Detailed Project Report

For

Technology Innovation Hub

Under NM-ICPS

on

TECHNOLOGIES FOR UNDERWATER EXPLORATION

By

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

भारतीय प्रौद्योगिकी संस्थान गुवाहाटी • Indian Institute of Technology Guwahati •

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September 2021

EXECUTIVE SUMMARY

The IIT Guwahati Technology Innovation Hub (TIH) is situated inside the campus of the Indian Institute of Technology, Guwahati. This Hub occupies about one and a half floors of the newly constructed research building (approx. ~ 32000 sq. ft.) at IIT Guwahati. The Hub is governed by a Hub Governing Body (HGB), comprising of members as required by the National Mission for Interdisciplinary Cyber-Physical Systems (NM-ICPS). It is now converted to a section 8 company named as "IIT Guwahati Technology Innovation and Development Foundation (IITG-TIDF)" and tripartite agreement have been signed among IIT Guwahati, IITG-TIDF and DST.

Currently 41 Faculty members from various Departments of IIT Guwahati have given their consent to be a part of the TIH team. It has collaborators from several academic and research institutes from all over the country. It also has a few foreign collaborators – such as New York University, USA, and Taiwan Ocean Research Institute (TORI). This Hub also has obtained expression of interest from several industries.

The technology innovation hub IIT Guwahati discussed with many research institutions, personnel from industry and business sector and get their feedback regarding the development of a technical innovation hub related to the technologies for underwater exploration. They have gone through available literature and several worldwide commercial and scientific developments in this field. For the purpose of clearly defining the beneficiaries, and objectives, the hub activities are divided into five components viz., (i) Technology Development (ii) Human Resource Development & Skill Development (iii) Centre of Excellences on Manufacturing of Cyber-Physical Systems (iv) Innovation, Entrepreneurship and Start-up Ecosystem (v) International Collaborations. The targets associated with these components are summarized in Chapter 2.

The TIH is setup to conduct interdisciplinary research and development in the broad area of underwater exploration. Therefore, a grand problem has been formulated, whose *aim is to design and develop Mechanical Structures, Prime Movers, Sensors, Controllers, Software, and Communication systems, of national and international importance for underwater applications. IIT Guwahati will provide a platform for bringing the experts together for generation of the knowledge through basic and applied research which can lead to generate* *several entrepreneurs, stat-up companies, skill developments, jobs, and research opportunities in this area.*".

The Hub shall focus on Research and Development (R&D) in two primary areas, namely (i) Underwater Systems Development and (ii) Underwater Vision, Monitoring, Surveillance, Intelligence and Tracking. While the first primary area will mainly focus on the mechanical structures, the second primary area will focus on the computer & electronics aspects. After several rounds of discussion with the subject matter experts, these primary areas are further divided into nine secondary areas viz., (1) Underwater repairing and maintenance, (2) Underwater autonomous vehicle, (3) Underwater electronics and powering, (4) Offshore energy & desalination of sea water (5) Underwater tourism (6) Underwater Aquaculture (7) Underwater healthcare and monitoring (8) Underwater vision & communication (9) Offshore bio-resources & mineral – resources.

The novelty in the proposed areas on which the hub shall work is based on designing and development of systems which (a) involve bringing together multiple live industrial research problems of national and international importance on a common platform and (b) can be built at low cost through advanced manufacturing techniques. Also the hub is intended to develop the training schools such as underwater maintenance and repairing training school, which will be a unique facility in the nation and a platform for skill development and experimentation. TIH – IIT Guwahati will also develop a facility for water body monitoring through drones. Marut Drone Pvt. Ltd. has expressed its willingness to establish a training school in collaboration with TIH – IIT Guwahati for the same. The CPS Technologies and TIH Strategy targets are summarized in Chapter 3.

The budget of the TIH has been divided into six components viz., (i) Technology Development (ii) Center of Excellence (iii) HRD & Skill Development (iv) Innovation, Entrepreneurship, and Start-ups Ecosystem (v) International collaborations and (vi) TIH Management Unit. The details of the budget distribution have been provided in chapter 4. The budget under the recurring, non-recurring, and capital head for all six proposed component has also been summarised. As per the tripartite agreement the project will utilize 57.41 % of the budget for recurring, 42.59% for the non-recurring head. The six components viz., Technology Development, Center of Excellence, HRD & Skill Development, Innovation, Entrepreneurship, and Start-ups Ecosystem, International Collaborations, and TIH Management Unit use 29.04%, 22.46%, 18.93%, 21.11%, 1.06% and 7.41% of the total budget respectively. The detailed year-wise distribution of the budget has been provided in Chapter 4. Also a description on the time frame, cost – analysis and risk analysis have been provided in Chapter 4.

The activities of the TIH will be performed by a team having six wings viz., (1) Coordination Wing (Hub Governing Body) (2) Basic Research Wing (Technology Development) (3) Applied Research wing (Technology Development & CoE) (4) Advanced Research Wing (Technology Development) (5) Technology Incubation and Entrepreneurship Wing (Technology Incubation Hub) (6) Education and Training Wing (HRD). Chapter 5 provides the details on the TIH Management and also contains the information of TIH members and their specializations. The purchase, procurement and requirement policies of the section – 8 company, IIT Guwahati, Technology Innovation & Development Foundation have been formulated.

It is hoped that the TIH will achieve all targets mentioned in this DPR and become a hub of national and international importance in the field of Technologies for Underwater Exploration.

CERTIFICATE

Name of the TIH: IIT Guwahati Technology Innovation and Development Foundation

Technology Vertical: TECHNOLOGIES FOR UNDERWATER EXPLORATION

1. This is to certify that the Detailed Project Report (DPR) on the Technology Vertical **TECHNOLOGIES FOR UNDERWATER EXPLORATION** is prepared and submitted to Mission Office, NM-ICPS, DST is as part of implementation of Technology Innovation Hub (TIH) at **IIT GUWAHATI, GUWHATI, ASSAM, 7891039** 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 30th December 2020 between Mission Office, DST, **IIT GUWAHATI** and **IIT GUWAHATI TECHNOLOGY INNOVATION AND DEVELOPMENT FOUNDATION.**

Date: 15/9/2021
Place: IIT GUWAHATI

(Prof. S K Dwivedy)
Name(s) and Signature(s) of Project Director (s)

Endorsement from the Head of the Institution

1. Certified that the Institute welcomes participation of **Prof. Santosha Kumar Dwivedy** as the Project Director for the Technology Innovation Hub (TIH) and that in the unforeseen event of discontinuance by the Project Director, the **IIT GUWAHATI** <Host Institute>….. will identify and place a suitable faculty as Project Director for fruitful completion of the TIH activities.

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

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

Date: 20-09-2021

Place: IIT GUWAHATI

(Prof. G Krishnamurthy)

(Dean II&SI)

Name and signature of Head of Institution

कृते निदेशक, आई आई टी गुवाहाटी
For Director, IIT Guwahati
संकायाध्यक्ष, औद्योगिक सहभागिता एवं विशेष पहल
Dean, Industrial Interactions & Special Initiatives

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Chapter–1

TIH Introduction

1.1 Background

IIT Guwahati has been selected to develop the Technology Innovation Hub (TIH) in the vertical of "***Technology for Underwater Exploration***" by the National Mission for Interdisciplinary Cyber-Physical Systems (NM-ICPS), Department of Science and Technology (DST) of the Government of India, New Delhi. It will work in collaboration with other 24 TIHs, selected for other different verticals. This TIH in the next five years will take up many innovative projects and will help to develop technologies of national and international importance, high quality manpower, incubation centres, training schools, and start-ups integrated with Cyber-Physical Systems (CPS). It will be in the line of initiatives by the government of India like Sustainable Development Goals (SDG), New Quality of Connectivity, Digital India, Make in India, Skill India & Stand-up India, Smart Cities, Industry 4.0 and Society 5.0.

In the next paragraphs different natural and manmade water bodies existing in our country are briefly described. The TIH on Technology for Underwater Exploration will centre its focus on these water bodies for various CPS related applications which will be described in later chapters. Table 1.1 shows some of the commercial, defense and scientific applications of underwater exploration based on water bodies.

India accounts for about 2.45 per cent of world's surface area, 4 per cent of the world's water resources and about 16 per cent of world's population. In our country, there are about 10,360 rivers and their tributaries longer than 1.6 km each. The mean annual flow in all the river basins in India is estimated to be 1,869 cubic km [*web ref 1*].

The Indian River system is made of ten major rivers along with their several tributaries and distributaries. These includes Brahmaputra, Kaveri, Ganga, Yamuna, Narmada, Tapti, Sutluj, Mahanadi, Godavari and Krishna. These rivers provide drinking water, irrigation to agricultural land, transportation, power and livelihoods for a large number of people in India. From the available surface water 9% has been used for domestic, 2% for industrial and 89% for agricultural applications. Similarly from ground water 3% is used for domestic, 5% for industrial and 92% for agricultural applications. Hence there is a large scope for utilization of NM-ICPS related to underwater exploration in these river net [*web ref 2*].

Table 1.1: List of Water bodies where TIH activities can be undertaken

S No	Water bodies	Remarks
1	Ponds	Approximately 9 lacks in numbers, where CPS can be utilized for aquatic crop management which can ensure the food security and rural employment generation.
2	Tube wells, wells, storage tank, rainwater harvesting system, water treatment plant, sewerage treatment plant	A large no of such systems exists which can be attached with CPS for efficient management.
3	Lakes, falls, wetland, lagoons, estuaries	Tourism activities, conservation of aquatic eco-systems and wetland management with the help of CPS technology innovations.
4	Rivers, reservoirs (Dams)	10 major rivers its tributaries and distributaries in India. CPS may assist in river health monitoring, flood management, tourism, and energy harvesting and water quality assessment. Also there are nearly 5264 active Dams in the rivers, their monitoring and restoration can be done effectively using integrated CPS.
5	Sea and ocean	India has a coastline of nearly 7,516 km. There are several fields (surveillance, underwater tourism, oil, gas and minerals exploration under seabed, ecosystem study, archaeological heritage exploration and restoration etc) where CPS may assist in better monitoring, security and management.
6	Water bodies for Industrial purpose, Cooling tower in power plants	Critical monitoring with the help of CPS
7	Miscellaneous and artificial water bodies (aquarium, swimming pool, water supply system, underwater cables, pipes etc)	Safety, inspection, repair, maintenance and management.

As per the information from Central Water Commission (CWC) 2019 report, India has 5264 (completed) and 437 (under construction) large Dams. These Dams are generally 10 to 15 m in height the length of the crest of these Dams are more than 500 m and contains more than 1 million cubic meter of water. As per NRLD there are 65 completed and 11 under construction Dams in the category of Dams of National Importance which has height of more than 100 m and has a storage capacity of 1 billion cubic meter. Many of these reservoirs are the life line of the agricultural and industrial growth of the states. The state wise distribution of Dams are listed in Figure 1.1 and the details are available in the NRLD report [*web ref 3*].

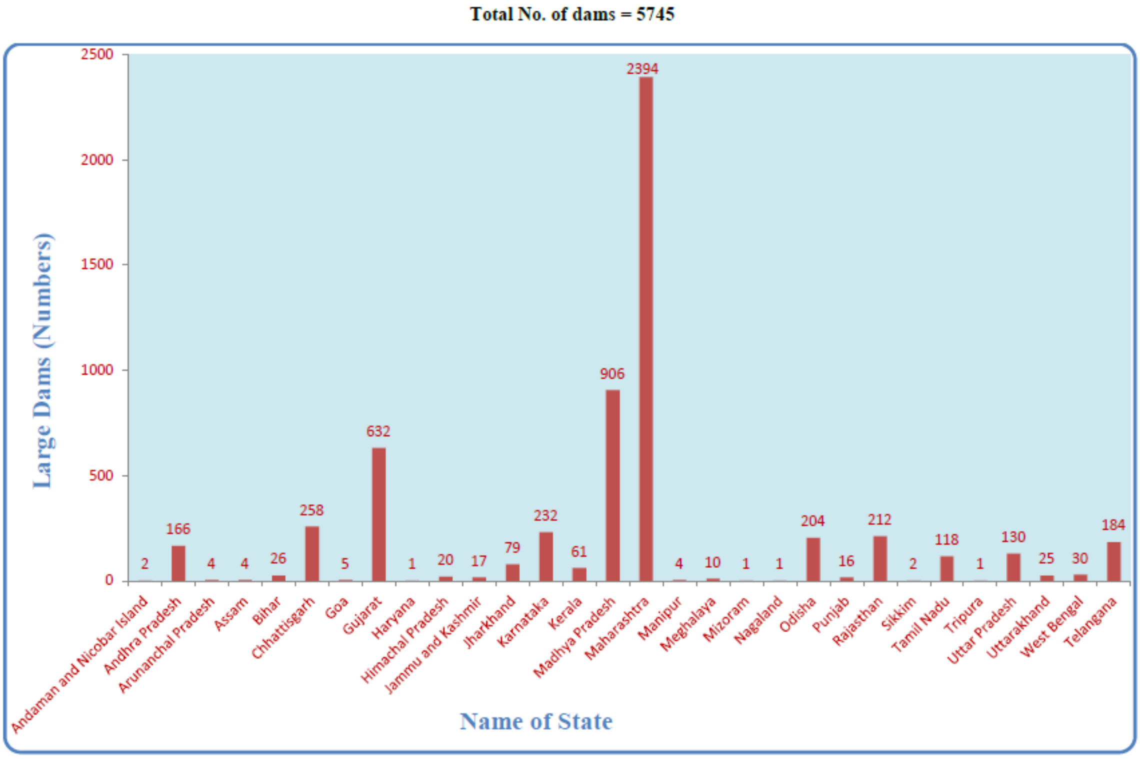


Figure 1.1: State wise distribution of Large Dams in India [*web ref 3*].

Many of these Dams are aging and requires continuous health monitoring and maintenance. NM-ICPS can play a great role in this regard.

India has 63 major lakes in 14 different states. Also there are 115 major wetlands spans over 24 states and 2 union territories. Some of these includes Dal Lake, Loktak lake, Bhopal lakes, Ropar lake, Sukna lake, Kanjli lake, and Pong dam lake, Chilka lake etc. There are many changes faced in the lake which include growth of invasive species like water hyacinth which results in breeding of vectors and consequently causing endemic diseases. NM-ICPS may be helpful in the conservation of aquatic eco-systems and wetland management for biodiversity and climate security. TIH will help to protect and restore all water-related ecosystems in the Nation.

As per the 2011 Census of India, there's a total of 664,369 villages and 7,935 towns in India. Considering at least one pond in a village these will be around more than 6 lakhs ponds in the country. They must be accompanied by similar number of water bodies [part of river basin]. As most of the villages are based near the rivers livelihood of the villagers mostly depends on these water bodies. So the NM-ICPS will play a major role to support the economic growth of the villagers, those depends on these water bodies. A brief study of the exploration activities in sea is given in the next paragraph.

India has a coastline of nearly 7,516 km where CPS integrated with underwater vehicles can play a major role in maritime security, surveillance, underwater tourism, exploration, ecosystem study, archaeological heritage exploration and restoration and the safety of global economic activities taking place in the Indian Ocean etc. India's prosperity, growth and economic development is intrinsically linked to the seas [*web ref 4*].

Challenger (a British ship) in 1872–76 was the first major undersea exploration. This survey helped in understanding the temperature and salinity distribution of the open seas. Since then the researchers in the field of oceanography have learned the underlying mechanism of oceanic wave pattern, storms, heat waves and seismic activities and its interaction with the atmosphere. Technological advancement in acoustical techniques and deep-sea submersibles with on-board sensors have revealed the zone of diverse fish populations, their distribution and the existence of unusual species. The existence of metals of economic importance including zinc, copper, lead, silver, gold, manganese, cobalt and nickel under the seabed have been found in nodules which are distributed over the entire ocean floor. These under sea explorations requires to develop the technology for deep-sea mining and transportation purpose where CPS equipped with underwater vehicles may be helpful in exploration, mining and transportation.

The Indian Ocean holds an economic and strategic importance to the Nation. It has been one of the important economic trade transport sea route between Europe, North America, and East Asia. The global economic growth highly depends on the trade routes (as can be seen in case of Belt and Road Initiative by China). Here CPS can be very helpful in monitoring, safety and navigation purpose. Recently the Indian Ocean is becoming the popular tourist destination due to its warm climate, unexplored beautiful beaches, and attractive azure waters. Fishing has been one of the major economic activity in the sea which gives livelihood to nearly 15 million people and comprises of around 2.5 lakh vessels. This is a major source of not only food but also helps in generating nearly $6 Billion of foreign exchange. The CPS equipped underwater exploration technologies are must to develop for assisting all the stakeholders depends on sea.

India has a vast oil and natural gas reservoirs reserves in Arabian Sea also strive to reduce its energy dependence on other countries by exploring oil and natural gas deposits under the sea bed not only in Indian Ocean, Arabian Sea but also in Pacific and Atlantic regions. The estimated crude petroleum and natural gas reserves in India in the eastern and western offshore regions are nearly 41 and 239 million metric tonnes respectively which are 6.73% and 39.6% of the total crude oil reserve in our country. Similarly the natural gas reserve in the eastern and western offshore regions are 507 and 302 billion cubic meters respectively which are 39% and 23% of the total natural gas reserve in our country. As they are present underwater region the CPS will play a major role in its exploration and other related activities [*web ref 5*].

India launched its own deep ocean mission on October 2019, to explore deep ocean minerals. It is observed that many minerals such as manganese, nickel, cobalt, copper and iron hydroxide are available in the Indian Ocean floor at depths of about 6,000 m. These metals can be used in electronic devices, smartphones, batteries and even for solar panels. The presence of these metals of commercial importance can be explored by using AUVs and RoVs and subsequently extracted by using modern extraction technologies [*web ref 6*]. Many countries such as Japan, China, African countries and South Korea are working in several regions in the sea for mineral exploration and mining [*web ref 7-10*].

Underwater exploration may be useful in the context of defence related activities [*web ref 11*] such as reconnaissance, surveillance, underwater docking, vision, infrared and acoustic guidance technologies and exploration missions.

Apart from the above mentioned natural underwater resources there are many other man made resources available for industrial uses. For example the water bodies are used for thermal and nuclear power plants. It may be noted that in India the thermal power plants accounted for

69.25% of the total installed capacity [*web ref 12*] and the share of Hydro and Nuclear energy are nearly 11.37% and 1.70% of total installed capacity. The renewable Sources (excluding hydro) accounted for an installed capacity of 70563 MW, accounting for 17.68% of the total installed Capacity. Further mini and micro hydel power plants, floating solar power plants may be developed in water bodies.

Also the integrated use of CPS will be helpful in water supply system for drinking and irrigation purpose, rainwater harvesting system, artificial water bodies such as aquarium and swimming pool, underwater cable for communication and pipes for oil and gas transportation.

Further the developed products under the TIH for underwater exploration will find many other applications in different technology verticals which includes the following

- Defence Research and Development
- Earth Sciences
- Health Research
- New and Renewable Energy
- Tourism
- Shipping
- Skill Development and Entrepreneurship.

1.2 Description of the Hub

The Technology Innovation Hub IIT Guwahati on Technologies for Underwater Exploration will be situated in the research building of the Indian Institute of Technology (IIT), Guwahati. It will occupy nearly one and half floors of the research building (3000 sqm ~ 32000 sqft) at IIT Guwahati. The TIH shall be governed by a Hub Governing Body (HGB), comprising of members as per the National Mission for Interdisciplinary Cyber-Physical Systems (NM-ICPS).

Currently 41 Faculty members from various Departments of IIT Guwahati, such as Mechanical Engineering, Computer Science & Engineering, Electronics and Electrical Engineering, Department of Design, Civil Engineering have given their consent to be a part of the TIH team. It has collaborators from Academic Institutions such as IIT Roorkee, IIT Indore, IIT Ropar, IIT

Dharwad, IIT Jodhpur, IIT Palakkad, IIT Bhubaneswar, IIT Jammu, IIT Delhi, IIT Kharagpur, IIT Kanpur, NIT Silchar, NIT Meghalaya, NIT Mizoram, NIT Rourkela, NIT Arunachal Pradesh, NERIST, Uttar Banga Krishi Vishwavidyalaya; and from research institutes such as DTRL, DRDO, CMERI Durgapur, NIOT Chennai, ICAR – CIFRI Kolkata, IRS Mumbai, Inland Water Transport, Assam, and Indian Navy. It also has a few foreign collaborators – such as New York University, USA, and Taiwan Ocean Research Institute (TORI). This Hub also has obtained expression of interest from several industries.

1.3 Aims and Objectives of the Hub

The Aim of this hub is "*to design and develop Mechanical Structures, Prime Movers, Sensors, Controllers, Software, and Communication systems, of national and international importance for underwater application. IIT Guwahati will provide a platform for bringing the experts together for generation of the knowledge through basic and applied research which can lead to generate several entrepreneurs, stat-up companies, skill developments, jobs, and research opportunities in this area.*"

To achieve the above aim the objectives are broadly classified into the following four categories:

1) Technology Development:
   a. Several technologies are intended to be developed in this project through three schemes viz., (i) expert & research-driven new knowledge generation/discovery, (ii) development of products/prototypes from existing knowledge (by experts or teams), and (iii) technology/product delivery in specific sectors.
   b. In "expert & research-driven new knowledge generation/discovery" 20 technologies will be developed by the member of the TIH. The focus of this category will be from fundamental to truly novel concepts leading to a prototype.
   c. In "development of products/prototypes from existing knowledge" 4 technologies will be developed by the member of the TIH. The focus of this category will be on the development of underwater CPS system (e.g. underwater welding, cleaning, machining, communication, vision, and healthcare).
   d. In "technology/product delivery in specific sectors" 4 technologies will be developed by the member of the TIH. The focus of this category will be on the product

development such as autonomous underwater vehicle for repairing & maintenance (e.g. Indian Navy, Inland water transportation, ONGC etc.), tourism (e.g. marine submarine, IRS, Mumbai), exploration (e.g. Coral bleaching for NIOT, Heritage), and monitoring (e.g. Aquaculture given by MPEDA, CIFRI)

2) HRD and Skill Development:

a. A fellowship will be provided to Doctoral & Post-Doctoral students through a *Centre of Intelligent Cyber Physical Systems (CICPS)* of IIT Guwahati newly established for this purpose. It will also provide PhD fellowship in other collaborating institutes.
b. A fellowship will be provided to the students of a newly started M. Tech program on 'Robotics and Artificial Intelligence' in the CICPS of IIT Guwahati. The students will carried out their project work related to underwater exploration.
c. A fellowship will be provided to the UG & PG students, selected for internship in the TIH – IIT Guwahati.
d. Faculty fellowships will be provided to the appropriate subject matter experts from academic institutes and industries.
e. A platform will be provided for organizing the preliminary and advanced skill development workshops through the CICPS.
f. A platform will be provided for conducting seminars, short-term courses, workshops, grand challenges and conferences periodically through the CICPS.
g. Three will be around 1500 overall beneficiaries under HRD & Skill Development programme.

3) Innovation, Entrepreneurship and Start-Up Ecosystem

a. TIH – IITG will collaborate with the Technology Incubation Center (TIC) – IIT Guwahati to provide a platform for Innovation, Entrepreneurship and Start-Up Ecosystem.
b. The TIH – IIT Guwahati will provide the financial support for the Start-ups, Young and Aspiring technology entrepreneurs, and entrepreneur in residence in the domain of underwater exploration through several schemes.
c. A social entrepreneurship program will be initiated to cater the technical / non-technical need of the society.

4) Centre of Excellence

a. The primary focus of the CoE will be on providing the manufacturing facility of different products related to the CPS. The crucial products such as mechanical structures, motors, electronics devices, mechanical devices, controllers, actuators, sensors, etc. will be in-house designed and manufactured.

b. The CoE will consist of nine different divisions viz., (1) Underwater Natural Resources Division (2) Product Development Division, (3) Reverse Engineering Division (4) Fabrication Division, (5) Virtual & Augmented Reality Division, (6) E-Mobility Division (7) Internet of Things Division, (8) Product Testing Division, and (9) Sensor & Actuator Fabrication Division. These divisions of the COE will directly/in-directly assist the research and development activities of the TIH – IIT Guwahati.

c. The CoE will provide a platform for training & skill development programs and help the TIH – IIT Guwahati to be self-sustainable after 5 - years.

