in this area. Introduction of new course material and programs in this area with inputs from industry, specifically to Small and Medium Enterprises (SMEs). Outreach to students from disadvantaged backgrounds to provide exposure to advanced technologies.
- **Linkages:** Establishment of linkages with other national institutes in a hub and spoke model. Infusion of new ideas via workshops and joint research initiatives. Establishment of an interface with socially-driven organizations for potential applications. Emergence of a community of networked researchers in this field in India.

We will share key outcomes from research under technical areas giving partners visibility into new emerging results and system prototype development. In the later part of the program, we will organize a capability/skill showcase demonstrating capabilities on research platforms bringing together research in multiple thrust areas. Such a showcase is intended to allow partners to conceptualize and initiate joint research, translational research, and technology infusions activities. Please refer to "Embodied Capabilities" of Figure 1.

The outcome of this research will be novel computational/mathematical models enabling robots to perform high-level tasks collaboratively with a human partner. Our approach will be built on computational tools that will enable a robotic platform or an intelligent machine to acquire semantic knowledge from sensing and interaction and utilize such knowledge in future decision making. Contemporary approaches have addressed the problems of perception, instruction following and planning largely independently making systems brittle in practice. Further, capabilities have been restricted to narrow and well specified tasks. This work will equip robots and intelligent devices with cognitive or semantic knowledge necessary for long-range planning for diverse real-life tasks.

The specific deliverables expected are as follows:

- A Medical Simulation Facility: In collaboration with AIIMS, New Delhi and other collaborative organisations, universities, and R&D organizations, we are planning to set-up a training centre for the medical doctors and students. This facility will provide India-centric customizations and research opportunities for indigenous development of associated products and services.
- Consolidated Grand Projects targeting CPS I, II and III are being developed keeping in mind the Perceived Application Scenario (Refer "Section 5: Target Beneficiaries" for more details). The targets are as follows:
    - CPS-I: Exoskeleton like wearables and soft/hard co-robotic manipulator tools operated by a human partner
    - CPS-II: Human-in-loop aerial/manipulation/mobile Cobotics CPS platforms
    - CPS-III: Novel sensing, processing and optimization payloads for Cobots
- Specific objectives as mentioned in Table 6

15. Evaluation

In addition to fulfil the "Targets of Hubs" specified by the DST and given year-wise in Table 6 in terms of the number of Technology Development, HRD and Skill development, Entrepreneurship and Start-ups, International Collaborations, etc., the proposed hub at IIT Delhi aims to contribute towards the advancement of science, systems and applications in the field of *Cobotics* by knowledge generation, novel technology/capability development and product innovation.

Table 6: Year-wise break-up of minimum targets specified by the DST

S. No	Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Target
1	Technology Development						
(a)	No. of Technologies (IP, Licensing, Patents)	-	5	7	10	10	**32**
(b)	Technology Products	-	-	10	10	10	**30**
(c)	Publications, IPR and other Intellectual activities	10	20	20	20	20	**90**
(d)	Increase in CPS Research Base	21	21	21	21	21	**105**
2	Entrepreneurship Development						
(a)	CPS- Technology Business Incubator (TBI)*	1	-	-	-	-	**1**
(b)	CPS- Start-ups & Spin-Off companies			10	20	22	**52**
(c)	CPS-GCC- Grand Challenges and Competitions	1	-	-	-	-	**1**
(d)	CPS- Promotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS)	-	1	-	-	-	**1**
(e)	CPS-Entrepreneur-in-Residence (CPS-EIR)	-	5	6	10	10	**31**
(f)	CPS-Dedicated Innovation Accelerator (CPS-DIAL)	-	1	-	-	-	**1**
(g)	CPS-Seed Support System (CPS-SSS)	1					**1**
(h)	Job Creation	1025	1100	3000	3000	5000	**13125**

3	Human Resource Development						
(a)	Graduate Fellowships	30	40	100	100	70	**340**
(b)	Post Graduate Fellowships	7	10	20	15	10	**62**
(c)	Doctoral Fellowships	5	5	5	5	5	**25**
(d)	Faculty Fellowships	0	1	2	2	1	**6**
(e)	Chair Professor	0	1	1	1	3	**6**
(f)	Skill Development	50	80	200	200	100	**630**
4	International Collaboration						
(a)	International Collaboration	1	-	-	-	-	**1**

* Since FITT-IIT Delhi has a well-established procedure, it will be done through an MoU with the FITT.

We aspire to fulfil the broader mandate of the *Technology Innovation Hub (TIH)* under the *National Mission for Interdisciplinary Cyber-Physical Systems (NM-ICPS)* for research capacity building, education and skill development by establishment of R&D infrastructure, training of students / research staff, and courses. Finally, aim to serve as a national-scale research collaborative connecting academia, industry, Govt. agencies and premier international partners.