5) International Collaborations

At-least 2 international collaborations with the researchers working in the reputed institutes abroad on the underwater technologies are intended.

6) Self-Sustainability objectives

In order to make the TIH self-sustainable after five years, an amount of approximately Rs 10.00 Crs. has to be generated per year. To generate the revenue after five years, six schemes will be explored viz., (i) Revenue through training schools, (ii) Revenue through CoE (iii) Revenue through start-ups, (iv) Revenue through collaborating institutes, (v) Revenue through Sponsored Ph.D. & M. Tech programs, and (vi) Revenue through Product's IP.

In line with the above objectives following will be the grand problem of the TIH:

Design and development of Mechanical Structures, Prime Movers, Sensors, Controllers, Software, and Communication systems, of national and international importance for underwater application will be the prime focus of this Technology Innovation Hub (TIH). IIT Guwahati will provide a platform for bringing the experts together for generation of the knowledge through basic and applied research which can lead to generate several entrepreneurs, stat-up companies, skill developments, jobs, and research opportunities in this area.

Following are the two major application areas of the hub

1) Underwater Systems Development

Due to harsh working conditions, underwater engineering processes are usually costlier and challenging. To minimize the cost and simplify the process, the users prefer to carry out any such operation at a repair site on land. However, it is infeasible to bring out large or fixed structures out of the water for any repairing operation. Conventionally, a skilled diver performs underwater operations such as welding, cutting, grinding, coating etc. on site. These underwater divers are need to be assisted with an optimally automatic equipment which requires a minimum or zero human intervention. Therefore, it is a need of the hour to develop optimally automatic **underwater manufacturing equipment**.

Traversing underwater terrain requires the development of flexible vehicles, whose motion is similar to underwater organisms. However, traditional autonomous systems and robots have lacked such flexibility. There is a need to develop flexible mechanisms with sufficient mobility to navigate the underwater environment. Investigation can be made into the use of piezoelectric materials, artificial muscles and other compliant mechanisms to design appropriate mechanisms for navigating the underwater environment. Also, a traditional problem in underwater systems is that such systems are under-actuated. Under-actuated control has proved to be problematic in the past and is still an active research topic today. Furthermore, novel propulsion mechanisms are needed to move underwater systems. Furthermore the development of electric, hybrid and alternative propulsion systems for AUV's (**Autonomous underwater vehicles**) is an important area of research.

2) Underwater Vision, Monitoring, Surveillance, Intelligence and Tracking

The current international situation has witnessed an increase in attacks upon nations by saboteurs and terrorists, who have found novel means of infiltration. Although such attacks may be generic in nature, they are often aimed at targeting critical assets of nations, be it financial or otherwise. The latest of these attacks have come due to the use of underwater environment for such purposes. The most important assets to be protected against such attacks are military bases, sensitive installations connected with offshore oil and gas production and transportation, nuclear power plants, amongst others.

Also, there is a demand for monitoring the subsea environment given the current pollution status. All of these problems require solutions dealing with **underwater monitoring and surveillance**. However, manual solutions are difficult to achieve given the limitation imposed by high water pressure in the subsea environment. There is a need for the development of autonomous underwater vehicles to achieve such surveillance and monitoring purposes. High-end research must be conducted to ensure sufficient autonomy is imparted to underwater vehicles so that they can be used for proper surveillance and monitoring purposes.

The Table: 1.2 lists the targets of the TIH at IIT Guwahati for the above mentioned aims

Table: 1.2: The targets of the TIH at IIT Guwahati

S. No.	Activity	Minimum Target	Our Target
	Technology Development		
1	No. of Technologies	25	28
2	Technology Products	25	28
3	Publications, IPR and other Intellectual Activities	75	100
4	Increase in CPS research Base	85	85
	Entrepreneurship Development		
1	CPS-Technology Business Incubator	1	1
2	CPS-Start-ups & Spin-off companies	43	50
3	CPS-GCC-Grand Challenge and Competitions	1	1
4	CPS-Promotion and acceleration of young and aspiring technology entrepreneurs (CPS-PRAYAS)	1	1
5	CPS Entrepreneur in Residence (CPS-EIR)	25	50
6	CPS- Dedicated Innovation Accelerator (CPS-DIAL)	1	1
7	CPS- Seed Support System (CPS-SSS)	1	1
8	Social Entrepreneurship Program	No Given	5
9	Job Creation	10625	10625
	Human Resource Development		
1	Graduate Fellowship	270	275
2	Post Graduate Fellowship	50	50
3	Doctoral Fellowship	24	31
4	Post-Doctoral Fellowship	No Given	15
5	Faculty Top-up	No Given	150
6	Faculty Fellowships	6	6
7	Chair Professor	6	6
8	Skill Development	510	600
	International Collaboration		
1	International Collaboration	1	2
	Center of Excellence (as per the NMI-CPS Mission report)		
1	No. of Candidates for Skill Development	-	5000
2	Revenue Generation	-	7.5 Cr.

1.4 Activities of the Hub

A brief description of the activities to be conducted by TIH are mentioned below

1) Basic Research in Technologies for Underwater Exploration– This shall be done by the Basic Research Wing (BRW). The primary activity of this Hub shall be to conduct fundamental research on topics in the technology vertical of Technologies for Underwater Exploration, dealing with

   (a) AI for Underwater Exploration

   (b) Underwater sensing

   (c) Algorithms for underwater missions

   (d) Defence Technologies for Underwater Exploration

   (e) Surveillance, Maintenance and Repair of Underwater Machine Components

   (f) Underwater Health Research

2) Applied Research on Technologies for Underwater Exploration– This shall be conducted by the Applied Research Wing (ARW). Another primary activity of this Hub is to conduct applied research (leading to product development) under the vertical of Technologies for Underwater Exploration. This wing shall apply conceptual theory as required for specific problems that are the mandate of the Hub. The development of underwater docking stations, ocean research vessels, underwater mining machines, manned and unmanned underwater vehicles, development of a variety of marine sensors, construction of underwater defence technologies, surveillance, maintenance and repair of underwater machine components, Underwater Health Research, amongst others, shall be the broad objectives of this wing. This wing shall be responsible for the Design, Testing and Manufacturing of the products.

3) Setting up of a Manufacturing Facility at its location– One of the important activities of this Hub is to develop a Manufacturing Facility at its location, to engage in production of material goods/products to be commercialized. The purpose of this facility is to develop indigenous products and to radically lower the cost of the product to be sold.

4) Advanced Research on Technologies for Underwater Exploration– This shall be done by the Advanced Research Wing (AdRW). A function of this Hub shall be to conduct research on advanced topics that require super-specialization in the technology vertical of

Technologies for Underwater Exploration. The list of such topics include, but are not limited to – Ocean state forecast and weather prediction, Ocean Survey, Ocean Science Services, Marine Biotechnology, amongst others.

5) Collaboration, Innovation and Entrepreneurship– This Hub shall also carry out the following activities:

(a) Identify and seek out potential collaborators for the mandate of this Hub to attract potential and harness expertise available nationwide, thus fostering research innovation, world class technology and product development.

(b) To identify budding entrepreneurs and venture capitalists who have/wish to setup firms in the technology vertical of Technologies for Underwater Exploration and to provide support to them.

(c) To seek out new products that have a respectable market, and communicate the same to other wings to consider for research/analysis & design/manufacture.

(d) To enhance competencies, capacity building and training to nurture innovation and start-ups.

(e) To provide funding assistance for start-ups

(f) To create linkages with existing Technology Business Incubators (TBI) or create new TBI in Host Institute.

(g) To connect Indian Research with global efforts, participate in international projects and receive grants for the same.

6) Education – As research on Technologies for Underwater Exploration requires knowledge of various fields like computer science, electronics, electrical, mechanical, civil engineering etc. - here interdisciplinary approach is needed to understand the subject. The foremost problem here is the transfer of knowledge and creation of awareness about subjects, technologies, state-of-the-art and emerging topics to person(s) not traditionally associated with such disciplines. The interdisciplinary nature of Underwater Exploration renders it difficult to educate persons on specific and emerging topics even for those who may be experts in the conceptual theory associated with one aspect of it. Within underwater exploration education, there can exist a barrier in presenting coherent activities due to the disjoint nature of concepts associated with subject(s) in a given discipline as compared to subject(s) associated with other disciplines, software platforms, and hardware devices. Educators may not possess advanced skills in all these areas simultaneously, thus reducing their ability to effectively perform an adequate transfer of knowledge to other working in related areas (or even to students).

The objective of this activity shall be to generate mechanisms for transfer of knowledge about the various fields of research activity in underwater exploration to person(s) who may not be traditionally associated with such a field. This may apply not just to professional researchers but also to students who wish to apply for (or are part of) advanced degrees (M.Tech/MS or PhD) in Underwater Exploration Technologies**.** The following activities shall be conducted by this Hub.

(a) Identify all areas of work related to Underwater Exploration.

(b) Contact other members of the TIH (or even professionals who may not be associated with the TIH) working in specific areas of Underwater Exploration to acquire details of theory, the state of the art and emerging technologies.

(c) Prepare information sheets, posters to disseminate the acquired information for those who may not be specialists in the field.

(d) Hold periodically, seminars, symposium, workshops, short term courses and conferences with oral and poster presentations wherein specialists from each area related to Underwater Exploration can present conceptual theory, state-of-the-art or emerging topics on the same.

(e) Hold contests on Underwater Exploration targeted towards students and Industrial engineers.

(f) Coordinate with specialists in the respective fields to create effective platforms by which Underwater Exploration education can be given.

7) HRD and Skill Development – The development of effective human resource is one of the key problems in the operation of any organization. One of the activities of this Hub shall be to generate mechanisms for the same.

Chapter-2

TIH Beneficiaries

2.1 Stakeholders Consultations

The technology innovation hub IIT Guwahati discussed with many research institutions, personal from industry and business sector and get their feedback regarding the development of a technical innovation hub related to the technologies for underwater exploration. They have gone through available literature and several worldwide commercial and scientific developments in this field. Due to the COVID19 pandemic situation most of the consultations were done using online platform over a period of time. TIH – IIT Guwahati organized online workshops on "Challenges and Opportunities in Underwater Technologies" where the subject matter experts in underwater domain interacted with the members of the TIH – IIT Guwahati. Table 2.1 gives the list of all participating stakeholders with whom online and offline consultations have been carried out.

Table 2.1: Consultative Participating Institutes and Industries

S No	Academic Institutions
1.	IIT Guwahati (Department of Mechanical Engineering, Electrical and Electronics Engineering Department, Computer Science Engineering, Department of Design, Civil Engineering Department)
2.	IIT Roorkee (Department of Mechanical and Industrial Engineering)
3.	IIT Jodhpur (Department of Mechanical Engineering)
4.	IIT Ropar (Department of Mechanical Engineering)
5.	IIT Dharwad (Department of Mechanical Engineering)
6.	IIT Kharagpur (Department of Mechanical Engineering, Ocean Engg and Naval Architecture)
7.	IIT Kanpur (Department of Mechanical Engineering)
8.	IIT Indore (Department of Mechanical Engineering)
9.	IIT Palakkad (Department of Mechanical Engineering)
10.	IIT Bhubaneswar (School of Electrical Engineering)
11.	IIT Jammu (faculty in the department of EE and CSE)
12.	NIT Rourkela (Department of Mechanical Engineering)
13.	NIT Mizoram (Department of Mechanical Engineering)
14.	NIT Silchar (Department of Mechanical Engineering)
15.	NIT Arunachal Pradesh (Department of Mechanical Engineering)
16.	NIT Agartala (Department of Mechanical Engineering)

17.	NERIEST (Department of Mechanical Engineering)
18.	NIT Meghalaya (Department of Mechanical Engineering)
19.	Uttar Banga Krishi Viswavidyalaya (UBKV)
Industries & Research Organization	
1.	Indian Navy
2.	Defence Terrain Research Laboratory, DRDO
3.	National Institute of Ocean Technologies (NIOT)
4.	Central Inland Fisheries Research Institute (CIFRI)
5.	Marine Products Export Development Authority (MPEDA)
6.	Indian Register of Shipping (IRS)
7.	Bhabha Atomic Research Center (BARC)
8.	Central Mechanical Engineering Research Institute (CMERI), Durgapur
9.	Assam Inland Water Transport
10.	Indian Agricultural Research Institute (IARI)
11.	North Eastern Space Applications Centre (NESAC)
12.	Shipping Corporation of India Limited
13.	Cochin Shipyard Limited
14.	Goa Shipyard Limited
15.	Mazagaon Dock Shipbuilders Limited
16.	Oil and Natural Gas Corporation Limited (ONGC)
17.	Indian Oil Corporation Limited (IOCL)
18.	Oil India Limited (OIL)
19.	National Aluminium Company (NALCO)
20.	Hindustan Petroleum Corporation Limited (HPCL)
21.	Nuclear Power Corporation of India Limited (NPCIL)
22.	Raufar Turnaround, India
23.	Maritime Research Center, Pune
24.	Guwahati Neurological Research Centre Ltd.
25.	Marut Drontech, Telangana
26.	Invento Maker spaces private Limited Bangalore
27.	Yantrabot Technologies Pvt. Ltd. Guwahati
28.	MKB (ASIA) Private Limited Guwahati
29.	Paramount Industry, Dibrugarh, Assam
30.	Planys Technologies, start-up IIT Madras
International Collaborators	
1.	New York University, USA
2.	Taiwan Ocean Research Institute (TORI)

Further members have gone through the websites of the following leading Institutes and companies world over working in the field of underwater explorations. Table 2.2 shows the list of leading National and International Research Institutes, Laboratories and Commercial companies actively working in the field of Underwater Explorations.

Table 2.2: Leading institutes and companies world over working on underwater explorations

S No	Labs	Institute
1	Broadband Wireless Networking Lab	Georgia Tech
2	Woods Hole Oceanographic Institution (WHOI)	MIT
3	Underwater Systems and Technology Laboratory	Universidade do Porto
4	Underwater Robotics Laboratory	Shenyang Institute of Automation Chinese Academy of Sciences
5	Underwater Research Lab	Simon Fraser University
6	Autonomous Undersea Systems Institute (AUSI)	Research institute
7	Heriot-Watt University Ocean Systems Lab	Heriot-Watt University
8	Acoustic Research Laboratory (ARL)	National University of Singapore
9	Underwater Technology Laboratory (UTL)	Florida Institute of Technology
10	Autonomous Underwater Vehicles	MIT Sea Grant
11	Adaptive Sampling and Prediction (ASAP)	Princeton
12	Undergraduate Ocean Engineering Degree Program	Florida Atlantic University
13	Autonomous Ocean Sampling Network	Monterey Bay Aquarium Research Institute (MBARI)
14	Underwater Robotics, Robotics Laboratory	IIT Madras
15	Naval Physical and Oceanographic Lab (NPOL)	DRDO
16	Underwater Robotics & Application (URA) Laboratory, Underwater Technology Research Center	The University of Tokyo
	Companies	**Web Links**
1	Bangalore Robotics, India	https://bangalorerobotics.org
2	Indian Underwater Robotics Society (IURS) , India	https://www.iurs.org/
3	Planys Technologies, India	https://www.planystech.com
4	Gridbots Technologies Private Limited, India	https://www.gridbots.com
5	Blue Robotics Inc, USA	https://bluerobotics.com/
6	Harbin Institute of Technology Robot Group, China	http://www.hrgrobotics.cn/en/
7	Notilo Plus, France	https://seasam.notiloplus.com

2.2 Stakeholders Engagement

A series of online and offline interactions from all the stakeholders from academic, R&D, industry and government institutions were organized to conceive consultative framework, details of which are given in Table 2.1. Accordingly a Detailed Project Report (DPR) is made to realize the Project objectives. Extensive literature study has also been carried out to know the state of the art and the challenges in the technology for under water exploration some of which are given in next Chapter. Gap analysis has been carried out and the research objectives have been identified. Table 2.3 shows the primary area of research applications utilizing CPS in the fields based on existing water bodies. It may be noted that in Table 1.1 statistics regarding the available water bodies for possible TIH activities has been mentioned.

Table 2.3: List of water bodies and corresponding applications of cyber physical systems

S No	Water bodies	Applications of cyber physical systems
1	Ponds	• Ecosystem study • Fish farming • Aquatic plants and flower harvesting • Weed management • Monitoring and management of water crops • Floating solar power system
2	Lakes, falls, wetland, lagoons, estuaries	• Migratory bird observation • Fish farming • Tourism • Micro hydel system for energy harvesting
3	Rivers	• Ecosystem study (flora and fauna) • Water quality check • Search and Rescue • Micro hydel based energy harvesting • Maintenance & repair of underwater structures • Monitoring flood • Navigation & communication • Tourism • Hydropower Dams inspection, maintenance and silt removal • River health monitoring
4	Sea	• Navigation & communication • Deep – sea exploration • Autonomous Underwater Vehicle • Healthcare monitoring of divers • Ship construction and maintenance • Underwater welding • Underwater tourism • Underwater data collection • Underwater Domain Awareness • Coral bleaching • Underwater Heritage • Maritime search and rescue • Energy harvesting from ocean waves • Mega structures construction and maintenance • Military and Defense related operations • Seabed oil, gas and mineral exploration • Ecosystem study • Understanding environmental changes

		• Study of Undersea Seismic activities • Understanding ocean heat waves • Oceanographic research • Underwater archaeology monitoring • Underwater lost treasure hunting • Supplies to submarines and ships • Underwater manned vehicles • Nuclear waste disposal and monitoring • Bio – fouling
5	Miscellaneous water bodies (underwater cables, pipes etc)	• Inspection and Cleaning • NDT for leakages • Drainage system management • Monitoring of rain water harvesting • Drinking water supply and management
6	Cooling tower in power plants	• Inspection • Cleaning • Health monitoring

2.3 Primary Research Areas

After discussion with all the stakeholders the following 7 application verticals have been decided for the primary research. They include Defence Research and Development, Earth Science, Health research, New and Renewable energy, Tourism, Shipping and Skill development and Entrepreneurship. Details of the technology are discussed in Chapter 3.

Following are the two primary application areas of the hub

1) Underwater Systems Development

Due to harsh working conditions, underwater engineering processes are usually costlier and challenging. To minimize the cost and simplify the process, the users prefer to carry out any such operation at a repair site on land. However, it is infeasible to bring out large or fixed structures out of the water for any repairing operation. Conventionally, a skilled diver performs underwater operations such as welding, cutting, grinding, coating etc. on site. These underwater divers are need to be assisted with an optimally automatic equipment which requires a minimum or zero human intervention. Therefore, it is a need of the hour to develop optimally automatic **underwater manufacturing equipment**.

2) Underwater Vision, Monitoring, Surveillance, Intelligence and Tracking

The current international situation has witnessed an increase in attacks upon nations by saboteurs and terrorists, who have found novel means of infiltration. Although such attacks may be generic in nature, they are often aimed at targeting critical assets of nations, be it financial or otherwise. The latest of these attacks have come due to the use of underwater environment for such purposes. The most important assets to be protected against such attacks are military bases, sensitive installations connected with offshore oil and gas production and transportation, nuclear power plants, amongst others.

Also, there is a demand for monitoring the subsea environment given the current pollution status. All of these problems require solutions dealing with **underwater monitoring and surveillance**. However, manual solutions are difficult to achieve given the limitation imposed by high water pressure in the subsea environment. There is a need for the development of autonomous underwater vehicles to achieve such surveillance and monitoring purposes. High-end research must be conducted to ensure sufficient autonomy is imparted to underwater vehicles so that they can be used for proper surveillance and monitoring purposes.

Figure 2.1 summaries the primary and secondary research areas of the TIH – IIT Guwahati. While in the first primary area structural design will be carried out and the second primary area the major focus will be on the software development. However, the experts in both the area will collaborate with each other to bring out the useful products.

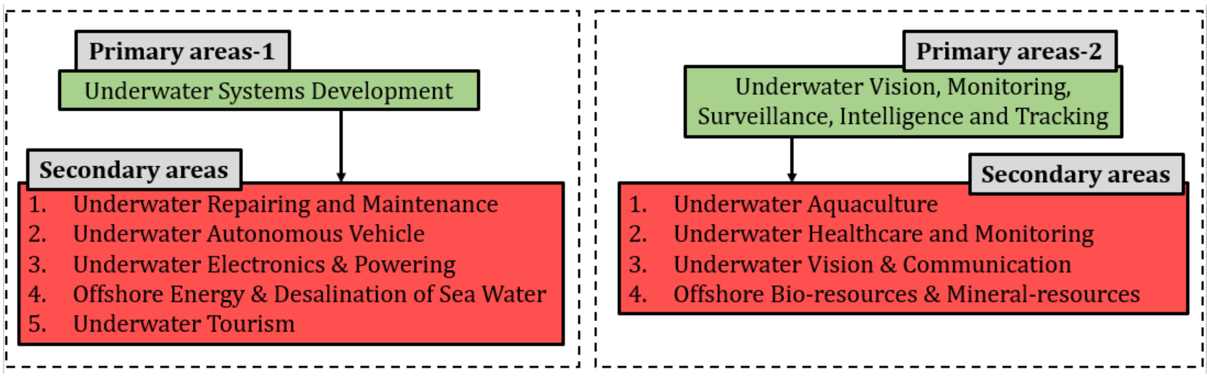


Figure 2.1: Primary and Secondary Application Areas of TIH – IIT Guwahati

The prime mover may be electric, hydraulic and pneumatic motors. One may use the on-board sensors (proximity, force, ultrasonic, pressure, altitude, vision sensor etc), microcontrollers, wired and wireless communication systems. It is observed that indigenously made thruster, sensors are not available to develop underwater vehicles. These items are usually imported from the countries like USA, China, Germany and France with very high cost and also takes several months to reach here in our country. To save precious time, taxpayer's money and achieve autonomy, indigenous development of these components are much needed necessity in the present geopolitical scenario in the Indian peninsula. Further high precision manufacturing facilities are not available in our country so that the most of the components are imported. Thus one of the primary objective of this TIH is to develop a centre of excellence (CoE) in manufacturing where the technology and products will develop to meet the national requirements.

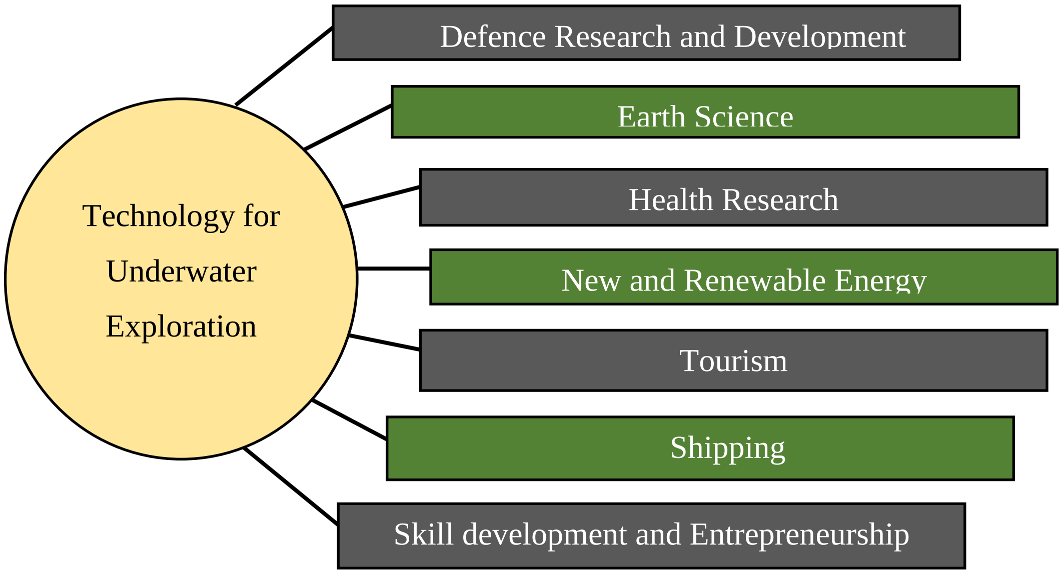


Fig. 2.3 Application Verticals/Areas of the TIH

The interactions from all the stakeholders' leads to pin point the thrust areas of national and international importance which has to be thoroughly looked to develop the technologies in underwater exploration.