The progress of the TIH towards the aforementioned goals is proposed to be determined by internal and external steering mechanisms.

- An *Internal Project Steering Committee* for steering and facilitating progress of activities/projects towards stated objectives convening annually.
- An *External Oversight Committee* for reviewing holistic TIH progress convening biennially (once in two years).

A preliminary list of reporting data/metrics associated with TIH outcomes appears in Tables 7 and 8. These would be refined and adapted based on feedback and suggestions.

Table 7: Metrics for R&D Contribution and Impact (Part I)

1. **Knowledge Creation**	
Contributing activities a) Three core scientific challenges in physical design, intelligence, capable sensing and computation payloads. b) 15 contributing projects in 10 thrust areas from 31 faculty members from 5 departments.	***Progress metrics*** 1.1 New models, algorithms, theory, frameworks addressing identified scientific/technical gaps. 1.2 Journal and conference publications (peer-reviewed /open-reviewed or archived). 1.3 Patents and design registrations. 1.4 Implementations, code, data sets and prototypes/designs.
2. **Technology/Capability Development**	
Contributing activities a) Development of 7+ technical capabilities (hardware prototypes, software). b) Capabilities embodied as cyber-physical systems (exoskeletons, soft tools, manipulation/mobile manipulation, novel sensors/computer payloads, software tools).	***Progress metrics*** 2.1 New CPS capabilities arising from thrust areas demonstrated in laboratories/field conditions. 2.2 Technical reports, validation/field reports and publicly released tools. 2.3 TIH *OpenHouse* event showcasing R&D activities and know-how to the broader community.
3. **Knowledge Translation and Applications**	
Contributing activities c) Establishment of an interface to engage industry and national agencies. d) Development of collaborative projects and technology infusion.	***Progress metrics*** 3.1 Technologies, knowledge and innovative applications developed addressing specific industry/sector/agency needs.

e) Industry-focused innovation and application creation. Incubation of innovative ideas as potential start-ups.	3.2 Collaborative projects initiated with Govt. institutions/departments, industry, Pvt. institutions, NGOs. Projects initiated towards National Missions. 3.3 Knowledge sharing, advisory/mentoring, technology adoption or transfer.

Table 8: Metrics for Capacity Building and Ecosystem Creation (Part II)

1. **National Ecosystem Creation**	
Contributing activities a) Establishment of linkages with other national institutes, agencies, institutions in a hub and spoke model. b) Infusion of new ideas via workshops and joint research initiatives.	***Progress metrics*** 1.1. Inter-departmental and inter-institutional partnerships, alliances and joint activities. 1.2. Visits, interactions and exchange activities. 1.3. Workshops, tutorials, symposia at scientific venues. Outreach and awareness activities.
2. **Education and Skill Development**	
Contributing activities a) Involvement of students and research staff in research and development. b) Introduction of new course materials and programs.	***Progress metrics*** 2.1. Participating Research staff, Post-doctoral Fellows, Students (PhD, MTech, BTech, MS(R), MSc). 2.2. Courses, academic programs and teaching modules. 2.3. Student projects and fellowships supported.
3. **Advanced Research Facility**	
Contributing activities a) Establishment of laboratory facilities to support research, development and training.	***Progress metrics*** 3.1. Establishment new research platforms (CPS platforms, sensors, equipment). 3.2. Establishment/upgradation of R&D support infrastructure (testing, fabrication, experimentation equipment, computing). 3.3. Facility use and equipment utilization.

Appendix I: List of IIT Delhi Faculty

S. No.	Name	Area of expertise	Roles/ Responsibilities
1	V. Ramgopal Rao	Nano electronics, Bio-MeMs, CMOS Reliability	PI
2	S.K. Saha	Robotics, Multi-body Dynamics	Team Lead
3	Kaushik Mukherjee	Orthopaedic Biomechanics & Implant Design	Team Member
4	Sithikanta Roy	Soft Robotics	Team Lead
5	Sushma Santapuri	Mathematical modelling of smart materials	Team Member
6	Rohan Paul	Robot Learning, Embodied AI	Team Lead
7	I.N. Kar	Nonlinear Systems, Robotics,	Team Lead
8	S. Janardhanan	Sliding mode control, Robust control.	Team Member
9	Shubhendu Bhasin	Nonlinear and Adaptive Control, Robotics	Team Member
10	Shaunak Sen	Mathematical methods of control & dynamical systems	Team Member
11	Manan Suri	Neuromorphic, AI, Security, Computing, Sensing	Team Member
12	Ankesh Jain	Circuit design	Team Member
13	Dhiman Mallick	Internet of Things (IoT)	Team Member
14	Arpan Chattopadhyay	Design, control, and learning of intelligent cyber-physical systems (CPS)	Team Member
15	Abhishek Dixit	Optical access networks	Team Member
16	Lalan Kumar	Signal Processing	Team Member
17	Harshan Jagadeesh	Wireless networks, Cyber-Physical Systems.	Team Member
18	Subashish Datta	Linear Control Theory, Multi-agent Systems	Team Member
19	Mashuq-un-Nabi	Control Systems, Guidance and Control	Team Member
20	Deepak U. Patil	Optimal Control, Multi-agent systems, Switched and Hybrid Systems.	Team Member
21	Bhim Singh	Power Electronics	Team Member
22	Sumeet Agarwal	Machine Learning, Cognitive Science	Team Member
23	B. Bhaumik	Biological Neural Networks	Team Member
24	Swades De	Energy harvesting sensor networks	Team Member