1. Underwater Repairing and Maintenance
2. Underwater Autonomous Vehicle
3. Underwater Electronics & Powering
4. Offshore Energy & Desalination of Sea Water
5. Underwater Tourism
6. Underwater Aquaculture
7. Underwater Healthcare and Monitoring
8. Underwater Vision & Communication

9. Offshore Bio-resources & Mineral-resources

Table 2.4 gives a list of projects related to underwater exploration suggested by the team members. Further projects also will be invited from the various stakeholders in open advertisement in due course of time.

S. No.	Grand Problems
1	**Underwater Repairing and Maintenance**
	Work Packages
	Design and Development of Apparatus for Underwater Repairing and Maintenance of Metallic & Non-metallic Structures
	Design and development of novel, cost-effective and integrated robot-laser-based drilling technologies for under water material processing
	Development of Shock Tube Facility and Measurement Diagnostics for Under Water Exploration of Submerged Structures through Blast Wave Analysis
	Experimental Investigations into the effect of reinforcement particles on the tribological and corrosion properties of marine grade AA5052 aluminium alloy joints through FSW
	Vibration Analysis of Underwater Pipe Line
2	**Underwater Autonomous Vehicles**
	Work Packages
	Development of Autonomous System for Underwater Vehicle
	Development of Unmanned Underwater Vehicle for monitoring of underwater eco system and weed management
	Development of flexible multi-link spatial manipulator mounted on a moving body for underwater exploration
	Analysis and development of computational intelligence based navigational strategies for an underwater robotic vehicle
	Design and Development of In-pipe robot
	Development and Analysis of Intelligent Integrated Water Born Robot for Surveillance, Monitoring and Cleaning
	Underwater Vehicle for water quality monitoring of river bodies
	Unmanned Exploration of underwater ecological system both in fresh and sea water
	Design, Analysis and Development of a Low Cost Underwater Vehicle (Mini Submarine) for (a) Tourism Purpose and (b) Bio-fouling cleaning
	Design and Development of passive high-static-low-dynamic stiffness (HSLDS) vibration isolators for underwater vehicles

	Ergonomic Evaluation of the Human-Robot Control Interface and Suggestions for Improvement of Usability
3	**Underwater Electronics & Powering**
	Work Packages
	Design and development of a digital holographic microscopic imaging system for detection and recognition of underwater microorganisms and particles
	Real-time Scour Monitoring using accelerometers and energy harvesters
4	**Underwater Tourism**
	Work Packages
	Study of Underwater Heritage
	Boosting underwater tourism by 3D printed coral reef & Sustainable technologies for underwater tourism
5	**Offshore Energy & Desalination of Sea Water**
	Work Packages
	Underwater compressed air energy storage system for standalone localized power generation
	Aerodynamic studies on innovative blades of vertical axis wind turbine for harnessing offshore wind power
6	**Underwater Aquaculture**
	Work Packages
	Dolphin monitoring Internet of Things (IoT) Network in River Brahmaputra
	Exploration of the aquatic ecosystem of river Brahmaputra
7	**Underwater Healthcare and Monitoring**
	Work Packages
	Design and development of different life supporting, monitoring, safety, assisting and communicating devices for divers to prevent and management of diving accidents during underwater exploration
8	**Underwater Vision & Communication**
	Work Packages
	Under water computer vision
	Design and development of shape memory alloy actuated soft jelly fish robot towards inspection of intricate structures and surveillance with IOT based health monitoring system
	Design and analysis of RF Section for K_a-band vacuum electronics devices & Design of a portable remote operated underwater video surveillance vehicle with robotic arm
	Investigation of Interaction Model of Cyber-Physical System(s) for Underwater Applications
	Smart underwater Monitoring System
	Design and Implementation of AI powered Autonomous Underwater Vehicle (AUV) and IoT Enabled Underwater Acoustic Sensor Networks

	Development of hardware setup and real time implementation of cooperative motion control algorithm for autonomous underwater vehicle under communication constrain
	Measurement diagnostics of saline water sloshing behavior through shockwave impingement
9	**Offshore Bio & Mineral-resources**
	Work Packages
	Smart Pond Monitoring System for Aquaculture Farming, Wetland monitoring System, and Flood monitoring System
	Drones for underwater resource surveillance and monitoring

2.4 Technology Innovation Hub (TIH)

The Technology Innovation Hub (TIH) at IIT Guwahati will focus on generation of new knowledge through basic and applied research in the area of technology for ***underwater exploration***. TIH will be the source for fundamental knowledge in this field that will be needed to keep India prepared for the next generation of technologies. The primary activity of TIH includes the development of new knowledge (intellectual property) and highly knowledgeable human resource with top-order skills, besides serving as a repository of papers and patents. It will also engage in International Collaborations to prepare India in its quest to be a leader in the domain. In line with the National mission along with discussions the TIH incorporate the following:

- Focus on Job creation and human resource development and technology commercialization.
- Collaborations with leading institutions and industries to gain the technological edge in underwater exploration, at a global level. These collaborations are listed in the Table (2.1).
- Industry partnerships in Centre of Excellence (CoE).
- The project is interdisciplinary in nature and provide solutions which have mass impact on the society.
- Real-time problems to be considered
- Facilitate collaboration and extend financial support to individual researchers and small industry R&D groups to bring them into mainstream research
- Planning to develop sub centres in other institutions to give opportunities to students and faculty
- For competitiveness among the collaborators incentive are introduced for excellence and output driven technical environment

2.5 Hub activities

For the purpose of clearly defining the objectives and the activities of the Hubs, it has been divided into four major streams as described in Chapter 1

- Technology Development
- Human Resource Development & Skill Development
- Centre of Excellences on Manufacturing of Cyber-Physical Systems
- Innovation, Entrepreneurship and Start-up Ecosystem
- International collaborations

Technology Development

Several technologies are intended to be developed in five years of this project. Around 30 Technological developments will be targeted indigenously where more than 100 physical products will be developed and a number of incubation centres and start-ups will be created. It will help to generate approximately more than 500 direct employment that may leads to a large no of indirect job creations in the due course of time.

As many of these technologies are related to the existing water bodies in mostly in rural and urban areas, this will involve and motivate several local youths for entrepreneurship and self-employment. For example the cultivation of aquatic crops such as Euryale ferox (or fox nut, also known as makhana), chestnut, water caltrop (singhara), spinach and flowers such as lotus, lily, iris, howthorn, poppy and hyacinth.

Many *aquatic plants* are also good food supplements [*web ref 16*] particularly for rural areas which helps in national food security programmes. Many of these crops can be processed and exported in the National and International markets with the help of cyber physical systems. The CPS integrated underwater system (with on-board sensors and actuators) may help in harvesting (plantation, growth and cultivation), weed control, and the overall management of the aquatic crops.

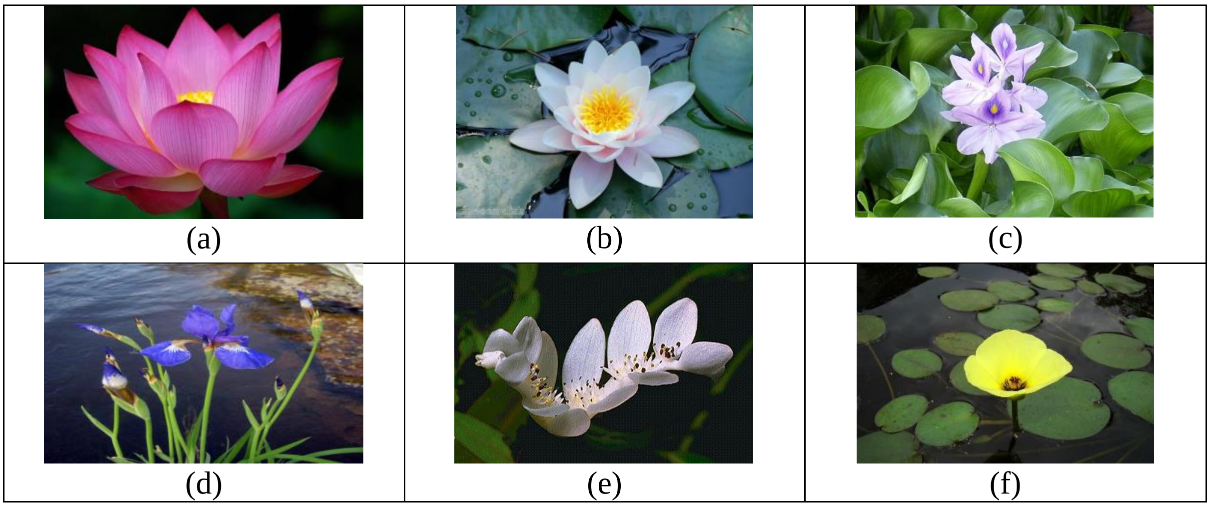


Fig. 2.4 (a) Lotus (b) Lily (c) Hyacinth (d) Iris (e) Hawthorn (f) Poppy [*web ref 15*]

The *fish cultivation* is also a huge market in the country which not only provide food security but create a lot of job opportunities. The quality of the water can be monitored by checking the critical parameters that include dissolved oxygen, un-ionized ammonia, carbon dioxide, nitrite and nitrate concentration, pH, turbidity and alkalinity level using IoT based Cyber Physical System. The management of associated activities are mostly manual till date. The artificial intelligent and vision assisted CPS will definitely enhance the productivity by many fold. Internet of Things (IoT) enabled smart pond and reservoir monitoring system for aquaculture farming with real-time-monitoring may help in achieving higher yield and productivity.

In another example there are more than 5000 Dams in India, in these Dams the underwater vehicles can be used for inspection and monitoring the conditions of the Dam and aquatic species in the adjacent reservoirs. The CPS technology associated with this physical system (Dams, reservoirs, rivers) will not only help in preserving the biodiversity but also create enormous skilled and unskilled job opportunities to the native population. Several start-ups will be created to develop the underwater vehicles. Presently the cost of these underwater vehicles are of several lakhs as they are imported from abroad in the absence of indigenous technology. TIH will also help in the development of Mechanized Country boats which will also be useful in the inland water body tourism and transportation.

Further these water bodies provides ample opportunities for tourism purpose. The technologies developed with CPS (such as virtual reality, AI, computer vision, communications and networking) will attract more National and International tourists, which will help in local job creation and the economic growth so that the migration of people will be reduced. Further the indigenous technology development will reduce the brain drain. The Centre of Excellence (CoE) for social entrepreneurship developed by this hub will help in creating awareness and facilitating the use CPS for achieving the National sustainable developmental goals.

Similarly the hub will benefit many start-ups and innovation cells in the research related to rivers and seas. For example Fig. 2.5 shows different aquatic animals available in rivers and seas. These sites are very rich in biodiversity where many cyber physical systems may be employed for exploration, monitoring and tourism attraction purposes. The presence of gems, pearls, crystals, corals, gold, diamonds and minerals in these water bodies may be explored using the underwater CPS technologies. The underwater communication is also a very challenging area of research for this TIH.

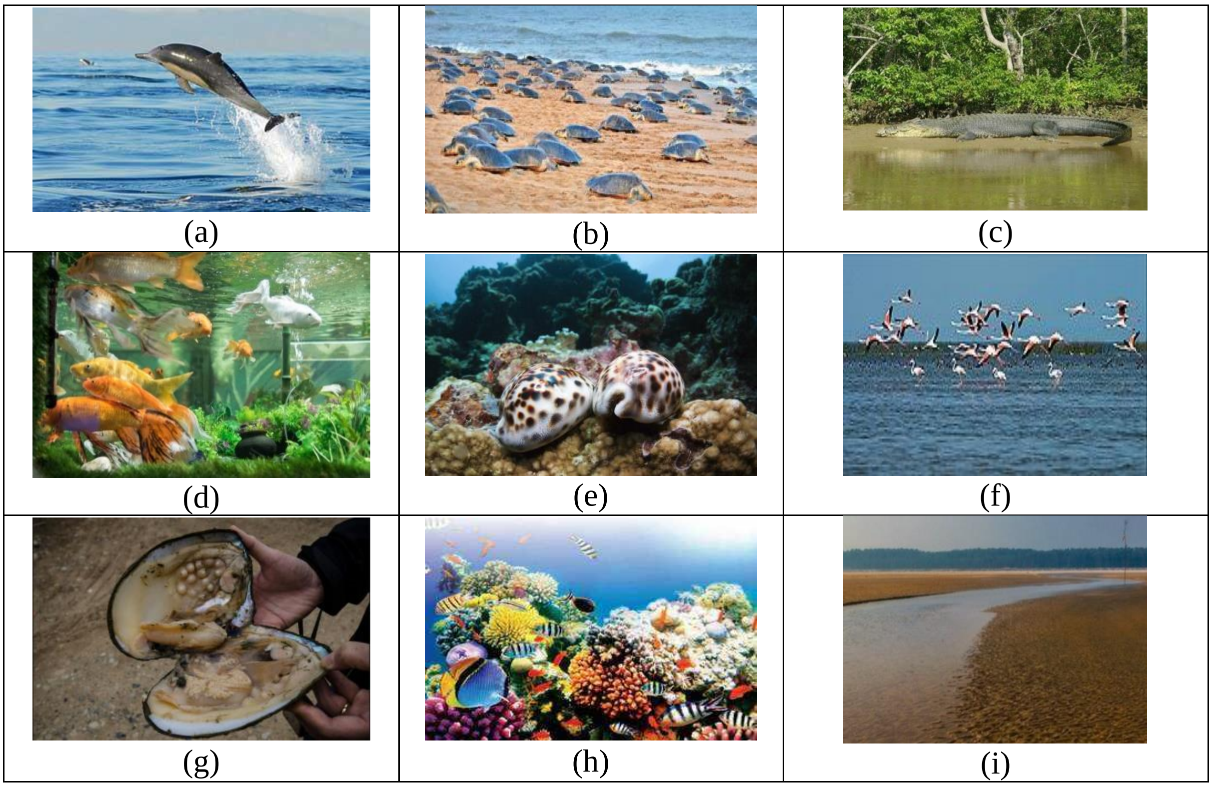


Fig. 2.5 (a) Dolphin in Brahmaputra [*web ref 17*] (b) Olive Ridley sea turtles in Gahirmatha marine sanctuary Odisha [*web ref 18*] (c) largest white crocodiles in Bhitarkanika National Park, Odisha [*web ref 19*] (d) Fishes in an aquarium [*web ref 20*] (e) Cowries [*web ref 21*] (f) Migratory birds at Chilika lake [*web ref 22*] (g) Pearl cultivation [*web ref 23*] (h) coral gem [*web ref 24*] (i) gold in subarnarekha river [*web ref 25*]

In sea and rivers pipe lines are used to transporting oil and natural gases where CPS assisted technology may help in inspection, monitoring and maintenance. Indian naval ship and defence sector requires indigenous technologies related to underwater autonomous vehicle, communication systems and computer vision system for improving their underwater surveillance, maintenance and monitoring capabilities. The TIH will be able to provide technological assistance to the defence sector.

The following list covers the technologies ***ready to be developed and commercialized*** by the hub for underwater exploration. The details of the technologies to be developed are elaborated in Chapter 3. Many more technological innovations will be included in the due course of time.

- *Underwater drones for ocean exploration*
- *Bio inspired underwater robot*
- *Smart dolphin monitoring system*
- *Vision-based Autonomous Underwater Robot*
- *Underwater inspection robot*
- *Unmanned underwater vehicle*
- *Autonomous underwater vehicle*
- *Sensors for underwater robot vision*
- *Smart 3D printed coral reefs*
- *Autonomous docking for Undersea persistence*
- *AI integrated smart defence technology*
- *Smart scuba suit for real-time health monitoring*
- *Aquatic robotic system for lake cleaning operation*
- *Tele operated underwater robotic manipulator*
- *Underwater healthcare devices*
- *Intelligent water born robot for surveillance, monitoring and cleaning*
- *Robotic vision system for underwater object tracking*
- *Technologies for underwater repairing and maintenance*
- *Underwater robotic system for surveillance of aquatic animals and plants*
- *AI based navigational path planning for underwater robots*
- *IoT based underwater vehicles to assess water quality*
- *Under water material processing technologies*
- *Vacuum electron devices for defense applications*
- *Portable and remotely operated underwater vehicle*
- *AI based device for underwater infrastructure damage checks*
- *Underwater recharge system*
- *Underwater corrosion monitoring technology*
- *Underwater robot for aquatic weed management*
- *IoT based underwater acoustic sensor*
- *Virtual reality technologies for the exploitation of underwater structures*
- *Digital holographic imaging system for underwater microorganisms detection*

Three schemes are identified for the technology development viz., (i) expert-driven new knowledge generation /discovery, (ii) development of products/ prototypes from existing knowledge (by experts or teams), and (iii) technology /product delivery in specific sectors. The details of the number of projects to be considered under these schemes are summarised in Table 2.5.

Table 2.5: Estimated no of Targets for the Technology Development

S. No.	Major Components	Targets*					
		Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	Expert Driven New Knowledge Generation /Discovery	6	6	7	1	0	20
2	Development of products/ prototypes from existing Knowledge (by experts or teams)	0	1	2	1	0	4
3	Technology /product delivery in specific sectors	0	2	1	1	0	4
Total		**6**	**9**	**10**	**3**	**0**	**28**

*these are the average targets which may vary in the due course

These three major components under the Technology Development program will be further subdivided into the mini, micro and mega projects with different slabs of funding. One unit of the Development of products/ prototypes from existing Knowledge may involve several subgroups /subprojects.

Human Resource Development & Skill Development

In HRD & Skill Development programme will have the following activities:

- Providing fellowships for UG, PG, Doctoral, Post-Doctoral, Faculties and Chair professors.
- Setting up groups of faculty members and students in association with organizations like IEEE etc.
- Offering temporary research and development positions for industrial engineers.
- Organizing the preliminary and advanced skill development workshops.
- Conducting seminars, short term courses and conferences periodically.
- Contests and competitions shall be organized, and prizes/awards shall be given to winners of these contests.
- Developing training schools for underwater activities such as welding, maintenance, repair, rescue, and ROV pilot.

15 Professional Skill Development Workshops will be conducted in the five years of the project. Each workshop will have 20 participants and hence a total of 300 participants in 15 workshops. Also the Advanced Skill Training School will have 100 participants in each unit. So three will be around 1500 overall beneficiaries under HRD & Skill Development programme. The Centre for Social Entrepreneurship and the Centre of Excellences on Manufacturing of Cyber Physical Systems will coordinate these training and skill development programme. Table 2.6 shows the number of targeted beneficiaries under the of HRD & skill development programme.

Table 2.6: Estimated No of Targets for HRD & Skill Development

	Major Components	Targets					
		Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	**Schemes for UG courses**						
	(i) Graduate Internships	8	98	50	56	88	300
	(ii) Development Fund (For Projects done under Graduate Internships)	0	47	56	44	15	162
	(iii) CPS Infrastructure development fund	0	0	1	0	0	1
2	**Schemes for PG courses**						
	(i) Post-Graduation Fellowships	0	10	10	10	20	50
	(ii) Development Fund (For Projects done under PG Fellowships)	0	6	6	7	14	33
	(iii) CPS Infrastructure development fund	0	0	1	0	0	1
3	**Doctoral Fellowships**	12	12	0	7	0	31
4	**Post-Doctoral Fellowships**	5	7	0	3	0	15
5	**Faculty Top-up**	28	40	16	44	20	148
6	**Faculty Fellowship**	0	2	1	2	1	6
7	**Chair Professor**	0	1	1	2	2	6
8	**Professional Skill Development Workshop**	0	6	5	2	2	15
9	**Upgrading PG Programme**	1	0	0	0	0	1
10	**Advanced Skill Training School**	0	2	0	1	0	3
	Total	54	231	147	178	162	772

Centre of Excellence (CoE)

The CoE to be developed in the IIT Guwahati Campus will focus on research and the development of underwater vehicles for different applications. Here the academia, industries, government and user agencies will be working together side by side. It will also collaborate with colleges and polytechnics to reach out to the remote locations and address local problems.

A centre of excellence entitled "**Centre of Excellences on Manufacturing of Cyber-Physical Systems (CEMCPS)**" will be developed in this project. The primary focus of the CEMCPS will be on providing the manufacturing facility of different products useful for a CPS. The crucial products such as motors, electronics devices, mechanical devices, controllers, actuators, sensors, etc. will be in-house designed and manufactured. The CEMCPS will have a workshop equipped with the cutting edge technologies such as 5-axis CNC machines, Polymeric & Metal 3D Printers, Lasers, Welding units, Robotic arms, and CAD/CAM/CAE software. The TIH will collaborate with many Industries to develop the CoE. CoreEL Technologies India Pvt LTD has expressed their willingness for collaboration in the development of the CoE (see Annexture).

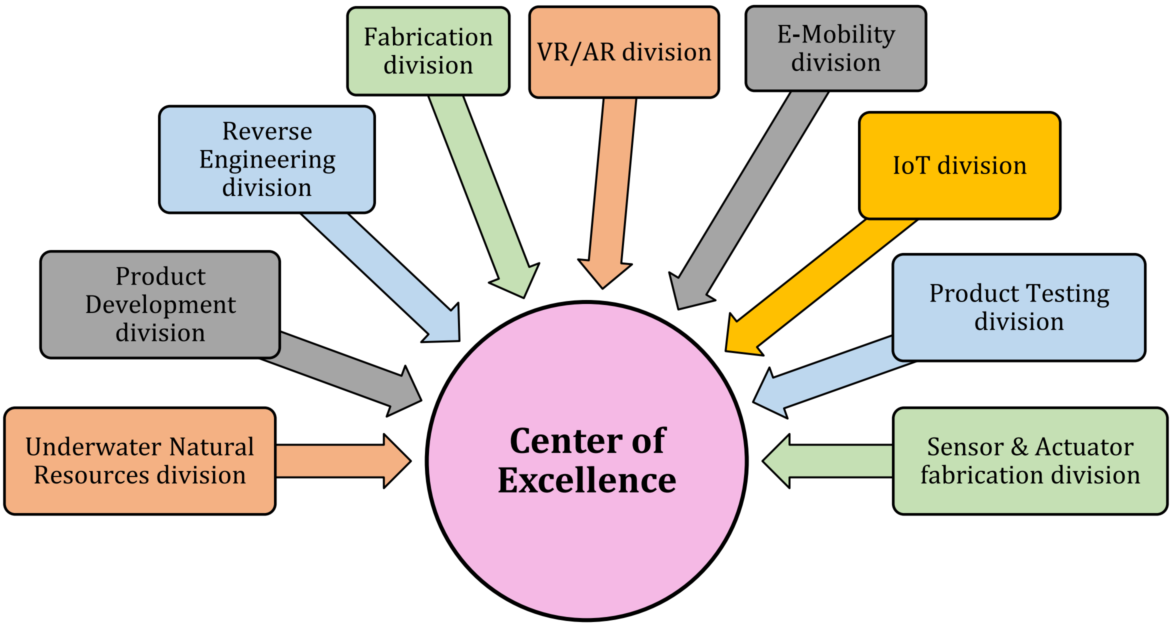


Figure 2.6: Architecture of the proposed COE

The architecture of the proposed Center of Excellence (COE) has been shown in Figure 2.6. The COE will consist of nine different divisions viz., (1) Underwater Natural Resources division (2) Product Development Division, (3) Reverse Engineering Division (4) Fabrication

Division (5) Virtual & Augmented Reality Division (6) E-Mobility Division (7) Internet of Things Division (8) Product Testing Division and (9) Sensor & Actuator Fabrication Division. These divisions or laboratories of the proposed COE will directly/in-directly assist the CPS. The requirement and the outcome from these divisions are summarised in the following paragraphs.

1. Underwater Natural Resources division

This division will be consisted of a data base of the water bodies of the nation. It will be focused on the monitoring of the wet lands, lakes, reservoirs, rivers, and marine life. It will help in providing the information related to the tourism, aqua agriculture, medicinal plants and many other re-creational activities. The major equipment in this laboratory will be GPS based monitoring system, hyperspectral sensors, monitoring drones etc. One of the major activities in this division will be on the development of the water body monitoring drones. Marut Drone Pvt. Ltd. has expressed its willingness to establish a training school in collaboration with TIH – IIT Guwahati.

2. Product Development Division

The product development division will consist of at least 100 workstations of appropriate configuration. These workstations will be equipped with the latest CAD, CAM, CAE, mechatronics, & optimization software. The input (facilities) required to develop this division has been summarized in Figure 2.7.

This division will assist the CPS by providing a platform for realizing the conceptual product design, industrial product design, mechatronics product design, design twins of the products, and optimal (manufacturing & operating) process parameters. This division is envisioned to provide skill development programs for at least 500 faculties/students from different parts of the country. *This division will play an important role in generating revenue for the CPS after five years.* Few (not limited to) outputs from this laboratory are presented in Figure 2.8.

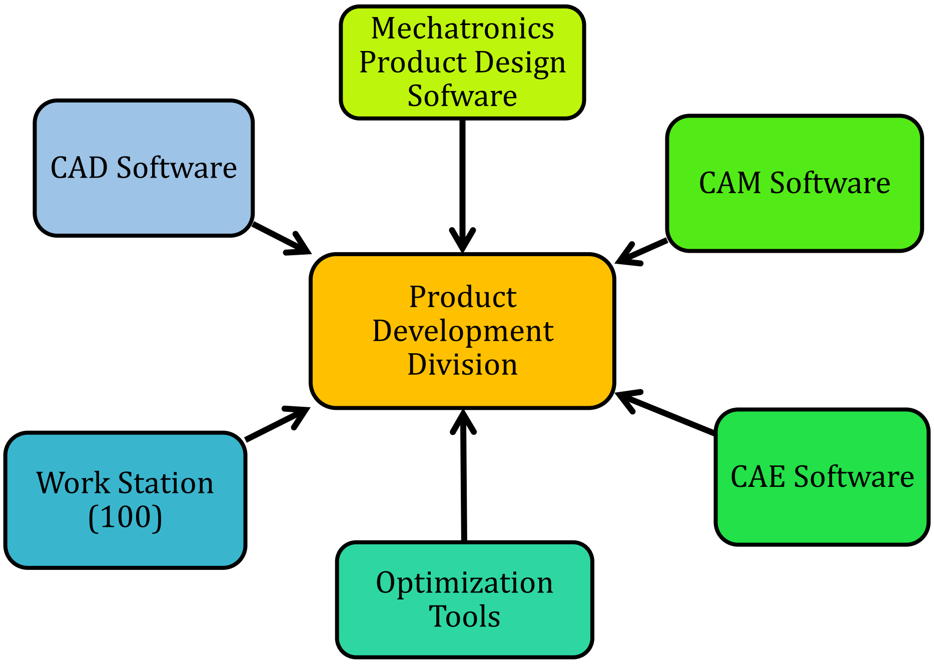


Figure 2.7: Inputs to the product development division of the COE

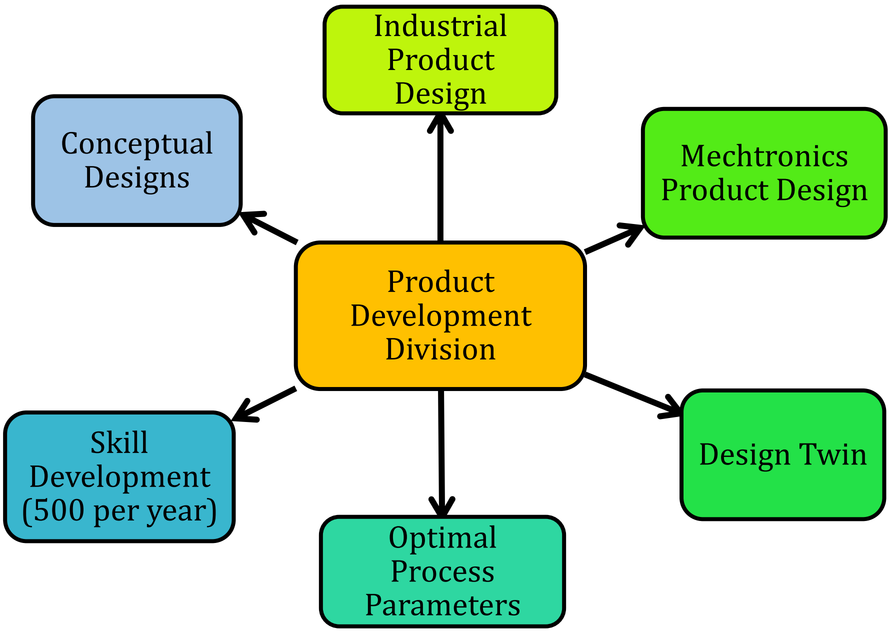
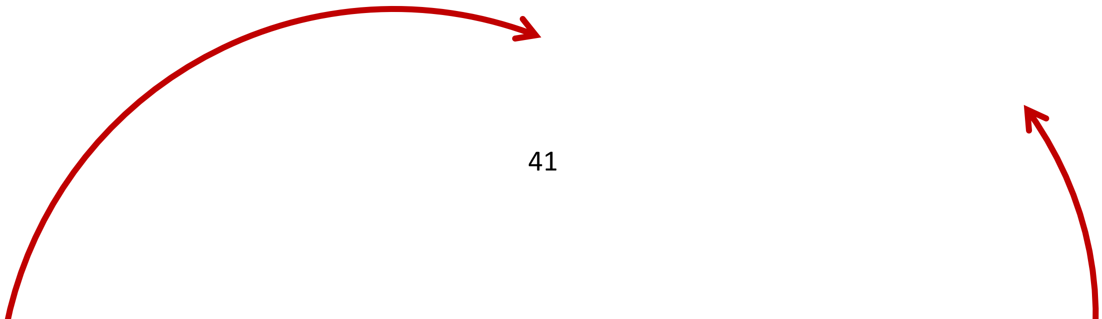


Figure 2.8: Outputs from the product development division of the COE

3. Reverse Engineering Division

Reverse Engineering is an important step in the development of products such as implants, restoration of the tools & antiques, underwater reverse engineering of non-movable objects, etc.



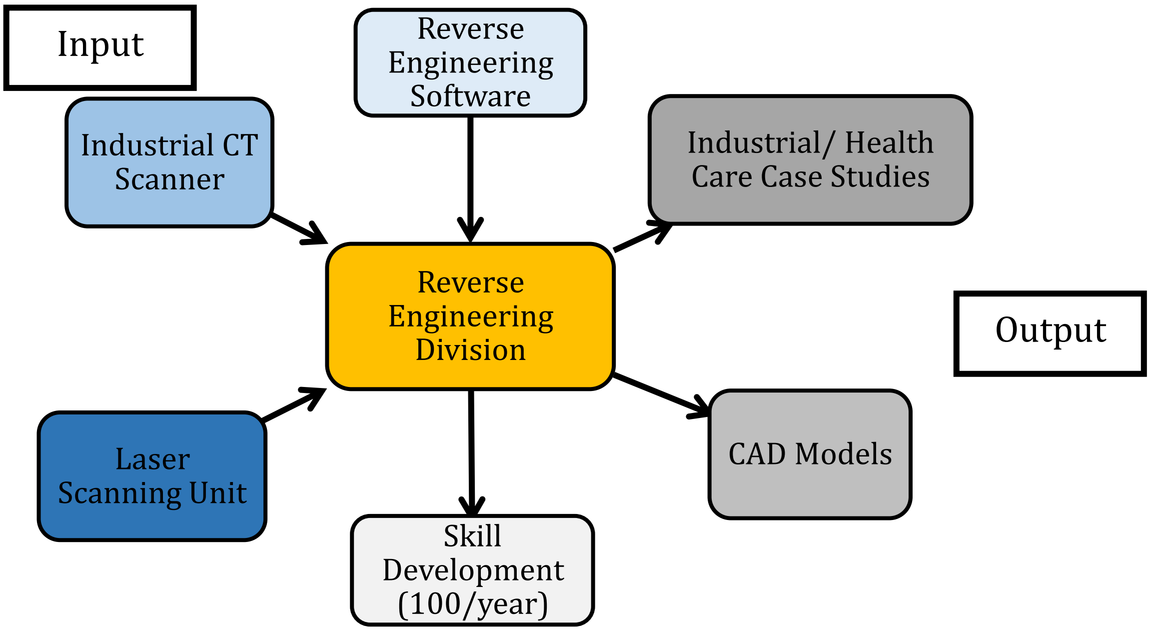


Figure 2.9: Inputs & outputs for the reverse engineering division of the COE

Laser scanning, industrial CT scanning, and reverse engineering software (to handle the cloud point data) are the facilities required for establishing this division, see Figure 2.9. This laboratory, in return, will provide a platform for conducting the industrial healthcare case studies. The reverse engineering software will provide a machine-readable CAD file (STL in most cases). Also, this laboratory is envisioned to provide a skill development program for at least 500 faculties/students from different parts of the country. These outcomes are also summarized in Figure 2.9.

4. Fabrication Division

Fabrication division (Fig. 2.10) will provide a platform for realizing the physical parts of the CAD models developed in previously discussed laboratories. This laboratory will be equipped with the vital machines viz., CNC milling machine, CNC lathe machine, 3D Printers (SLS & FDM), injection molding machine, welding machines with 6-axis robotic arms and laser cutting/engraving/marking machine.

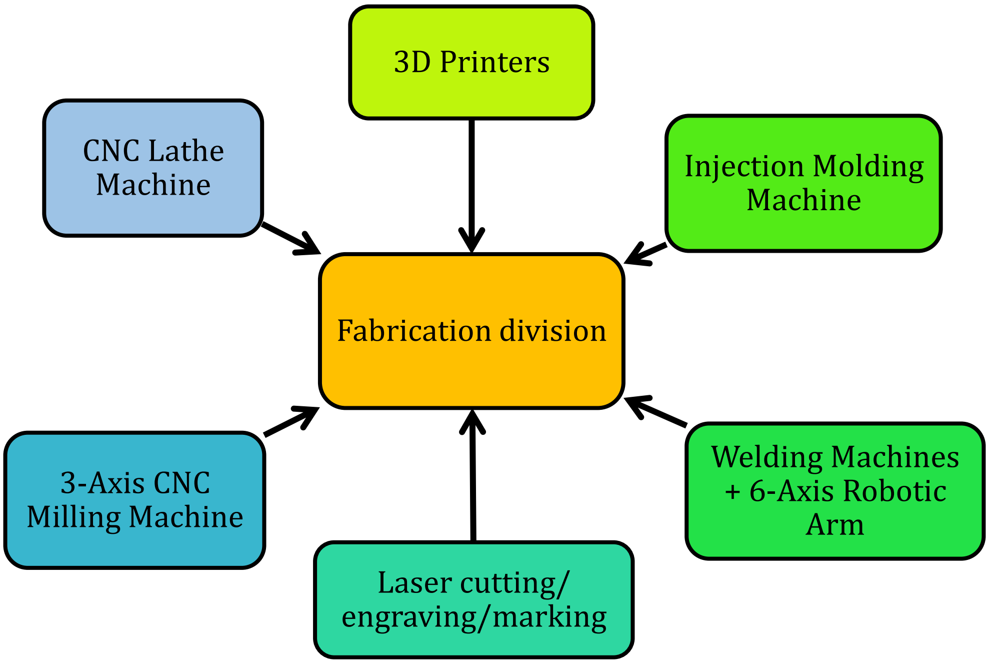


Figure 2.10: Inputs for the fabrication division of the COE

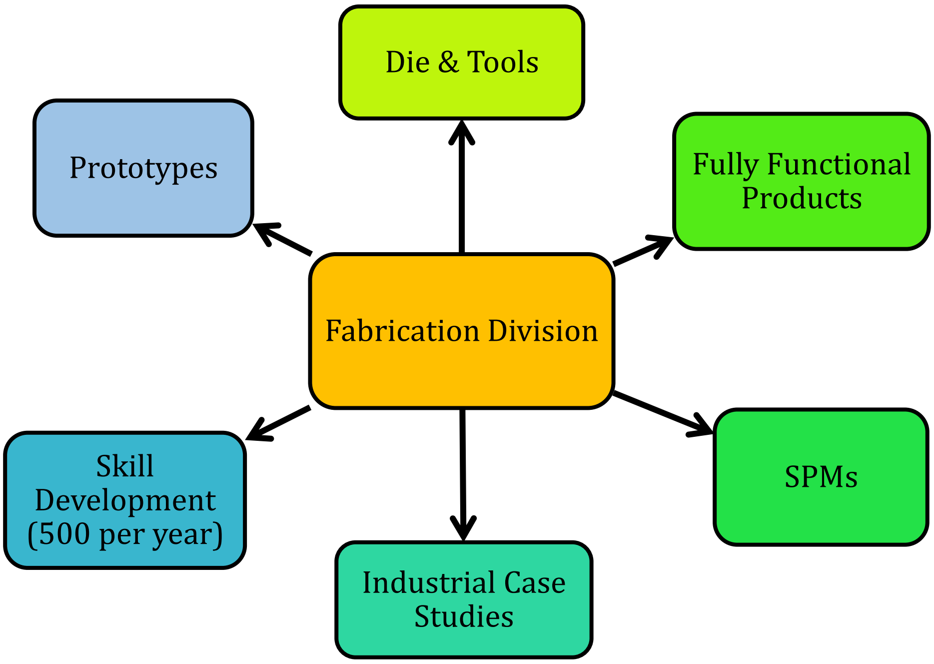


Figure 2.11: Outputs from the fabrication division of the proposed COE

Fabrication division is envisioned to provide skill development programs per year to at least 500 students, faculties & lab staff of different colleges/industries. Also, the prototypes, tools, fully-functional parts, special purpose machines, design in the CPS will get realizing in this laboratory. This laboratory will also take industrial case studies as research projects which will help in the self-sustainability of the CPS. The outcomes form this laboratory are summarized in Figure 2.11.

5. Virtual and Augmented Reality Division

A virtual & augmented reality division will provide a platform for providing the training, testing, and optimizing several tasks before performing them in the real world. The laboratory will require VR/AR tools for manufacturing, education, and underwater diving. In return, this laboratory will accept case studies from different industries. It will also help in manufacturing process planning and testing for the production of a new product. One of the primary outcomes from this laboratory will be conducting a high number of skill development programs for providing training up-to 500 students, faculties, lab staff of different colleges. The inputs and outputs for this laboratory have been summarised in Figure 2.12.

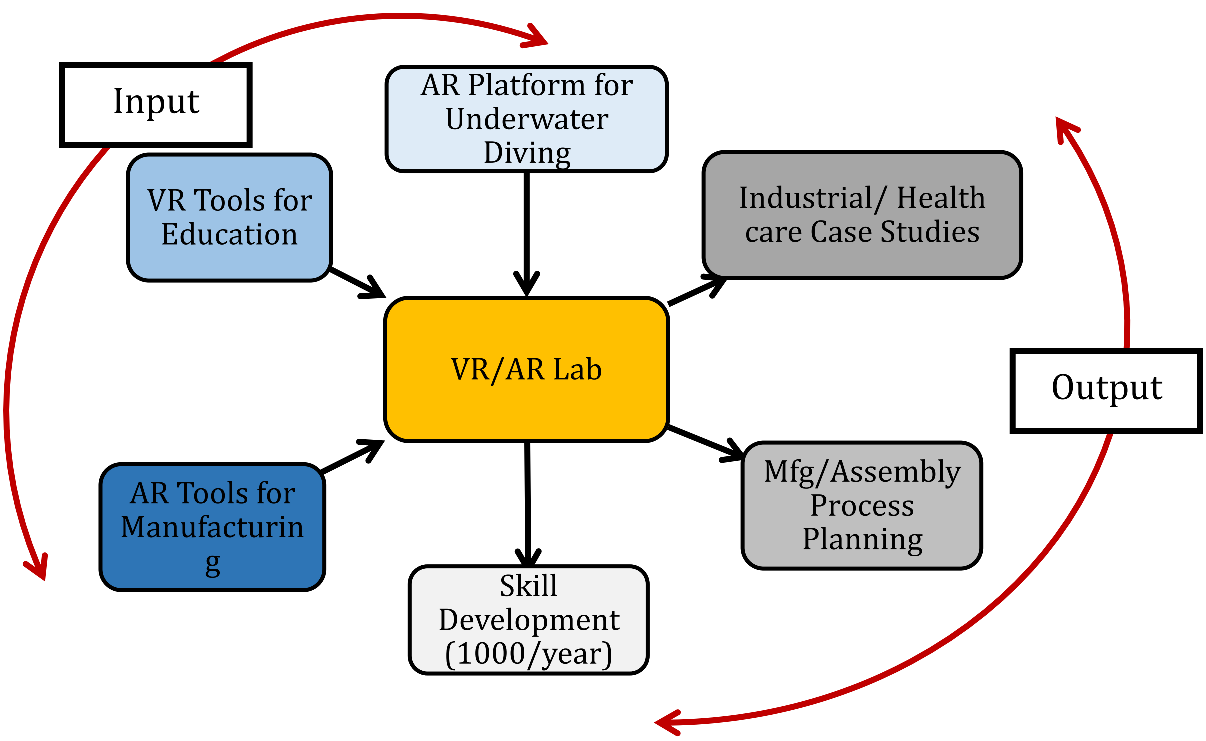


Figure 2.12: Inputs & outputs for the VR/AR division of the proposed COE

6. E-Mobility Division

E- Mobility division will be equipped with the advance driving assistance tools, vehicle

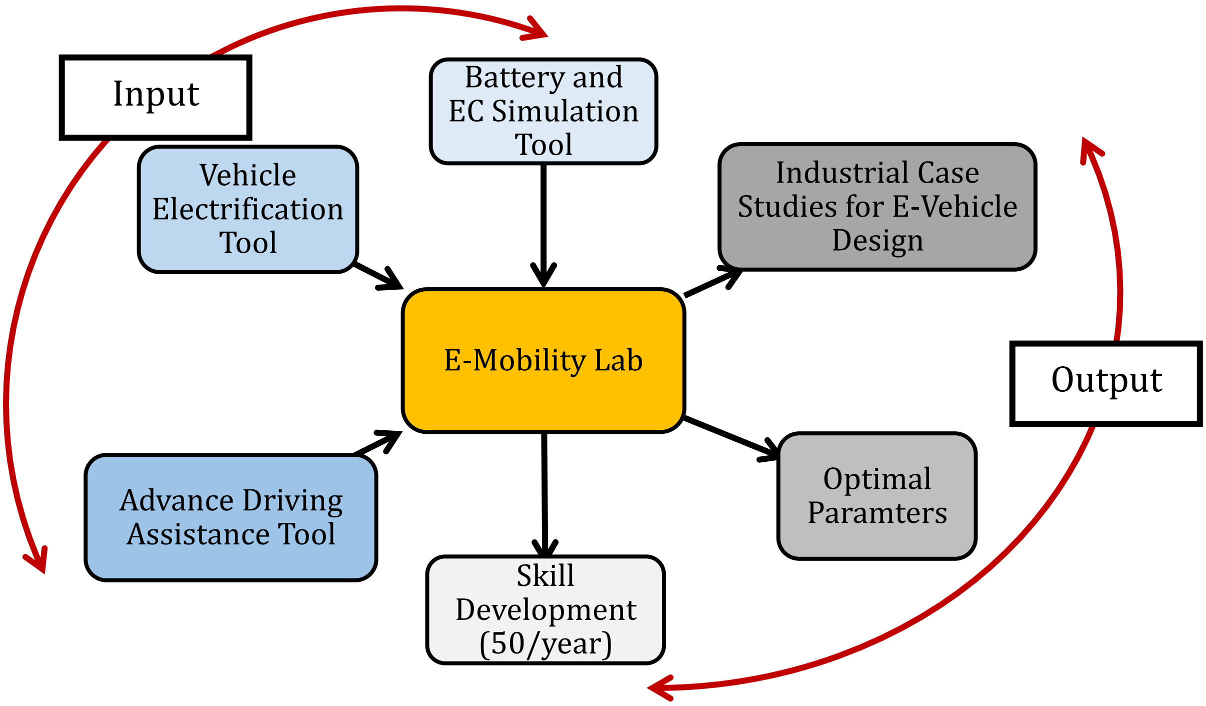


Figure 2.13: Inputs & outputs for the E-mobility division of the COE

electrification tools, and battery & electrochemical simulation tools for assisting the designed underwater vehicles in the CPS. The inputs and outputs for these laboratories are summarized in Figure 2.13.

7. Internet of Things Division

The Internet of Things division (IoT Lab) will interrelate the mechanical digital devices/machines and computing devices of the CPS. For establishing this laboratory, high-performance computing clusters, cloud space, local server, application development platform, PCB making machine, function generators, wireless device tasting platforms, data acquisition tool, artificial intelligence & machine learning platforms, etc. are required (see Figure 2.14). In return, it will provide a facility to transfer data over a network without requiring human-to-human or human-to-computer interaction. Particularly, this laboratory has been envisioned to provide a platform for manufacturing automation, communication with divers, monitoring the marine life, survey and feedback of the developed products, and development of mobile applications. Also, it provides a skill development program for at least 100 students, faculties from different institutes. Figure 2.15 summarised the outcomes of this division.

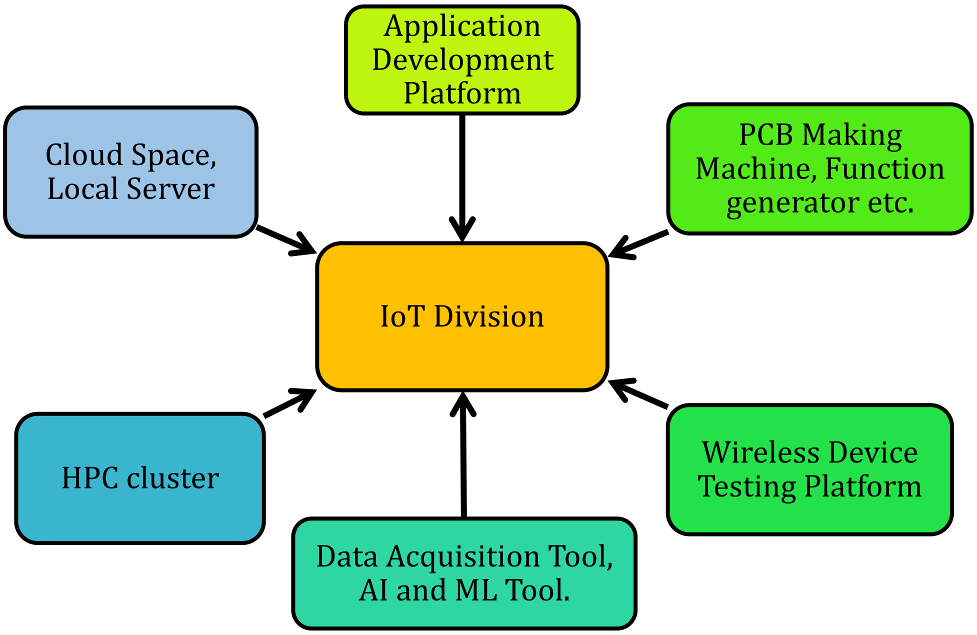


Figure 2.14: Inputs for the IoT division of the COE

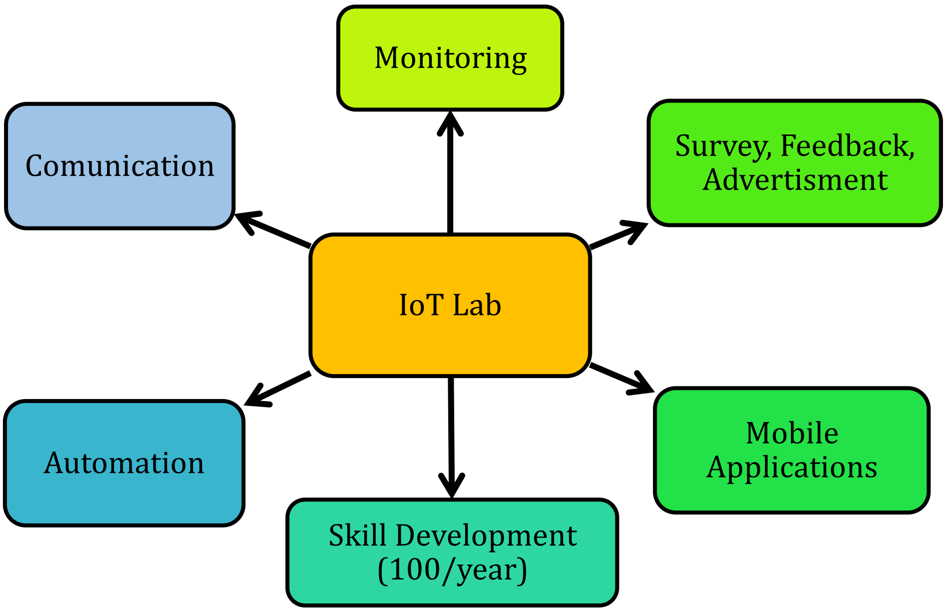


Figure 2.15: Outputs from the IoT division of the COE

8. Product Testing Division

Testing of the product is required at various stages during the development of a new product. The product testing division will assist the CPS by providing a platform for testing the developed product from different aspects. It will be equipped with the facilities viz., portable X-ray diffraction, optical microscopes, electron microscopes, coordinate measuring machines, universal testing machines, and vibration testing platforms. Figure 2.16 summarised the inputs to the product testing division.