25	Sumantra Dutta Roy	Computer Vision, Image analysis, Pattern Recognition	Team Member
26	Tapan Kumar Gandhi	Computational Neuroscience, Neuro-Inspired Engineering, Assistive Technology	Team Member
27	Jayadeva	Machine Learning, Neuromorphic Engineering	Team Member
28	Ranjan K. Mailk	Communication Theory and Systems	Team Member
29	Pratosh A.P.	Vision and image processing audio, speech and music analytics and learning	Team Member
30	Subrat Kar	Optical sensing and communication	Team Member
31	Deepak Joshi	Brain-Computer Interface (BCI), Signal Processing and Machine Learning for Neuro-prostheses	Team Member
32	Dinesh K.	Biomedical devices	Team Member
33	Niladri Chatterjee	Machine Translation, Artificial Intelligence	Team Member
34	J.P. Khatait	Medical device design	Team Member
35	Ramakrishna K	Kinematics and Mechanisms	Team Member
36	Sunil Jha	Robotics, Manufacturing Automation	Team Lead
37	Sudipto Mukherjee	Mechanism , Robotics	Team Lead
38	Chetan Arora	Computer Vision and Machine Learning	Team Member
39	M. Balakrishnan	Assistive technologies	Team Lead
40	Subhashis Banerjee	Computer Vision, Robotics	Team Member
41	Vinay Joseph Ribeiro	Computer and Network Security, Internet of Things (IoT)	Team Member
42	Mausam	Artificial Intelligence, Natural Language Processing	Team Member
43	Prem K Kalra	Computer Graphics, 3D Animation	Team Lead
44	Subodh Kumar	Tele-robotics and physical simulations	Team Lead
45	Shouribrata Chatterjee	Analog circuit design and VLSI	Team Lead
46	Bodhaditya Santra	Quantum gases, Precision spectroscopy	Team Member
47	Pintu Das	Nanomagnetism, Magnetic sensors	Team Member
48	Brejesh Lall	Object representation, tracking and classification, odometry, depth map generation	Team Member

49	Souvik Chakraborty	Deep learning, Digital Twin, Stochastic Mechanics, Reliability Analysis, Reduced order models	Team Member
50	Satyananda Kar	Experimental Plasma	Team Member
51	Deepak Raina*	Robotics and AI	Team Member
52	Udayan Banerjee*	Robotics and Control	Team Member
53	Shraddha Chaudhary*	Computer Vision and AI	Team Member

*Research fellows

Appendix II: List of Individual Proposals

The key aspects of each individual proposal from the IIT Delhi and outside collaborators, as received, are attached next.

S. No.	Name of IIT Delhi Collaborators	Page No.	S. No.	Name of External Collaborators	Page No.
1	Arpan Chattopadhyay	43	1	Rishabh Agarwal	84
2	Abhisek Dixit	45	2	Bittu Kumar	87
3	Brejesh Lall	47	3	Soumen Sen	89
4	Bodhaditya Santra	49	4	Joydeep Mukherjee	93
5	Dhiman Mallick	51	5	K. Raman	96
6	I N Kar	53	6	Vikas Rastogi	99
7	Kaushik Mukherjee	56	7	G C Nandi	102
8	M. Nabi	59	8	Jainendra Shukla	105
9	Manan Suri	61	9	Sayan Basu Roy	108
10	Pintu Das	63	10	Vineet Vashista	111
11	Rohan Paul	66	11	Ashish Dutta	113
12	Shubhendu Bhasin	69	12	M. Manivannan	116
13,14	Sitikantha Roy	72, 75	13	P. V. Padmapriya	120
15	Souvik Chakraborty	78	14	Asokan T	123
16	Shaunak Sen	80	15	Felix Orlando	125
17	S. K. Saha	82	16	Pushparaj Mani Pathak	127
			17	Tapas Kumar Saha	130
			18	Nayan M. Kakoty	132
			19	M. K. Padmanabhan	135
			20	Deep Seth	138
			21	Laxmidhar Behera	140
			22	Nobuto Matsuhira	143
			23	Evgeni Magid	145
			24	Seul Jung	148
			25	Spandan Roy	150