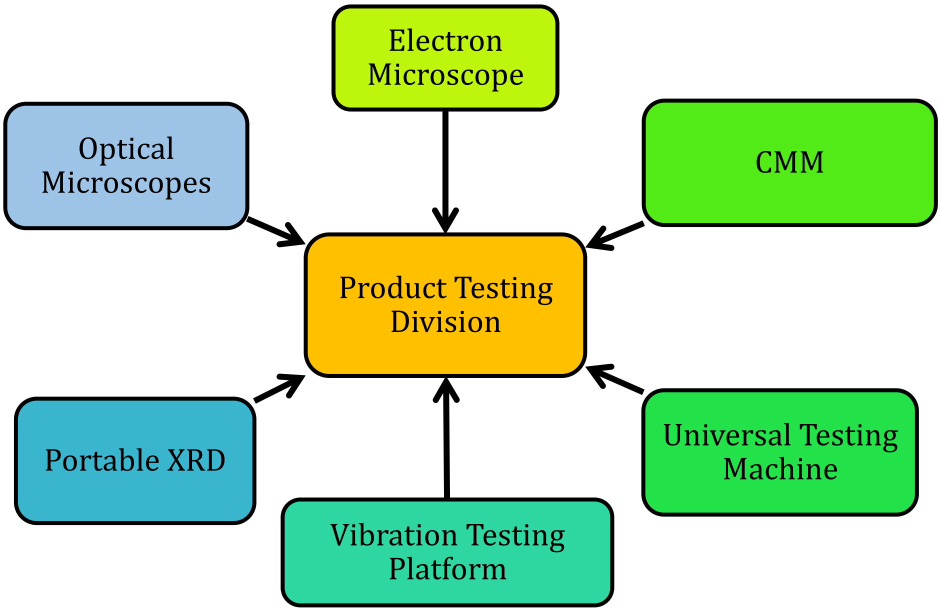


Figure 2.16: Inputs to the product testing division of the COE

The results obtained from experiments conducted in this division will help in optimizing the manufacturing & design parameters. This laboratory will allow the researchers from different institutes to conduct the desirable experiments on a payment basis, which will help in the self-sustainability of the CPS.

9. Sensor/ Actuator Fabrication Division

Sensor / Actuator fabrication division will indigenously produce the sensors and actuators for the CPS. Generally the thrusters (Actuators) and sensors are imported. The purpose of this Lab is to develop indigenously these items so that it will help in the ***Make in India*** drive. The electric motors such as AC, DC, stepper, and servo motors of different size and capacity will be developed in this Lab.

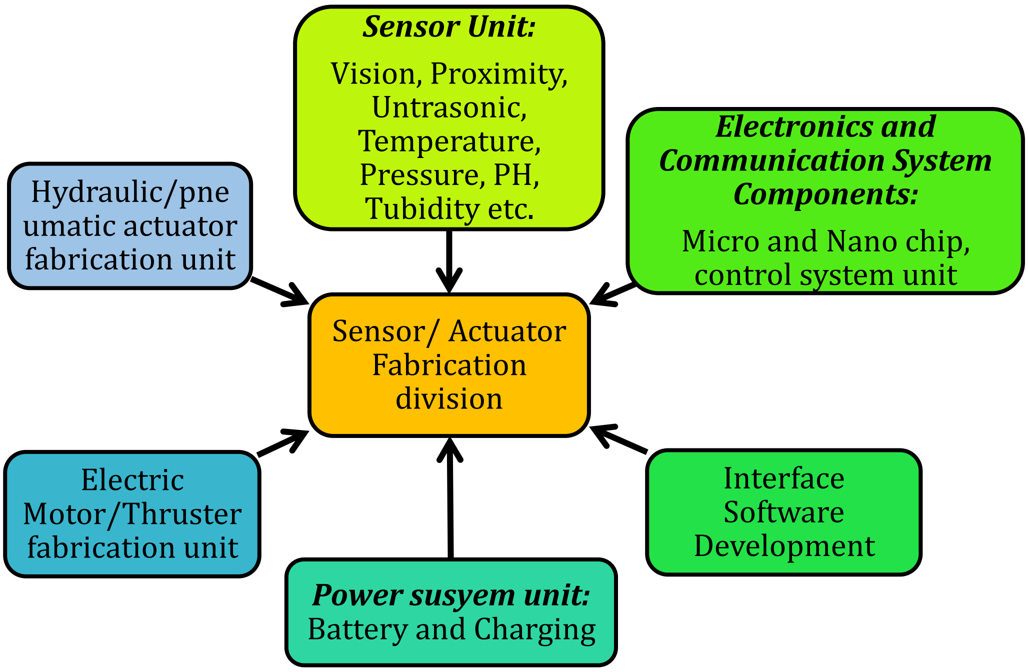


Figure 2.17: Outputs of the sensor/actuator fabrication division of the COE

The required machines such as coil winding, coil inserting, Slot Bottom Insulating, Lacing machines etc to fabricate different components of thrusters for underwater vehicle. Similarly machines for fabricating pneumatic and hydraulic actuators will be procured to develop these actuators. Many sensors such as temperature, pressure, turbidity, PH, dissolve oxygen in water, vision system and ultrasound (sonar) will be required during the underwater exploration. The CoE will contain facility to develop these sensors. Also the on-board electronic components and power system will be developed. Collaboration will be made with different companies to develop this Lab. The outcomes of this laboratory are summarised in Figure 2.17.

Table 2.7: Estimated no of Targets for the Center of Excellences

Major Components	Targets					
	Yr1	Yr2	Yr3	Yr4	Yr5	Total
Centre of Excellences on Manufacturing of Cyber Physical Systems	0.19	0.21	0.50	0.01	0.08	1
Total	0.19	0.21	0.50	0.01	0.08	1

Further a ***Centre for Social Entrepreneurship*** will also be created which will support students and young entrepreneurs to find innovative business ideas to solve pressing problems related to the Sustainable Development Goals. The overall task of the Centre is to improve the living standards of people in disadvantaged communities through innovation. The aim is to become a knowledge hub to connect those who have the capability as well as the desire to serve the deprived class of the society.

Innovation, Entrepreneurship and Start-up Ecosystem

Start-ups and other corporate ventures in the domain area of the CPS, initiated by students at IIT Guwahati and other reputed institutes, shall be provided temporary support at the initial stages. Several activities are identified under this program. The estimated targets for each activity are given in Table 2.8.

Table 2.8: Estimated Targets for Innovation, Entrepreneurship & Start-ups ecosystem

Major Components		Targets					
		Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	Grand Challenges and Competitions	0	1	0	0	0	1
2	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS	0	1	0	0	0	1
3	Entrepreneur In Residence	10	10	10	10	10	50
4	Start-up	5	15	15	10	5	50
5	Technology Business Incubator (TBI)	0	0.5	0.5	0	0	1
6	Dedicated Innovation Accelerator	0	0	1	0	0	1
7	Seed Support System	0	0	1	0	0	1
8	Social Entrepreneurship Program	1	1	1	1	1	5
Total		**16**	**28.5**	**28.5**	**21**	**16**	**110**

International collaborations

To gain the global competitiveness and international visibility the TIH will collaborate with different International labs, Institutes, centres and Industries related to the field of underwater explorations. It will facilitate the movement of students, project staffs and faculty members associated with the Hub to gain the expert knowledge and to know the state of the art activities available in the global knowledge hubs. At-least 5 International collaborations are intended during this project. The probable list of International Collaborators are available in Table 2.2.

Sustainable Development Goals (SDG)

Table 2.8: Sustainable Development Goals

Goal No	Sustainable Development Goals (SDG) / Area	TIH IITG contribution
1	**End poverty in all its forms everywhere /** Rural Development	Assist in aquatic crop management and fish farming
2	**End hunger, achieve food security and improved nutrition and promote sustainable agriculture /** Agriculture & Farmers Welfare	Smart irrigation system, flood monitoring and warning em, fish farming, aquatic crop cultivation (water chestnut, er caltrop, fox nut, lotus, lily, spinach, Mosquito ferns etc), extraction from river bed for idol making, making clay pots, food collection
3	**Ensure healthy lives and promote well-being for all at all ages /** Health & Family Welfare	Healthcare for underwater divers, wearable sensors for assisting divers, delivery of health essentials to the submarine crew, water quality management (identification and removal of heavy metals pollutants such as arsenic, cadmium, chromium, copper, nickel, lead and mercury in water), water purification, conversion of seawater into drinking water
4	**Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all /** Human Resources Development	The developed CoE will promote the skill development, learning opportunities and ensure job creation through entrepreneurship in the field of underwater exploration.
5	**Ensure availability and sustainable management of water and sanitation for all /** Water Resources, River Development & Ganga Rejuvenation	water quality management (identification and removal of heavy metals pollutants such as arsenic, cadmium, chromium, copper, nickel, lead and mercury in water), water purification, conversion of seawater into drinking water,
6	**Ensure access to affordable, reliable, sustainable and modern energy for all /** Power	Hydropower generation and distribution system; Micro and large hydel power plant, floating hydro turbines. Floating solar system, ocean wave energy harvesting, health monitoring of Dams and water bodies using RoVs and AUVs.

Goal No	Sustainable Development Goals (SDG) / Area	TIH IITG contribution
7	**Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all /** Labour & Employment	Generate high skilled and next-generation workforce.
8	**Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation /** Commerce & Industry	Robotics, SMART manufacturing, AI-based autonomous underwater systems and catering to Industry 4.0. Start-up development and employment generation
9	**Make cities and human settlements inclusive, safe, resilient and sustainable /** Urban Development	Enabling sustainable management of water and sanitation for SMART Cities development
10	**Take urgent action to combat climate change and its impacts /** Environment & Climate Change	Sensor-based systems development for pollution estimation, modelling and systems approach for climate change data analytics using AI based RoVs, AUVs and Drones.
11	**Conserve and sustainably use the oceans, seas and marine resources for sustainable development /** Earth Sciences	The TIH at IIT Guwahati will develop CPS based underwater systems for: Development of marine, e-Navigation and port management, assisting naval research, preserving biodiversity and ecosystem management, oil and natural gas exploration and mining in the eastern and western coastal areas, supporting tourism etc.
12	**Strengthen the maritime security on the Nation /** Defence	Underwater surveillance and reconnaissance, helping defence related activities, maritime security of economic activities.

Overall TIH Outcomes

Several technologies are intended to be developed in five years of this project. The HRD sub-mission will support more than 500 individuals during the project. There will be 20 skill development programs in this project; those will help in developing the skill of around 700 participants. Several programs are intended under the sub-mission 'Entrepreneurship, Innovation, and Start-ups' to provide temporary support at the initial stage. The international collaboration will be taken forward, particularly after the first year of the project. For the smooth functioning of all the sub-missions, a mission management unit will be established in IITG. A feasible target has been assigned for each sub-mission. These targets are given in Table 2.9.

Table 2.9: Overall Year-wise Physical targets

S No	Sub-Missions	Year 1	Year 2	Year 3	Year 4	Year 5	Total
1	Technology Development	6	9	10	3	0	28
2	Center of Excellences	1	0	0	0	0	1
3	HRD & Skill Development	54	231	147	178	162	772
4	Entrepreneurship, Innovation and Start-ups	16	29	29	21	16	110
5	International collaborations	0	1	1	0	0	2
6	Mission management Unit	1	0	0	0	0	1
	Grand Total	**77**	**270**	**187**	**202**	**178**	**913**

Table 2.10: Expected and measurable output indicators under TIH at IIT Guwahati

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
1	To promote and foster R&D in Cyber-Physical Systems (CPS) and related areas like Data Science (DS), Internet of Things (IoT), Cyber Security and quantum communication.	Increased core researchers base in advanced and cutting technologies	No of researchers in CPS	50	100
2	To develop technologies, prototypes and demonstrate associated applications pertaining to national priorities.	A set of technologies, tools, algorithms to feed into some of the national priorities	No of technologies	30	100

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
3	To enhance high-end researchers base, Human Resource Development (HRD) in these emerging areas.	Delivery of next-generation technocrats, Scientists, Engineers, Skilled and semi-skilled workforce.	No of students	400	700
4	To establish and strengthen the international collaborative research for cross-fertilization of ideas.	Global standard Collaborative research for some of the India specific issues.	No of collaborations	5	10
5	To enhance core competencies, capacity building and training to nurture innovation and Start-up ecosystem.	Start-up companies, job creation and economic growth	No of start-ups	10	25
6	To set up world-class interdisciplinary collaboration centers of excellence in several academic institutions around the country, with a substantial amount of funding to enable them to achieve significant breakthroughs.	Dedicated translational research centers aimed at Academic to Industry	No of CoEs	1	1
7	To involve Government and Industry R&D labs as partners in the collaboration centers. Incentivise private participation to encourage professional execution and management of pilot scale research projects	Enhanced participation of private industry in R&D, PPP model demonstration in technology development	No of partnerships developed	2	10
8	To set mission mode application goals and foundational themes for excellence for different centers. Set up CPS test beds at various centers.	Proven prototypes, national test beds for sector-specific solutions	No of prototypes/ testbeds	0	5
9	To tie up with incubation centers and accelerators to foster close collaboration with entrepreneurship eco-system	Enhanced delivery mechanism	No of incubation centers	1	1
10	To address some of the National issues and development of sector-specific solutions.	Technologies to address some of National issues.	No of domain-specific solutions	5	8

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
11	No of Research Papers published	New knowledge generation	Number	25	100
12	No of start-ups in CPS		Number	10	25
13	Number of Center of Excellence established	Dedicated translational centers	No of centers	1	1
14	Number of new tools created	New processes developed	Number	2	10
15	Number of Solutions created for Govt Departments/ Organizations	New solutions	Number	5	10
16	Number of Best Practices developed	Best practices	Number	0	10
17	Number of UG/PG fellowships awarded	Preparation of next-generation technocrats	No of fellowships	150/40	450 (360+90)
18	Number of Ph Ds/ Post-Docs	Delivery of next generation researchers	No of fellowships	10/10	50 (25+25)
19	Number of faculty Trainers Trained	Generation of pool of trainers	No of trainers	0	5
20	No of student training programmes organized	Delivery of skilled human resource	Number	10	15
21	Number of entrepreneurship development programmes organised	Start-up culture enhancement	Number	0	5
22	No of the new CPS application areas identified	Scaling up of CPS in various areas	No of areas/ Sectors	0	5
23	Number of tie-ups with industry	Academic-Industry interactions	No of tie-ups	0	10
24	Number of proposal received for Venture capital/seed money etc.	Start-ups	No of start-ups	0	25
25	Number of international collaborative research projects started/completed	Cross-fertilization of ideas	Number	1	5
26	No of cluster-based network projects started	Directed research	Number	1	3
27	Number of awareness programmes launched	Development of scope of CPS	Number	0	2
28	Number of participants benefited through awareness programmes	Scale and volume	Number	0	100

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
29	No of national workshops/ conferences organized	Development of intellectual networks and interactions	Number	1	4
30	Number of collaborative international conferences organized	Development of international networks	Number	0	1
31	No of CPS Infrastructure projects started/implemented	Technology platforms	Number	0	1
32	Number of international experts participation in CPS	Attracting attention of experts from abroad	Number	0	5

Chapter-3

CPS Technologies and TIH Strategy

3.1 Introduction

In this chapter a number of projects which will be undertaken by the TIH are briefly described. The application verticals will be in the areas of (i) Defence Research and Development, (ii) Earth Science, (iii) Health research, (iv) New and Renewable energy, (v) Tourism, (vi) Shipping and (vii) Skill development and Entrepreneurship. The interactions from all the stakeholders' lead to pin point the thrust areas of national and international importance which are thoroughly looked in to develop the technologies for underwater exploration. Here the problems are divided into 2 primary and 9 secondary areas as given below.

1) **Underwater Systems Development,** primary area -1 comprises of the following secondary areas:

   a) Underwater Repairing and Maintenance
   b) Underwater Autonomous Vehicle
   c) Underwater Electronics & Powering
   d) Offshore Energy & Desalination of Sea Water
   e) Underwater Tourism

2) **Underwater Vision, Monitoring, Surveillance, Intelligence and Tracking** primary area -2 comprises of the following secondary areas:

   a) Underwater Aquaculture
   b) Underwater Healthcare and Monitoring
   c) Underwater Vision & Communication
   d) Offshore Bio-resources & Mineral-resources

A group will be formed for each secondary area which will be consisted of the following:

I. Government organization, PSU etc. (for giving the problem statements)
II. A group of experts (for solving the problems)
III. A group of relevant private industries (for expertise and commercialization)
IV. A marketing organization such as magazine/news channel etc. (For marketing the developed product or Technology)

Based on the above strategy, after several round of presentations and discussions, following challenging problems of National and International importance are selected to be undertaken as soon as possible and more problems will be added in each verticals in due course of time.

3.2 Projects to be Undertaken

3.2.1 Underwater Repairing and Maintenance

In this secondary area following work packages are identified:

1. Design and Development of Apparatus for Underwater Repairing and Maintenance of Metallic & Non-metallic Structures
2. Design and development of novel, cost-effective and integrated robot-laser-based drilling technologies for under water material processing
3. Development of Shock Tube Facility and Measurement Diagnostics for Under Water Exploration of Submerged Structures through Blast Wave Analysis
4. Experimental Investigations into the effect of reinforcement particles on the tribological and corrosion properties of marine grade AA5052 aluminium alloy joints through FSW
5. Vibration Analysis of Underwater Pipe Line

The scope, and outcome of these work packages are described in detail in the subsequent sections:

Design and Development of Apparatus for Underwater Repairing and Maintenance of Metallic & Non-metallic Structures

Due to harsh working conditions, underwater engineering processes are usually costlier and challenging. To minimize the cost and simplify the process, the users prefer to carry out any such operation at a repair site on land. However, it is infeasible to bring out large or fixed structures out of the water for any repairing operation. Therefore, conventionally, a skilled diver performs underwater operations such as welding, cutting, grinding, coating etc. on site. These underwater divers need to be assisted with an optimally automatic equipment which requires a minimum or zero human intervention. Also, each method of underwater repair must be tailored to suit the surrounding conditions. To ensure smooth and defect free operation on site, it is essential to carried out laboratory trails on both repair methods and materials.

The aim of this project is to "design and develop optimally automatic apparatus for performing underwater operations such as Cleaning, Cutting, joining (welding), and Polishing on metallic and nonmetallic freeform surfaces at a shallow depth (up to 200m)".
The scope of this project has been illustrated in Fig. 3.1.

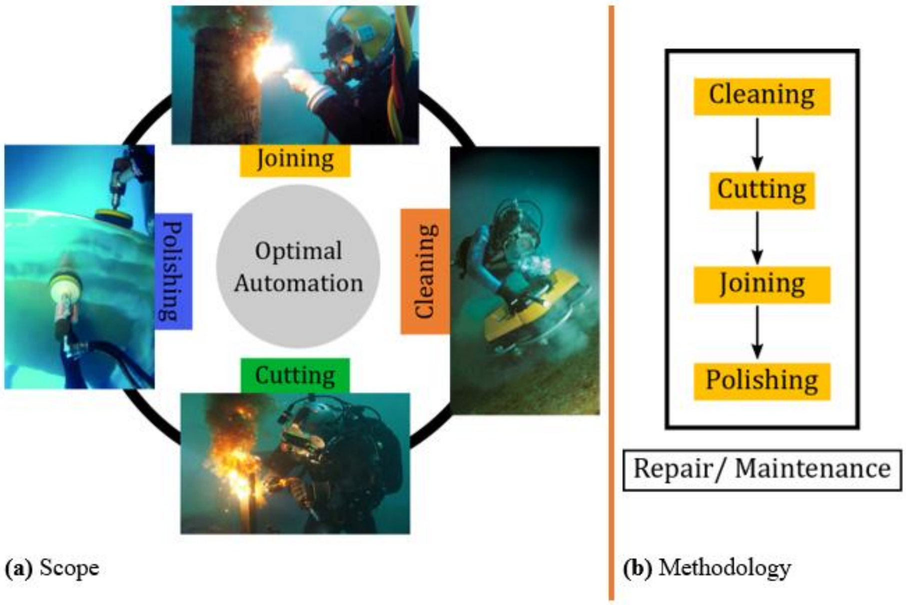


Fig. 3.1: Optimal automation of underwater repairing and maintenance

Methodology:

The proposed methodology for repairing and maintenance the underwater metallic and non-metallic structures has been summarized in Figure 1b. Each step has been further discussed in the following sections.

Underwater cleaning: Cleaning will be the first operation before performing any other action on the surface of a metallic/non-metallic structure. It is required to remove marine fouling from the surface. Also, marine fouling impact the hydrodynamic performance of vessels and hence the speed, power performance and fuel consumption. Rotating brush & scrubbers are the most popular methods for underwater cleaning (Walton and Walton (2004) and Bixler and Bhushan (1967)). However, to remove the hard scale, a grinding operation can also be used. In this project, an easy to handle semi-automatic underwater scrubbing apparatus will be developed. Minimum electronic devices and a low powered (12-24 volts) DC motor will be used to avoid the shock hazard.

Underwater cutting: Cutting operations such as contouring, drilling etc. are require prior to welding/stitching the damaged zone. Also, there are many kinds of parts that are required to be replaced after underwater service. A high power laser (4-6kW) is a very flexible tool for cutting thick steel plates (50-60mm) (Chida et al. (2003) and Sin et al. (2019)). However, the oldest and well established process for underwater cutting is Oxy-fuel cutting (Orville and Bunnell

(1947)). In this project, an optimally automatic, laser/oxy-fuel cutting head will be designed and developed for assisting the divers.

Underwater joining: Welding is found to be the most preferable option for underwater joining of metallic structures. There are three types of welding operations used underwater viz., wet welding, local cavity welding and dry welding. Wet welding is executed at ambient pressure with no mechanical barrier between water and welding arc. Straightforwardness of this process makes convenient to weld on freeform surfaces. The most commonly used wet welding technique is shielded metal arc welding (SMAW) and flux cored arc welding (FCAW) (Łabanowski et al. (2008) and Nixon (2000)). In this project, an underwater robot assisted SMAW system will be developed for joining the metallic structures. Also, for non-metallic structures such as composite pipes an apparatus will be developed for jointing the damaged pieces using epoxy-based thermosetting polymers (Mally et al. (2013)).

Underwater Polishing: High speed revolving disc of chemical and diamond are used for underwater polishing the freeform surfaces. Such operations are frequently used for maintaining a desired surface roughness on the propeller blades. In this project a semiautomatic robotic arm will be developed for assisting the divers.

Deliverables:

1. A laboratory setup for performing the underwater experiments
2. Following semi-automatic apparatus will be designed and developed:
    a. Underwater cleaning/scrubbing apparatus
    b. Underwater oxy-fuel/laser cutting apparatus
    c. Underwater SMAW apparatus for joining the freeform surfaces
    d. Apparatus for joining underwater composite pipe (including T and elbow joints)
    e. Underwater polishing apparatus particularly for propellers
3. Optimization of process parameters for operating the above discussed apparatus

Design and development of novel, cost-effective and integrated robot-laser-based drilling technologies for under water material processing

Laser technology in drilling is finding promising prospects in oil and natural gas exploration under the sea and rivers due its potential to reduce drilling time. It reduces the drilling time by removing the necessity to stop and replace a mechanical bit (Jurewicz (1976)). Moreover, it has less maintenance due to its non-contacting and non-rotating nature of operation. The lasers cut the rocks sharply and produce cleaner features, which certainly help for efficient and smooth oil and gas production (Jamali et al. (2019)). Engineers and scientists are certain of that recent lasers have the capabilities to drill the rocks 10 to 100 times quicker than the conventional boring technologies. This will be an enormous advantage in minimising the high costs of operating a drill rig and elimination of steel casing. However, the research and development work on using lasers is in its infancy due to various hurdles such as limitation on depth of the holes, laser production, conveyance, high laser energy consumption, availability of operating guidelines, proper/optimal process parameters (Tsai and Li (2009)). The main objective of this project would be to develop simple, novel, more efficient, cleaner technologies to drill and perforate under-water rocks and structures. The specific objective is to develop a robot-laser-based-drilling tool which will efficiently spall, melt, and vaporize rocks.

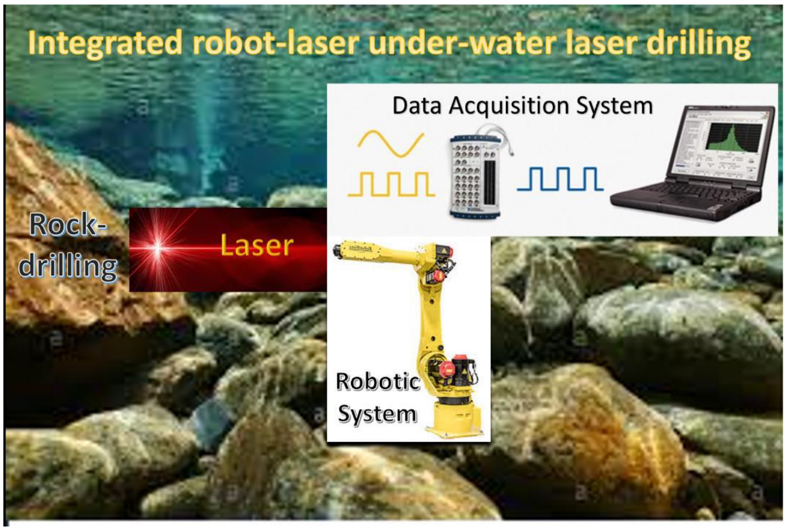


Fig. 3.2: Proposed robot-laser based under-water drilling technology

Figure 3.2 shows various elements of the proposed system. These elements will be explored, designed and developed to achieve the defined objectives. Various steps of the work packages are listed below.

a. A detail theoretical study on laser drilling of high-strength materials, under-water laser-material interaction.
b. Technical interactions with the oil extraction agencies such as Oil and Natural Gas Corporation (ONGC), Shell, Schulmberger etc.
c. Field visits to the drilling sites and understanding of the existing drilling technologies being used in India and world-wide.
d. Extensive literature review on state-of-art technologies on under-water laser drilling.
e. Survey and selection of suitable lasers (Nd:YAG / CO_2) for drilling of various materials such as lime-stones, sea rocks, shells, granites etc.

f. Design and development of experimental set-up to study the laser-rock interaction in submerged (under-water) mode.
g. Design/selection of suitable robotic configuration to assist the under-water laser drilling.
h. Fabrication of various prototypes of the integrated system.
i. Performing the experiments on laser drilling of various types of rocks; recording of data.
j. Systematic analysis of the results/data. Metallurgical characterization of processed rocks.
k. Optimum selection of process parameters. Verification of the parameters. Recommendation and actual trials.
l. Design and fabrication of under-water laser carrying vehicle, fixtures required for carrying out the operations.
m. Design and development of vision-based process monitoring and controlling mechanism.
n. Numerical analysis of laser-rock interaction to understand the physics of the process. Study of gas bubble formations and numerical simulations.

Deliverables:

- Estimation of true energy requirement for laser-rock drilling.
- Optimum laser processing parameters for minimum amount of energy required to cut and melt rocks.
- Simple, novel, and efficient laser-rock-drilling tool and necessary accessories.
- Knowledge regarding the laser-material interactions of un-explored laser-materials combinations.
- Skilled human resource in-terms of engineers, technicians and field workers.
- State-of-the-art training facility at Research-Park IIT Guwahati.
- The developed robot-laser based integrated configurations may further utilized for under-water laser welding.

Development of technologies, and prototypes which can be commercialized through professional start-ups.

Under Water Explosion and Associated Shock Wave Implications on Submerged Structures through Blast Wave Analysis

Shock waves are disturbances, which travel faster than acoustic waves in a medium. They carry large amount of energy and has the ability to dissipate it rapidly. Shock waves have shown to cause devastating effects on both living and nonliving bodies. It replicates the scenario of the high-energy waves created by sudden release of energy occurring during supernova collapse, lightning, nuclear or other high intensity explosion etc. To greater extent, the shock waves and its properties are understood with "air" as propagation medium. However, the shock wave propagation in "water medium" is still not studied fully. Water being 1000 times denser than air, can have significant consequences in shock wave behavior and its properties. For example, an incident shock wave of strength (Mach 2), propagating in "air and water" do not imply same effect rather, the later can have severe devastating consequences. The study the shock wave behavior in "water medium" is of utmost importance because underwater explosion can result in generation of shock wave, which can propagate and interact with the nearby object like oil refineries, ships and submarines and cause destruction of it. But, the control mechanism of shock wave exposure (i. e. dumping large amount of energy in millisecond/microsecond duration) in various applications can be miracle if it is understood properly. A schematic representation of one such explosion and the shock waves generated is shown in Fig. 3.3. Therefore, a comprehensive understanding of the shock wave behavior in water and its interaction with nearby objects is essential in order to protect the structures.

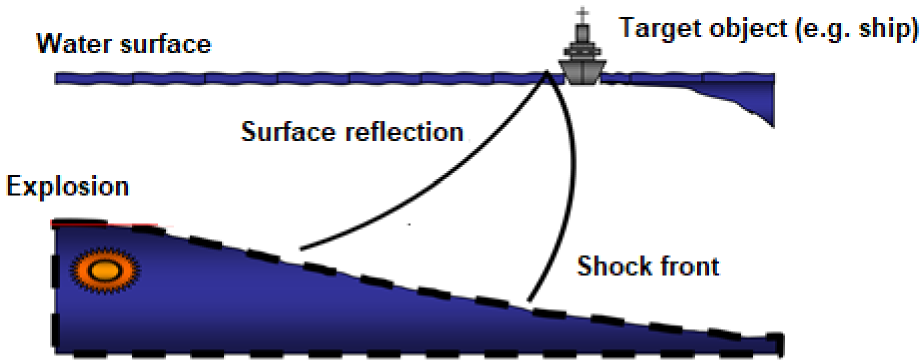


Fig. 3.3: Schematic representation of underwater explosion and wave generation.

The propagation and attenuation of shock wave propagation in water is one of the important aspects of research in naval warfare. The development of a shock tube facility for blast wave generation in under water structures is a new paradigm for which the measurement diagnostics is almost rare and limited. In fact, the blast wave propagation is very fast in liquid medium and needs high response sensors to detect their motion in terms of quantum pressure and temperature rise within a few milliseconds. In this aspect, the proposed project is intended for in-house sensor fabrication of surface junction thermal probes and their usability towards blast wave detection. Moreover, the structural stability of submerged objects under blast wave exposure will be one of the focal point of research by measuring their induced strain.

Objective of the project:

The objective of the present research is to simulate underwater explosion scenario in laboratory scale by generating shock waves in water in a controlled manner and study its behavior. It includes the following tasks:

- Effect of shock strength on wave propagation, reflection and its interaction with surrounding objects.
- Measuring the impact loads on the nearby sub-scale objects and mechanism to mitigate them.
- Explore sloshing behavior of water through shock wave penetration
- Understanding the complete dynamics of shock wave propagation in water by visualizing the complex flow field.

Experimental methodology:

The indigenous shock tube setup at Mechanical Engineering Department, IITG, shall be utilized to generate shock wave of varying intensity in "water medium". It is proposed to be integrated with a water tank with associated instrumentations. The varying fill conditions in the shock tube will generate shock waves of different strength. The structures replicating ship hull, submarines and other under water structural elements shall be housed inside the facility with instrumentation. The measurement diagnostics involve localized pressure and temperature across the shock waves, force measurements on structures through strain history and flow visualization through high-speed imaging capturing through "Schlieren/ Shadowgraph system".

Expected research outcome

The technology of fabrication miniature surface junction probe is already in place and can be extended for under water measurements. It will initiate local fabrication of such fast response probes under "Made in India Scheme" for budding startup companies. Moreover, an experimental shock tube based impulse facility for under water blast wave exploration will be very unique in the country. Also, this facility will earn next generation sponsored research to study various design aspects of naval ships, submarines and oil refineries research. Give a scope; the facility can be used to explore experimental simulation towards the Tsunami behavior through under-water blast wave propagation.

Experimental Investigations into the effect of reinforcement particles on the tribological and corrosion properties of marine grade AA5052 aluminium alloy joints through FSW

Nowadays in commercial and industrial applications, the usage of aluminium alloys has been increased because of its excellent corrosion resistance, a high strength-to-weight ratio and good properties even at moderate temperature. Among the aluminium alloys, AA5052 which is commonly known as marine grade alloy is widely used in marine applications, as well as in space and aircraft applications where it requires material with high wear & corrosion resistance as well as strength. But welding of aluminium alloy is difficult by means of conventional fusion welding methods; therefore, it is classified as difficult to weld materials. Therefore, advance welding processes such as friction stir welding (FSW) is recommended for joining of these materials. Moreover, its use in many of the engineering applications is limited due to its tribological properties. Many non-metallic and metallic elements are used to enhance the welding surface of AA5052 alloys by using reinforcement to improve its tribological properties. The amount of corrosion resistance is dependent upon temperature, airborne chemicals, and the proximal working environment; however, under ambient environments, AA5052 aluminum holds up exceptionally well. The alloy AA5052 does not contain any copper, which means it does not readily corrode in a saltwater environment which can attack and weaken copper metal composites. However, welding areas are the weakest portion where corrosion attack takes place. Therefore, significant enhancement in the corrosion and tribological properties need to be achieved not only in the ambient conditions but also in marine environments AA5052 aluminum joints as it has wide range applications in marine environments.

On the other hand, the friction stir welding (FSW) might be the potential and cost effective technique which can be adopted to improve the corrosion and tribological properties of marine grade AA5052 aluminum alloy compared to other fusion welding. FSW is a solid-state joining process that uses a non-consumable tool to join two work pieces without melting the work piece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. Frictional heat is generated between the wear-resistant tool and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. The quality and microstructure of the weld is dependent on various factors such as, welding speed, rotational speed, tool tilt angle etc. hence, the mechanical, tribological and corrosion. The properties of the welds are controlled by its ‘‘weakest part’’, i.e., the region between the nugget’s thermo-mechanically heat-affected zone. Within this region, the coarsened precipitates control the corrosion behavior.

Therefore, in this project, the existing FSW process is planned to be used as a method to improve tribological and corrosion resistant properties of the AA5052 aluminum alloy joints in both ambient and tribological environments. Later, the addition of suitable reinforcement into the weld on various properties of are planned to evaluated and compared. Once it is successfully implemented, it can address the present difficulties related to AA5052 alloys joints in both ambient and marine environment i.e., mechanical, tribological and corrosion problems.

Importance of the proposed project in the context of current status

From the literature review conducted (both international and national levels); many researchers [7-11] have worked to improve the weldability of AA5052 through FSW. It is proven that FSW is a potential alternative to weld AA5052 with relatively ease compared to the conventional fusion welding even though it has some difficulties related to the formation of IMCs layer. The studies related to the formation of various defects and its effect on the microstructure especially related to the corrosion and tribological properties which are not explored. The tool material and its shape play an important role in obtaining better weld quality and hence the various properties. In addition, the hardness of the weldment is also crucial properties to compare the other microstructural properties, various FSW zones are having different microstructural properties. These properties are totally dependent on microstructure of the weld and it can alter by adding suitable reinforcements. Therefore, the addition of suitable reinforcements into the weld interface can modify the weld properties by changing microstructure effectively. In this project, it is planned to explore the mechanical, corrosion and tribological properties and possibility of using reinforcement for the improvement these properties through FSW at ambient and marine environments. Therefore, the successful implementation of this project (achievement of the objectives) can suppress the total cost by using FSW process due to its non-consumable tool and can obtain high corrosion & wear resistant joints of AA5052 at both ambient and marine environment.

Vibration Analysis of Underwater Pipe Line

In an underwater environment, structures and fluids affect each other in a complicated manner through many factors. Some of them are buoyancy, drag, and fluid-related vibrations, making it difficult to experimentally measure the dynamic properties of underwater structures.

There are a variety of excitation mechanism which can be present in a piping system and can produce vibration and finally failure resulting from fatigue. Few of those causes are flow induced vibration caused by the turbulence of the flowing fluid. Mechanical forces from equipment are caused by the excitation forces of reciprocating and rotary equipment like pumps, compressors, etc. High-frequency acoustic excitations generated by relief valves, control valves, or orifice plates.

Piping Vibration causes dynamic stresses (fatigue) in a piping system. If this stress is more than the critical value it will initiate a crack that will propagate slowly and end in the failure of the component. The present proposal is aimed for identification of vibration detection of underwater pipelines. Simply supported, clamped, and clamped-simply supported pipelines will be studied. The influence of pipe radius to pipe wall thickness, ratio of liquid mass density to pipe wall mass density, the fluid velocity, and fluid pressure also will be considered.

Methodology

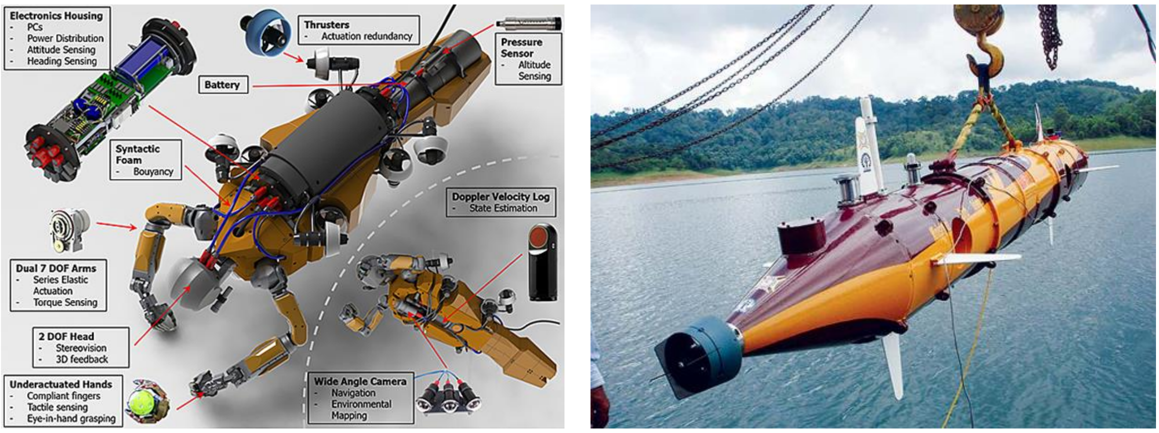
Pipe carrying fluid in a fluid medium will be modelled using Finite element method (using FEM software). The vibration response of the pipe in the fluid medium will be obtained for different input signal such as sine and random. Experiments will be performed to find out the frequency response of the piping structure. Experimental results will be compared with the numerical result. The following are the expected outcome:

(i) Detection methodology of vibration in underwater pipes

(ii) Expected publication 06

3.2.2 Underwater Autonomous Vehicles

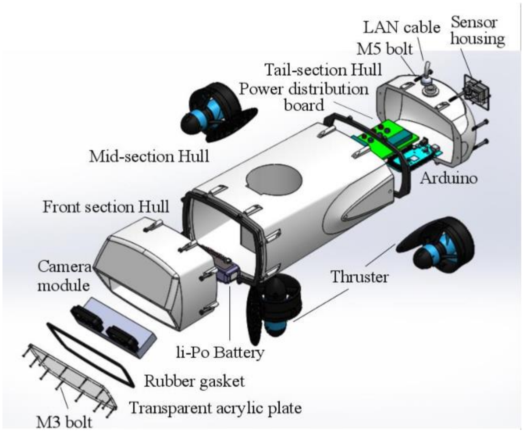
Two major types of Underwater Robots namely Autonomous Underwater Vehicle (AUVs) and Remotely Operated Vehicles (RoVs) are generally used for underwater applications. The structural body of the robot may be inspired from the nature (Biomimetic (fish, tortoise, snake, etc), Humanoid etc) as well. The driven mechanism of the Underwater Vehicle may be based on glider, propeller or hybrid (both glider and propeller based) driven vehicles.



(a) (b)

Fig. 3.4 (a) Humanoid Diving Robot [*web ref 14*] (b) Autonomous underwater vehicle developed at CMERI Durgapur

It has been observed that the global underwater robotics market is expected to reach around USD 7 Billion by 2025 [*web ref 13*]. Few recently developed AUVs and RoVs are shown to highlight different components of the vehicle in Figure 3.4 and 3.5. While in Figure 3.4 (a) shows a humanoid robot used for coral reef management developed by Stanford University, Figure 3. 4 (b) shows an autonomous underwater vehicle developed in CMERI-Durgapur India.



(a)

(b)

Fig. 3.5 (a) Exploded CAD model of remotely operated underwater vehicle (b**)** RoV developed at IIT Guwahati

The major components of underwater vehicle comprises of a physical structure along with electrical/electronic components such as prime mover (thruster), sensors, controller and manipulators. The physical structure of the underwater vehicle can be made up of wood, metal, composite materials, functionally graded materials, sandwich structures and further research can be done to develop new material to withstand the operating conditions at higher depth. This physical structure undergoes hydrostatic and dynamic stresses depending on its shape and size and operating conditions such as depth, environmental conditions (fresh/sea water, static /flowing water conditions). 3D modelling and Finite element based structural analysis may be required to design and develop many new types of underwater vehicles. In this secondary area following work packages are identified:

1. Development of Autonomous System for Underwater Vehicle
2. Development of Unmanned Underwater Vehicle for monitoring of underwater eco system and weed management
3. Development of flexible multi-link spatial manipulator mounted on a moving body for underwater exploration
4. Analysis and development of computational intelligence based navigational strategies for an underwater robotic vehicle

5. Design and Development of In-pipe robot
6. Development and Analysis of Intelligent Integrated Water Born Robot for Surveillance, Monitoring and Cleaning
7. Underwater Vehicle for water quality monitoring of river bodies
8. Unmanned Exploration of underwater ecological system both in fresh and sea water
9. Design, Analysis and Development of a Low Cost Underwater Vehicle (Mini Submarine) for (a) Tourism Purpose and (b) Bio-fouling cleaning
10. Design and Development of passive high-static-low-dynamic stiffness (HSLDS) vibration isolators for underwater vehicles
11. Ergonomic Evaluation of the Human-Robot Control Interface and Suggestions for Improvement of Usability

The scope, and outcome of these work packages are described in detail in the subsequent sections:

Development of Autonomous System for Underwater Vehicle

About 70% of the earth is covered with water, and the oceans are full of resources that can be of great use for humanity. To explore the oceans and lakes, there was a need to develop a vehicle that could dive underwater and can perform various tasks. The idea of submersible vehicles originated a long time back. The first American submarine was titled "Turtle" built in 1975. In 1879 the Reverend George W. Garrett designed the "Resurgam" – considered the world's first practical powered submarine. There have been many more submersibles developed and used for different operations in the past decade. Torpedoes, which are considered as first autonomous underwater vehicles, also developed along with these submarines.

There are various kinds of vehicles developed till now, and they can be typically classified into two types, i.e. the Manned Underwater Vehicle (Fig. 3.6 (a)) and Unmanned Underwater Vehicle (Fig. 3.6 (b)). Military submarines and non-military submersibles are examples of manned vehicles which are mostly used for underwater military operations. Unmanned vehicles are again classified into various categories. The simplest ones are those machines that are towed behind the ships. They act as platforms for various sensor suites attached to the vehicle frame. The second type is the remotely operated vehicle which a controller operates. They are equipped with various sensors and electronic components to perform various tasks.

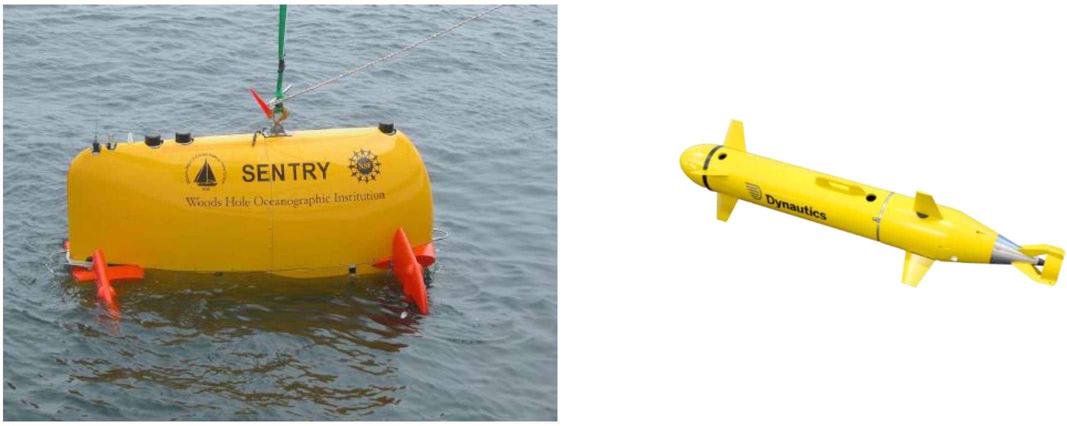
(a) (b)

Fig. 3.6: Example of ROVs, (a) BlueROV2 from Blue Robotics and (b) Millennium Plus ROV by Oceaneering.

Underwater vehicles are systems intended to traverse underwater for various purposes ranging from civilian (exploration, commercial use and research) to military (Fig. 3.7(a))) (surveillance, search and rescue crash/damage investigations). Such activities are typically fraught with danger especially considering the harsh underwater environment. Historically, this has led to the development of unmanned vehicles which can travel underwater while avoiding the danger to human life. A typical example of an underwater vehicle is the ROV (remotely operated vehicle), an underwater robot capable of navigating underwater. The ROV has an articulated arm that can be used to retrieve small objects, cut lines, or attach hooks to lift large objects. Some ROVs may not have an articulated arm, especially when their purpose is to inspect the underwater environment. The ROV is unmanned in the sense that there exists no human operator within the robot. However, the robot is connected to a ship by a set of cables, which transmit command and control signals between the operator (on the ship) and the ROV. This allows remote navigation of the vehicle. An example of an ROV is the BlueROV2 (Fig. 3.7(b))), developed by Blue Robotics, as shown in Fig. 3.6(a), which is used mainly for inspections. An example of an ROV with an articulated arm is the Millennium Plus ROV developed by Oceaneering, as shown in Fig. 3.6(b).

The electronic world has led to research in autonomous cyber physical systems, which has propelled the development of autonomous vehicles, sometimes known as AUVs or Autonomous Underwater vehicles (Salhaou, 2020). These vehicles can carry out underwater missions such as inspections and surveillance *without operator intervention*, capture and store the data and return to a pre-programmed location where such data can be accessed. In this sense, given its autonomous operation, the AUV is somewhat more complicated to develop than an ROV. The first AUVs were built in the 1970s, put into commercial use in the 1990s, and today are mostly used for scientific, commercial, and military mapping and survey tasks. Developed in cooperation between Kongsberg Maritime and the Norwegian Defense Research Establishment, the HUGIN (Hagen, 2007), series represents the most commercially successful

AUV series on the world market today. AUVs are compact, self-contained, low-drag profile crafts powered (in most cases, but not all) by a single underwater DC power thruster. The vehicle uses on-board computers, power packs and vehicle payloads for automatic control, navigation and guidance. They can be equipped with state-of-the-art scientific sensors to measure oceanic properties or specialized biological and chemical pay-loads to detect marine life when in motion. As is common in most developments today, AUVs have been operated in a semi-autonomous mode under human supervision, which requires them to be tracked, monitored, or even halted during a mission so as to change the mission plan. However, there have been successful attempts at true autonomy. Two examples of AUVs are shown in Fig. 3.7.



(a) (b)

Fig. 3.7: AUVs, (a) SENTRY, developed by the Woods Hole Oceanographic Institution, and (b) Phantom AUV, developed by Dynautics Ltd

OBJECTIVES

Designing unmanned vehicles is an interdisciplinary topic which combines multiple fields of technical expertise such as Control Systems, Robotics, Vision, Intelligence, Planning amongst others. The current challenges in designing and controlling unmanned underwater vehicles require addressing the research domains of navigation, communication, autonomy, and endurance. *The objective of this WP is to design and develop an Autonomous underwater vehicle (AUV) which will be capable of carrying out specific missions in water bodies*. The tasks include real-time exploration and monitoring of things in the underwater environment (rivers and lakes), sample collections etc. Such AUVs will be useful in various domains like aquaculture, defence, shipping, oil and gas, and can also be extended to automate inspection, maintenance, and repair tasks. One of the crucial things towards the development will be the design criteria and material selection. Raspberry Pi Board will be used to process, transmit and receive all information. The AUV can be used for various purposes such as underwater environmental monitoring (JosuéGonzález-García 2020), oceanographic survey (Willcox 1998), pipeline and subsea structure inspection and debris inspection in shallow water bodies.

The proposed AUV offers many advantages, such as being available in various domains like surveillance or mapping (for security and marine science) and deep-water oilfields (for inspection, repair and maintenance). Equipping vehicles to execute these missions successfully requires that they are able to adapt their mission plans dynamically in real-time. This project addresses the design and retrofitting the existing underwater vehicle to make the vehicle intelligent, which will be capable of doing various tasks underwater.

The specific sub-objectives can be defined as the development of an AUV capable of

(i) Underwater Stealth
(ii) Underwater Path Planning
(iii) Underwater Tracking

Methodology

The work plan involves four stages Mechanical Designing, Electronic Setup, Manufacturing, Experimental studies. Building an AUV majorly comprises of the three parts i.e. Electronic, Mechanical and Software part.

Mechanical Designing

The outer casing of the AUV will be leak-proof, capable of shielding all the components inside the casing from wetting. A casing made of composite material – CFRP/GFRP (Rubino 2020) will be used for this purpose. This material will be tested for its strength in an aquatic environment.

Electronic Setup

Figure 3.8 shows a few of the essential electronic components that will be used to develop the AUV.

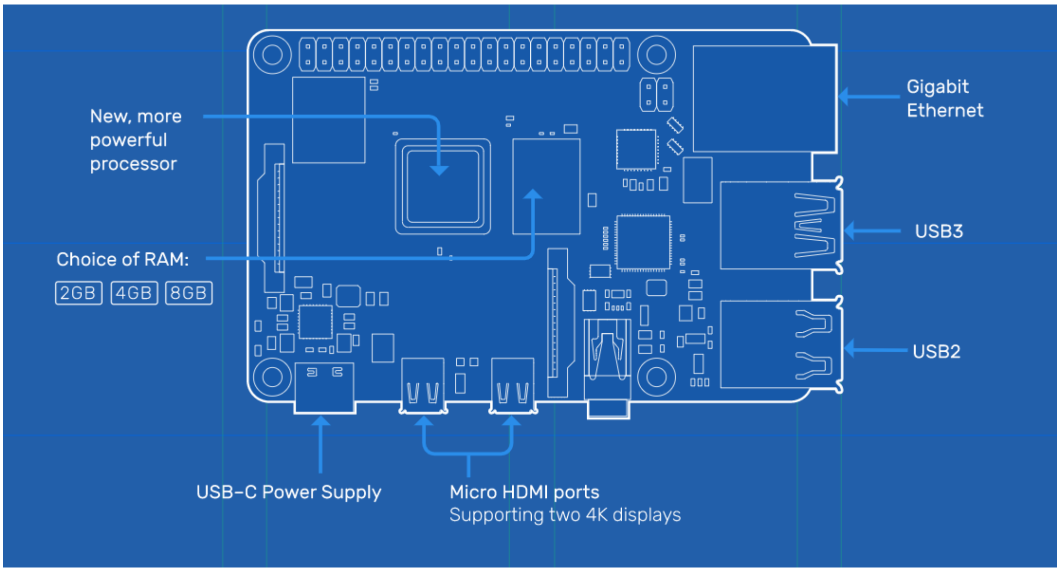


Fig. 3.8: Raspberry Pi 4 Board ([https://www.raspberrypi.org/products/raspberry-pi-4-model-b/specifications/)

Main Board and Sensors: All the major processes and the functioning of the AUV including the functioning of the camera and other essential sensors, detecting the obstacles, controlling the thrusters should be controlled and managed via a main board. In this work, the initial plan is to use a RASPBERRY PI 4 board (MENG 2016) (Fig. 3.8). Considering the amount of data that needs to be managed in real time, the AUV operation needs a high-speed processor to efficiently receive and send commands. With its high processing speed and various other features, this will be a good fit.

Furthermore, its lightweight, small size, and low power consumption make it suitable for our application. This board has the following features (Refered from https://www.raspberrypi.org)

- Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
- 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model)
- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
- Gigabit Ethernet
- 2 USB 3.0 ports; 2 USB 2.0 ports.
- 2 × micro-HDMI ports (up to 4kp60 supported)
- 2-lane MIPI DSI display port
- 2-lane MIPI CSI camera port
- 4-pole stereo audio and composite video port
- H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)
- OpenGL ES 3.0 graphics
- Micro-SD card slot for loading operating system and data storage
- 5V DC via USB-C connector (minimum 3A*)
- 5V DC via GPIO header (minimum 3A*)
- Power over Ethernet (PoE) enabled (requires separate PoE HAT)
- Operating temperature: 0 – 50 degrees C ambient

A good quality 2.5A power supply can be used if downstream USB peripherals consume less than 500mA in total. All ports of this board will be used. The serial port is dedicated to the rotating body while the two cameras, the sensor board, and the transceiver module will be connected to the USB ports.

To navigate safely, an AUV should be provided with a minimum of information about its environment so that it can take appropriate decisions. Fig. 3.9 shows the main block diagram of the processor connections. The data collection will be mainly from the sensors. The work will include the following sensors.

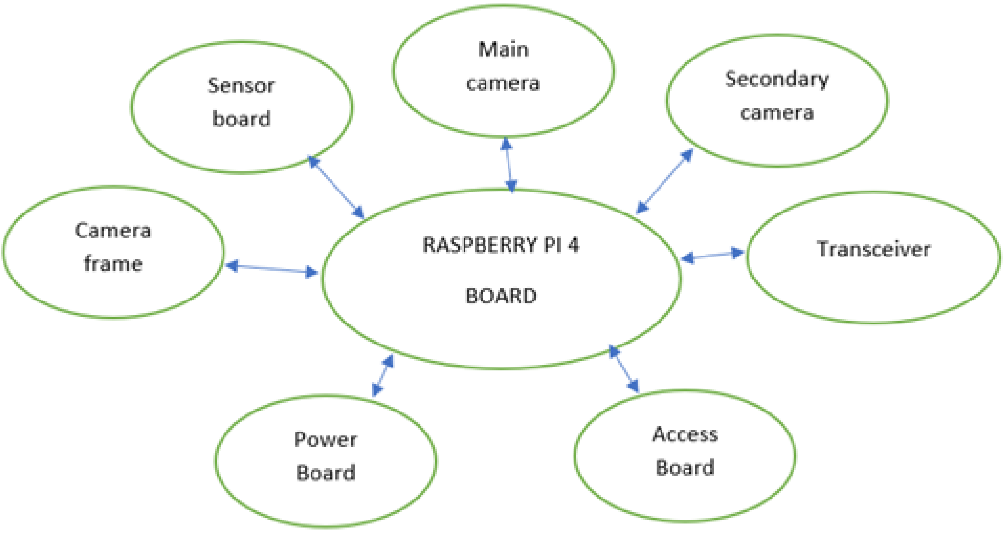


Fig. 3.9: Block Diagram of Processor connections.

- Compass Sensor (Balestrieri 2021) for knowing the direction of the magnetic North.
- IMU (Aras 2017) sensor for collecting data on Roll and Pitch angles and acceleration.
- Pressure sensor (Investigation and Evaluation of Low cost Depth Sensor System Using Pressure Sensor for Unmanned Underwater 2012) to know the water pressure and depth of the device.
- Humidity and temperature sensors for measuring the temperature and humidity of the chamber of the device.
- Photocell sensor (Autonomous Underwater Vehicles: Localization, Using Underwater Unmanned Vehicles: Field Applications, Challenges and Feedback from Water Managers 2020) to measure ambient light.

IMU Sensor

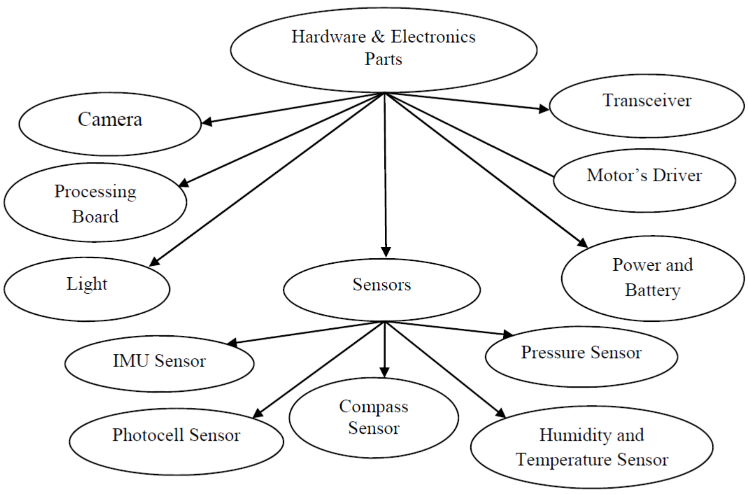


Fig. 3.10: Block Diagram of setup of Electronic Parts

Important sensors and their connection to the hardware is shown in Fig. 3.10. IMU Sensor includes three sensors the Acceleration counter, Gyroscope and the magnetometer (Aras 2017). All three sensors are used to perform measurements in the three directions of the coordinate system, The acceleration counter measures the acceleration of the device, its balance, and its deviation. The gyroscope measures the circulation rate of the device and the magnetometer determines the position of the device in comparison with the North Pole. The selected sensor is the MPU-9250, one of the most advanced sensors with a 3-axis gyroscope, 3-axis accelerometer, 3-axis compass, internal temperature sensor, and equipped with an advanced system of digital motion processing. Unlike its predecessor chips, the MPU-9250 chip is equipped with the I2C communication protocol that leads to very high speed communication, extremely low current consumption and protection against noise.

Camera and Light Board

For the underwater exploration and to capture the real time images, two cameras are included in the AUV design. The first in a transparent dome-like space at the top of the AUV with a capability of a 360° circulation and the second on the AUV floor, both for observing the surroundings and detecting obstacles (MENG 2016). These cameras, the HD Webcam C615, have the following specifications:

- low-voltage and low current consumption
- high resolution of 1080p and 720p
- USB port for connection to the main processor board
- automatic recognition by the main processor board
- automatic setting up of light and resolution

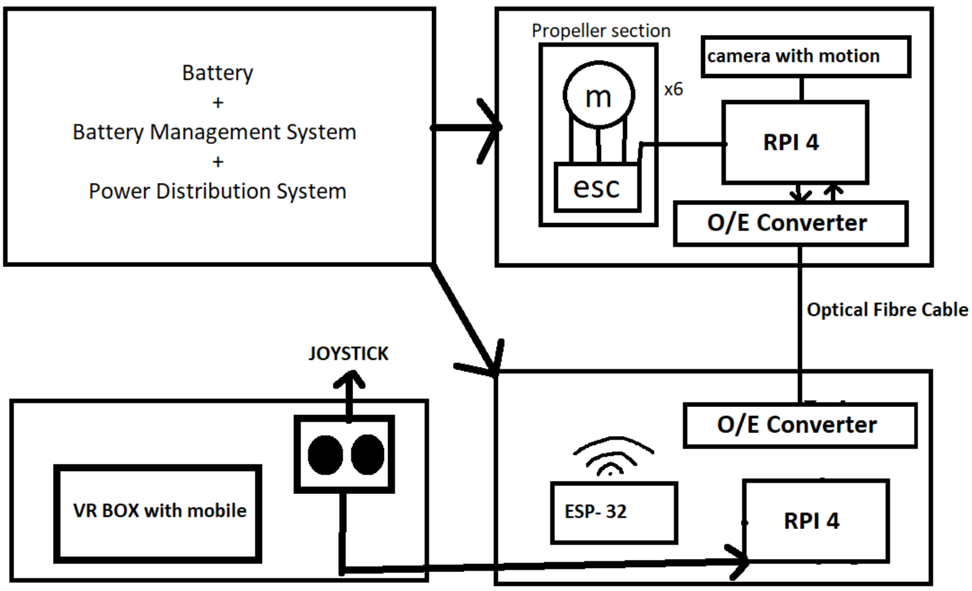


Fig. 3.11: Block diagram of controls of the ROV

Engine Driver Board

A single driver is used for controlling all the thrusters. This driver is responsible for receiving commands in a serial form from the main processor board and via the sensors board, and controlling the direction and speed of all engines. It includes two BTN7971B motor driver modules for control of DC motors. This board produces the PWM signals required by all engines via a mega64 microcontroller. Also the control system of the entire AUV with the controller is shown in the figure below in Fig. 3.11.

Manufacturing

The manufacturing of the entire vehicle will be carried out starting in various steps

1. After purchasing an existing vehicle, redesigning and modifications shall be made according to the task at hand, such as retrofitting with the appropriate sensors.
2. Further modifications in design will be done to provide movements like Yaw, Pitch and Roll in the underwater environment.
3. Installations of Smart devices like Cameras and other sensors.

Making a Software module for the Camera for real time Imaging and decision making through AI/ML algorithms.

Design and development of underwater robot for aquatic ecosystem study and weed management

An aquatic ecosystem is comprised of the community of organism that live, grow and interact within water environment. All the plants and animals live either in or on water bodies like river, pond and sea for their survival. Some plants are important and play necessary role in balancing the ecosystem but there are many weeds in the aquatic system that hinders the growth of useful organisms as well as deteriorates the quality of water resulting an imbalanced aquatic ecosystem. Aquatic weeds are the unwanted aquatic plants that grows either in or on the water bodies by encroaching the space and nutrients, that deplete the quality of the water bodies so that it becomes difficult for the organisms to survive in that environment.

Aquatic weed as problem to agriculture and water bodies

Aquatic weeds are serious threat to environment and agriculture worldwide. Many Rivers, lakes, irrigation canals and ponds are flooded with aquatic weeds in India. This explosive growth of aquatic weeds causes many direct losses to agriculture, fish culture, and aquatic ecosystem. Excessive growth of weeds interfere in navigation, impedes water flow in canals, reduces the water by transpiration and interferes with irrigation supply to the fields.


(a)


(b)


(c)


(d)


(e)


(f)

Fig 3.12: (a) Pistia stratiotes (b) Hydrilla spp. (c) Lemna spp. (d) visible effect of bio agent on water hyacinth (Pathak and Kannan 2011) (e) controlled experimental setup of water hyacinth in an aquatic tank (f) a close-up of water hyacinth floating on the water surface of an aquatic tank

There are many different types of aquatic weeds including various algae, the most common and dangerous aquatic weeds in India are *Eichhornia crassipes*, *Hydrilla verticillata (Fig. 3.12b)*, *Pistia stratiotes (Fig. 3.12a)*, and *Salvinia molesta*, *Azolla caroliniana*, *Alternanthera philoxeroides* etc. It causes heavy water loss thus makes it unsuitable for fish culture and for cultivation of many aquatic crops like water chestnut and fox nut.

Water hyacinth (*Eichhornia crassipes*) *(Fig. 3.12d-f)*, usually floats on the freshwater surface is the most successful colonizer and encroacher. Its rapid rate of proliferation results not only in the reduction in dissolved oxygen but affects the flora and fauna as well. It also causes an increase in the rate of water loss due to evapotranspiration. That's why it poses a serious threat to the biodiversity (Sotolu, 2013) and hence required a serious effort for effective management.

Status of management so far

Aquatic weed management is biggest challenge to environment. Mechanical, chemical and biological efforts are been used to control aquatic weeds, but each approach has some advantages and disadvantages. Mechanical control does not require a technical expertise especially when used for the removal of the weed, but the growth of the weeds is so high that boats and many other machines cannot move freely in the aquatic system. However, when the plants chopped manually /mechanically the dissolved oxygen fluctuates and it can lead to eutrophication. That ends up increased water hyacinth blooms. Chemical control very rapid in action like mechanical control, in large scale the use of herbicides is less expensive when compared to mechanical, but these herbicides can kill non target crops, algae as well as macrophytes that again cause imbalance to the ecosystem. Biological control can be a promising alternative to mechanical and chemical control. Biological agents are eco-friendly, self-sustaining, host specific and cost-effective method for aquatic weeds (Pathak and Kannan, 2011). However, there also lies some disadvantages like persistency and efficacy with the environmental changes. In this regard one can opt to have an integrated management approach where more than one control measures can be utilized simultaneously. For the integrated weed management an underwater robot can be designed as per the need and can be utilized to study the aquatic ecosystem without disturbing the necessary aquatic plants and animal community. Further this robot can spray the bio agents to the specific site where the plant population is higher.

Objective of the study:

- Design and develop an underwater robot capable of maneuver inside the water bodies.
- Design and develop the manipulators attached with the underwater robot to be capable of injuring the weed for supporting bio agents to augments its population and effectively kill the weed.
- To develop on onboard sensor to find the quality of the water.
- To develop the wireless communication system for the underwater robot system.

To collect the water chestnut, fox nut and plug flowers from the water bodies.

Underwater Robot Design:

The underwater robot consists of thrusters (for motion and balancing), onboard sensors and manipulators (Salvador et al. 2013, Giacomo et al. 2009, Satja et al. 2018, Dwivedy and Eberhard 2006). The attached manipulators will help in managing the aquatic weeds. The schematic of the underwater robot with two manipulators attached upfront are shown in Fig 3.13.

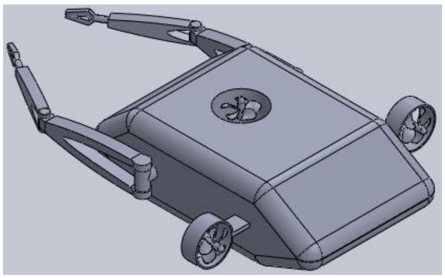


Fig 3.13: The schematic of the underwater robot

Socioeconomic impact: The project also intends to create awareness along with employment in the rural and semirural areas of the nation. Specially the region where water bodies exist in abundance. For example, the water hyacinth can be used to make handicrafts and organic fertilizer.

Development of flexible multi-link spatial manipulator mounted on a moving body

The demand of developing flexible robotic manipulators finds a great enthusiasm among the researchers because of its significant industrial applications i.e., space exploration, hazardous nuclear power plant, surgical operations, micro and macro fabrications, underwater operation and in many other precision industrial applications, to avoid direct human contact and subsequent human fatigue due to repetitive, monotonous, tedious, dangerous and contagious work environments. Notwithstanding, the applications of present industrial robots are not limited to terrestrial and airborne applications, these robots have extensively been engaged in various underwater applications that will eventually turn into a critical tool of underwater vehicles for performing various interactive operations such as opening and closing of valves, cutting, drilling, sampling, and laying in the fields of scientific research and ocean systems engineering. With the advancement of new technologies, the use of underwater robotic manipulator has widely been diversified into various applications in the offshore oil and gas industry, maritime search and rescue, oceanographic research, underwater environmental monitoring. Often, due to unstructured reality of interactive tasks and hazardous undersea environment, operations of these robotic manipulators are mainly being made with remotely operated.

The Offshore Oil and Gas and industry and maritime research team have been constantly innovatively engaged to build and design the reliable robotic systems for variety of underwater applications including drilling, material handling, cutting, material removal, non-destructive inspection, underwater exploration, assembly, and transport with precise automation and accuracy in these repetitive tasks. Underwater robots often utilize for undersea tests of sample acquisition, monitoring, processing and handling systems performed to validate undertaking operations concept. In many occasions, underwater robots have been remotely used to inspect and monitor hazardous areas for the damage using laser camera system. Sometimes, powerful and long-reach robotic manipulator is needed to perform the underwater exploration with positioning accuracy. Underwater robots mainly employ to persuade the operations either in the places which are not accessible to the humans or located remotely difficulty to have direct human intervene. Most of these operations, it is desired to build and design a robot system with long-reach robotic arms so that to protect its human presence with high safety in the hazardous locations. The long-reach manipulator finds diversity in its applications with the potential advantage greater payload-to-manipulator-weight ratio, better manoeuvrability, better transportability and safer. The engagement of long-reach manipulators, particularly in undersea applications plays an important role and has shown a rapid growth emerged as new challenges for ever-increasing productivity.

Dynamics of underwater robotic manipulators include uncertainties hydrodynamic parameters those are generally highly non-linear, coupled and time varying. In contrast to robots used in terrestrial applications, a number of complex and critical issues play important role while describing its dynamics and trajectories analysis. Dynamic formulations become more critical when the robotic system includes the multi-links interactions correction with unalike joints. Moreover, the influences of hydrodynamics forces on each link of the underwater robot are inevitable and must be considered in the dynamic modelling to predict its end point locations. The effects of the hydrodynamic forces on the surfaces of each link that may mainly consist of added mass effects, hydrodynamic drag and lift forces and moments, and buoyancy forces. Accurate modeling and dynamic characteristics is required and needs verification with the findings using simulation software i.e., ANSYS or Multi-body dynamic simulators including three-dimensional graphics and virtual reality capabilities.

The design of technically reliable multi-link spatial robotic manipulator for various underwater assignments requires a concrete mathematical model to understand of its dynamics of mechanical systems with variable configurations that interconnects either rigid or elastic components or combination of both. Generally, underwater robotic manipulators often perform upon movable base which can freely reciprocate and rotates in the operating environment. Thus a special attention is required to highlight the dynamics coupling between the arm and the base during this manipulation. Hence, the operational performance of space manipulators reduces to that of the ground based ones. Taking into account of flexural behaviour due to elasticity and inertia in the deformed links of underwater manipulators, influence of elastic oscillations due to fast manoeuvring on the dynamics of the systems is desired to be investigated that leads to position inaccuracy. This proposal deals with dynamic modelling and optimal motion designing of spatial multi-link underwater robotic manipulators accompanied with physical realization. The system is composed of a multiple rigid-flexible links and joints mounted on a moving object or body like submarine. A theoretical assessment and trajectory analysis of the dynamic model will be validated with the findings using dynamic simulator. Finally, a prototype will be built based on the experimental verification with numerical simulations.

Objectives of Research Project

Accurate designing and subsequent the performance evaluation of underwater robotic system enables the unattainable solution to the fields of robot applications and suitable control strategies to overcome numerous challenges. This project will start with a dynamic model providing closed-form analytical expressions and showing mechanical coupling and dynamic interaction between links, joints and moving body. This project also will take up the challenges to overcome the difficulty due to parameter uncertainties, external differences (e.g., buoyancy and payload variations), and disturbances (e.g., underwater current). The effectiveness of the dynamic models will also to be verified with results using multi-body simulation software.

Objectives:

- Dynamic model consisting of rigid-flexible links with extended payload, lumped parameter model for kinematics pairs and moving body. A schematic diagram is shown in Fig.3.14.
- Study the dynamic responses and show the effect of payload parameters i.e., payload mass, payload inertia, offset ratio and offset angle, and actuators parameters.
- Study end-point trajectory and it's variation under payload parameters, and actuator parameters and influences of moving base.
- Show the effect of added mass effects, hydrodynamic drag forces and moments, and buoyancy effects onto the dynamic responses and end-point trajectory.
- To build a prototype model and their evaluation for comparing the performance.

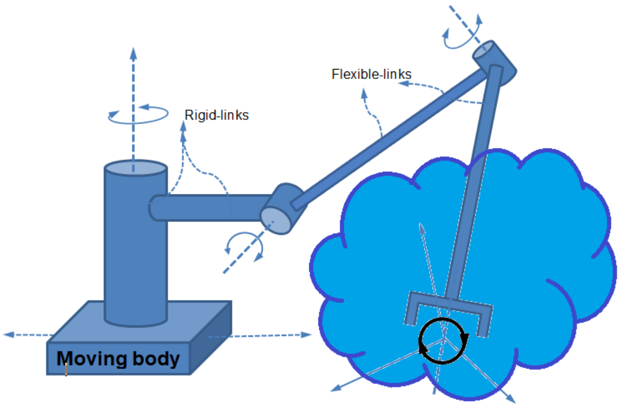


Fig.3.14: Schematic diagram of partially submerged multi-link underwater robotic manipulator

International status: The development of robotic manipulator has been found interesting in the fields of robots, especially for underwater applications. However, in most of these applications, autonomous underwater vehicles instead of typical robotic systems have been employed and exhaustive used of traditional robots is those areas are far lagging behind. Robotic manipulator with long-reach arms not only can perform the desire tasks located at remote areas but also end-effector of these robots can hold and release any arbitrary shape and size of autonomous underwater vehicles. World-wide there are numerous research and development groups (non-profit organizations), involved in the design and development of autonomous underwater vehicles along with some prominent R&D groups are listed in Table

2.2. However, most of these researches have been demonstrated related to AUVs design. Using the multi-link spatial robotic manipulators combined with rigid-flexible links and joints has yet been developed with practical realization.

National status: The scientific community in India has been continuously undergoing various sculptures of scientific challenges to develop new era robotic systems for the requirement of industrial and societal needs since last decade. However, significant development towards the design of robotic systems for underwater applications has not yet been explored as far as the India is concern. The use of flexible manipulators in industrial applications has been very limited world-wide and even in India. However, the challenges of designing multi-link robotic manipulator by the researchers are being carried on.

To the best of current state of art in the field of robotics, limited research has been followed through for the design of a robotic manipulator in underwater applications. The design of long-reach robotic structures mounted on a moving support is subsequently needed especially underwater applications like in sub-marine and ships. Simultaneously, subsequent control strategies and experimental investigations are also required to assess the developed dynamic model.

Methodology

Proposed project will describe theoretical studies into the dynamics of rigid-flexible multi-link robotic manipulator mounted on a moving body a way forward to build a prototype model comparing the performance with numerical simulations (Fig. 3.15(a)). An attempt will be necessitated by the investigator to provide a comprehensive exposition of the modelling and dynamics of combination of rigid-flexible links and pairs robots validated with physical realization. The outline of methodology is summarized in following figure and will follow the following approach/methodology for realizing the proposal objectives.

Task 1: Select the links and joints for rigid-flexible underwater robotic manipulator

Rigid and flexible beam elements (Fig.3.15 (b)) can be used to replace the links of multi-link rigid-flexible robotic manipulators with the combination of rigid-flexible joints parameters. While, elastic deformation would be highlighted to indicate the flexibility of the link, appropriate lumped parameter model can be used for representing pairs comprises with discrete mechanical elements like inertia, springs (linear and rotary) and damping elements.

Task 2: Develop a mathematical model of long-reach manipulators with moving support

The mathematical model of rigid-flexible multi-link robotic manipulator connected with revolute and prismatic pairs would be developed using analytical mechanics approach. Flexible arm robot can mathematically described by partial differential equations reflecting the distributed nature of mass, stiffness, and damping with joint flexibility modelled as a combination of torsional/linear spring-inertia element, while rigid link would be discussed with ordinary differential equation with initial conditions. Initially, modal analysis for understanding various modes of vibration will be evaluated and graphically demonstrated.

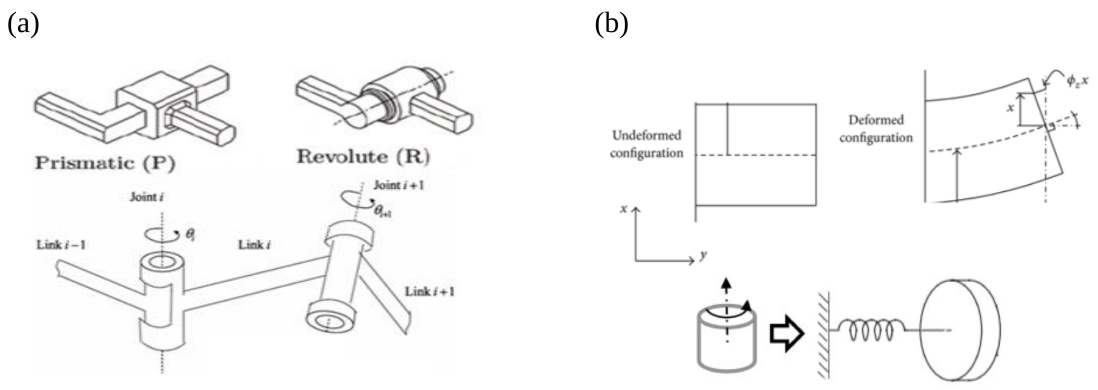


Fig. 3.15: (a) Rigid-links and joints (b) Flexible beam element

This analysis is first-rated step for analysing the trajectory planning and subsequent position accuracy. Modal analysis is inevitable to understand the robot's operating zone to avoid any behavioural uncertainties and subsequent structural damages. End-point trajectory will then be evaluated at certain mode shape. Analytically obtained results will enable a useful insight into vibration attributes associated with dynamic behaviour and operating limits under joint motion.

Task 3: Design and simulations using CAD, CFD and Graphics software

An accurate and computationally efficient dynamic model always leads to reliable design which is a foremost technical requirement for the system working repeatedly. Simulations on the developed dynamic modelling will be facilitate by using CAD, CFD and graphical visualization tools of designing, constructing and inspecting the robots in the specific application. Simulations obtained by using CAD and CFD software along with results obtained using dynamic model enable a pre-understanding operational characteristics through simulation without actually performing the real task that may further escalate the process of design and synthesis (Fig. 3.16).

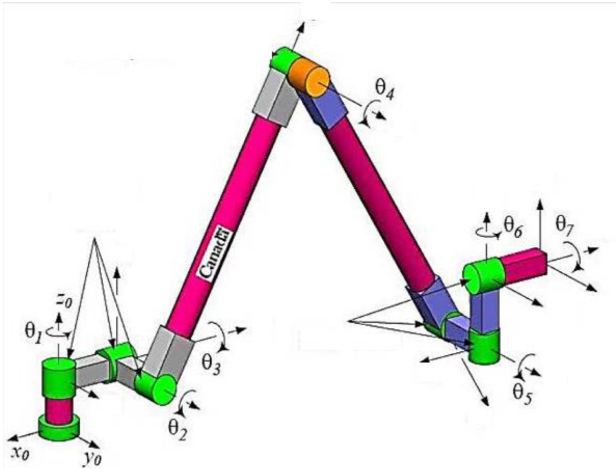


Fig. 3.16: Solid modelling for trajectory planning

Task 4: Finally, a multi-link long-reach flexible manipulator attached to moving platform will be designed and fabricated (Fig. 3.17). The developed model will be validated by comparing its prediction with that of the designed prototype of long-reach robot arms. The dynamic flexibility will be compared between the simulation and experimental runs to validate the predictions. This approach is justified since the dynamics of the system represents the important part of the model.

Fig. 3.17: Equivalent prototype models

Analysis and Development of Computational Intelligence Based Navigational Strategies for an Underwater Robotic Vehicle

Nowadays requirement for Autonomous Robots or vehicles has increased rapidly in many environments. Because of their ability to explore any in environments where human physical communication is inhibited or not possible. The underwater environment is one of an environment in which communication is the biggest challenge. Therefore underwater mobile robots are deployed in oceanic environments. The underwater mobile robots also play a vital role in the exploration and exploitation of resources in deep oceanic environments. The path planning is a major concern for underwater mobile robots. In path planning the robot has to search for a safe and shortest path in the environment to reach the target without colliding with obstacles. Enormous research has been carried out for solving the path planning strategies for Autonomous Underwater Vehicles (AUVs).

This project work proposes the analysis and development of computational intelligence based navigational methodologies for an underwater mobile robot. Our objective includes contributing to science by increasing the limit of these technologies altogether by developing new algorithms.

Objectives of proposal:

- To perform kinematic and dynamic analysis of the underwater robot.
- To develop the mathematical architecture of the Robot Path Planning.
- To develop computational intelligence-based navigational strategies.
- To validate the developed navigational strategies in real-world environment.

Expected Outcome and Outputs of the Proposal:

The developed navigational strategies will be embedded in to the physical robot and that can be deployed in many practical situations and real-time applications.

Contribution to Science:

1. 3D simulation GUI of navigation strategy.
2. Research papers on implemented methodology and results outcomes.
3. Technology transfer to various applications.
4. Training program on implemented methodology.

Applications of Robot:

1. It can be useful for inspection of an underwater structure.
2. It can be useful for locating minerals and oils in underwater environment.
3. It can be useful for military operation and unmanned manoeuvrings launch pad for missiles or as an unmanned intelligent defence system.
4. It can be useful for surveillance, an inspection of machines in radioactive affected areas.

Originality the Project Proposal:

The world’s population continues to grow at an unprecedented rate. In today world’s robotics applications are evolved in such a way that a robot can able to survey at any terrains without human intervention. Many robots are being developed but most of them are task-specific. Thus, a mobile robot that is adaptive in nature is required to increase the overall productivity in commercial success. Underwater robots have potential advantages over robots, and they have already succeeded in carrying out many tasks in an underwater environment. The underwater robot can explore into the submarine area, mine countermeasures and many more. The present target of the robot is to intelligent navigation ability so that it can take the decision autonomously. To achieve this target researches are being conducted in the field of intelligent navigation strategies, object recognition and information systems. Some navigational strategies work on a specific condition and others on local condition problems but not in global problems. Many classical methods are also employed in robot navigation strategies but the main issue is that sometimes robot gets trapped at the local minima condition. In this context, the present project is focused to analyse and develop the new navigational strategies for underwater robots with considering high accuracy in terms of safe path and obstacle avoidance.

To accomplish the proposed project, we will complete the whole project in four major phases.

(1) Kinematic and Dynamics analysis of the robot
(2) Formulation of architecture for a robot path planning
(3) Developing computational intelligence based new navigational strategies simulator by coding.
(4) Field Testing of the Robot using developed navigational strategies.

In the first phase, the kinematic and dynamic analysis will be performed to describe the expression of robot motion in the base reference frame and the robot's local reference frame. In the second phase, the architecture of the robot navigational strategy will be framed based on two primitive behaviors i.e. obstacle avoidance and target seeking. Based on the above two behaviors the objective function for navigational strategy will be formulated. The proposed objective function will be optimized using computational intelligence techniques. The obtained optimized path will be the shortest and safest path for the robot. The simple concept of navigational strategy is presented in Fig.3.18.

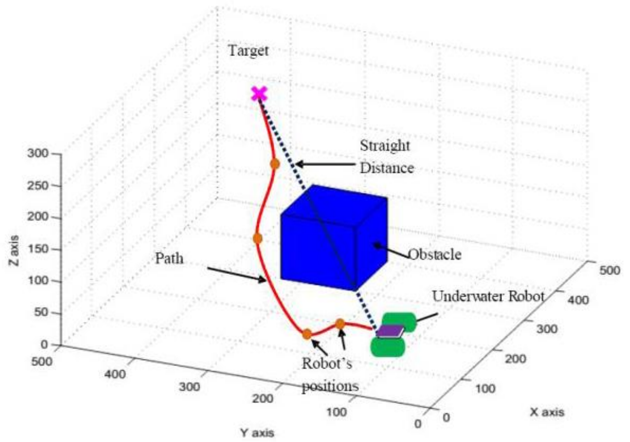


Fig. 3.18: Concept of Robot Navigation Strategy

In the last and final phases, the developed navigational strategies will be embedded into the real robot to perform experiments in underwater environments.
The proposed project will have no negative environmental impact whatsoever. Develop Computational Intelligence (CI) based navigational strategy and real-time validation is also environmentally safe in all aspects.

Design and Development of an In-Pipe Robot

Pipelines are considered to be the primary medium for the transportation of fluids such as fuels, chemicals, gas, oil, water, etc. As the rapid increase of pipe line several years, the fault detection, maintenance, and mapping technique of pipe line are essential. These requirements up lift the development of in-pipe robotic systems and some advanced inspection techniques such as visual inspection, magnetic leakage detection, eddy current inspection, ultrasonic inspection, and acoustical method etc. These methods are used for detecting corrosion, leakage and welding flaw. The variety and complexity of industrial pipe line environment accelerate the innovation of robotic system, for example, autonomous motion without cable, reliable communication between inside and outside of pipeline, long time field operation, rapid tracing, and accurate localization. There are a wide variety of pipelines such as sewage, urban gas, chemical plants, nuclear power plant etc. A number of researches have been carried out on in-pipe inspection systems, which are mainly classified into two groups, passive and active systems. The typical examples of passive systems are intelligent pigs driven by the pressure difference of fluid inside the pipelines. They have been utilized for pipelines large in diameter but are not adequate for the urban gas pipelines. The active one is the system employing robotic technologies and the proposed system belongs to the case. There are two types of pipe inspection methods. One is the in-pipe inspection method and other is the out-pipe inspection method. The in-pipe inspection method is relatively simple, because there are not many obstacles inside of the pipes and the pipe internally is usually uniform. However, in order to use this method, the pipe need to be cut or other special inlet should be established. Another drawback is that the robot can be contaminated by the materials inside of the pipe. In case of the out-pipe inspection, there are many obstacles such as pipe connection flanges, frames to fix the pipe, and other pipes, which make it difficult to design the robot mechanism, but it is simple to install and low possibility to contamination. Since decades, researchers are working on various robots that can move and manoeuvre themselves with little or no help of the person controlling the robot. Such robots that move inside the pipelines and perform various tasks are known as In-pipe Robots. These robots may have to travel long distances, horizontal and vertical pipes and curve themselves through long range of angles. For this, various locomotion mechanisms have been introduced such as wheel-type, crawlers, legged types, inchworm type, etc. Some are better in moving long distances, while some are better in manoeuvring sharp curves. There can be another type of situation, where the robot has to manoeuvre inside the pipe, but the pipes are not empty, i.e. the condition where the pipes are filled with some fluid. In such cases, where it is not possible to evacuate the fluid, the robot must be capable of thrusting through fluid inside the pipes. In such case, the robot can move with the help of thrust force i.e. using a propeller. There are various placement options for thrusters to allow varying degrees of manoeuvrability, such as, three thruster arrangement, four thruster arrangement and five thruster arrangement, etc. Manoeuvring is achieved through asymmetrical thrusting based upon thruster placement as well as varying thruster output.

The literature survey on the existing In-Pipe Robot revealed the following research problems that can be addressed by researchers:

1. Inspection and Repair of pipes from inside.
2. Solve problems of sagging, deformation, infiltration, debris, corrosion.
3. The mechanism and controller to propagating/manoeuvring the in-pipe robot inside pipes should be very adoptive in nature. Because the behaviour of surfaces (in terms of friction), varying pipe diameter, different pipe configuration (horizontal, vertical, sloppy or sharp bends), pipe diverging/converging scenario and varying fluid and its flow inside pipe are always varying in nature. One scenario may be, at some point the surface may me normal, rough or slippery in nature, that demands different amount of traction force to counter varying friction. So to address all these challenges not only a very versatile design is required, it also demands a very adaptive and advanced force controller clubbed with position control scheme.
4. Proper dynamic model is not available that incorporates all the physical challenges.

Model of In-Pipe Robot

In-Pipe robot comprises of three main parts: the propeller, universal joint and steering part. The first part comprises of the thruster and fixture to hold the guiding arms. And the last part i.e. the steering part comprises of the steering arms, one on both the sides of the base driven by a separate motor, camera with flash fixed on the head for capturing the scenario inside the pipe during inspection phase. The schematic diagram of the robot is shown in Fig. 3.19. As the robot traverses through the pipe, all the forces and torques are transferred from the end-effector to the base. The configuration of both the arms in taken as R (revolute joint) having single links.

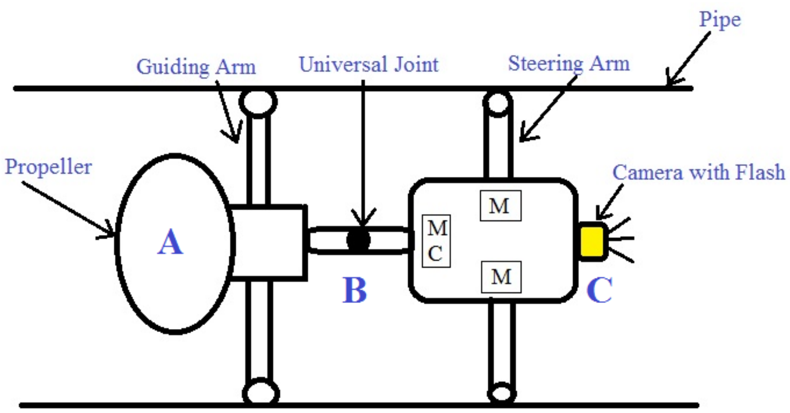


Fig. 3.19: Schematic Diagram of In-Pipe Robot
(A: Propeller and Guiding Arm, B: Universal Joint, C: Steering mechanism and Camera with Flash)

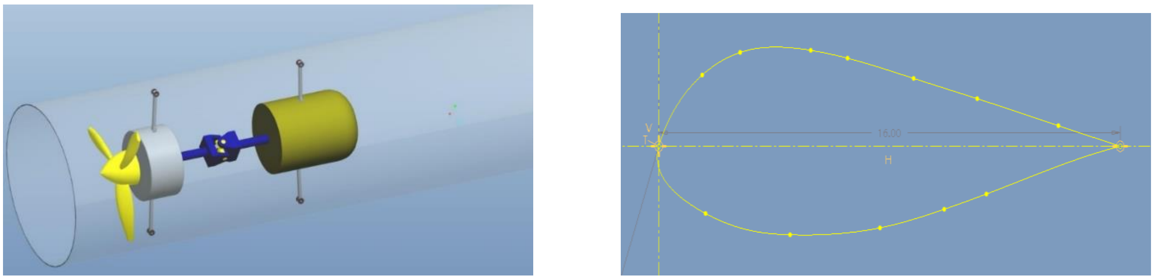


Fig. 3.20: CAD assembly of In-Pipe Robot (left) and sketch of propeller blade profile (right)

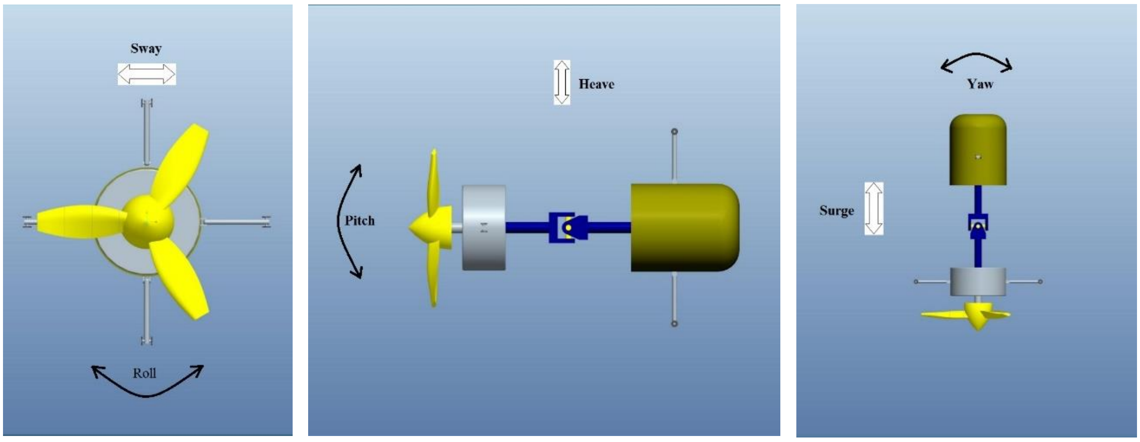


Fig. 3.21: Various possible motions of underwater thrust robot

The CAD model of the in-pipe robot is animated to show that the calculated values of torque from the simulation and results hold true and valid. Therefore, by considering some dimensions relative to the dimension of the arm (considered in kinematic and dynamic analysis) and size of the pipe, the CAD model was prepared in Pro-Engineer software as shown in Fig. 3.21. As described the model of in-pipe robots consists propeller, propeller base to support the holding arms, universal joint to accommodate during turning, a head which in the CAD model is made as a solid cylinder (considering that it contains a mass equal to the sum of sub systems fitted inside the head (such as, motors, microcontrollers, wires, etc.), which houses the electronic system of the robot and the steering arms. The Propeller blades were made by taking a section suitable for underwater vehicles. The sketch of the section or the profile of the blade is shown in the Fig. 3.20 (right). Figure 3.20 shows the various possible motions of underwater thrust robot. Figure 3.21 shows some of the captures taken of the robot while moving inside the pipe and taking turn on a curved path.

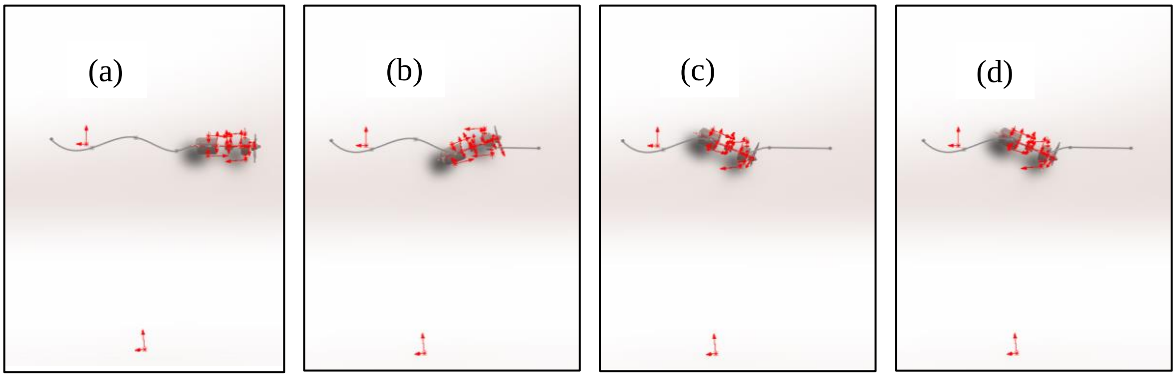


Fig. 3.21: Animation, (a) Position on a straight path, (b) Position while taking first turn, (c) Position while taking right turn and (d) Position while taking another turn

Aims and Objectives

The goals and objectives decided based on research gaps presented under heading problems to be addressed are listed below

1. Design and develop a versatile mechanism to propagate/manoeuvring inside pipes of varying surface properties (in terms of friction), varying pipe diameter, different pipe configuration (horizontal, vertical, sloppy or sharp bends), pipe diverging/converging scenario, varying fluid and its flow inside.
2. To address all these challenges not only a very versatile design is required, it also demands a very adaptive and advanced force controller clubbed with position control scheme. So the next objective is to develop an adaptive control scheme.
3. Development of a real time routing map from the position of the robot inside pipe and also incorporating the features of automatically calculating the shortest routing path and minimal energy consuming path using artificial intelligence for the In-pipe robot to maneuverer inside the pipe line if routing map is already provided.
4. Dynamic modelling of the proposed in-pipe robot on the simulation platform will be addressed to visualize the exact performance and behaviour of the proposed mechanism and control law.
5. Finally, mechanical design (prototype) of robot components and system integration will be done.

Strategy

The work plan strategy is divided into following stages as described below-

Stage 1 Concept Development: Conceptualization of idea and CAD model of the mechanism of In-Pipe Robot with its potential applications in various domain.

Stage 2 Mathematical Modelling: Development of proper kinematic and dynamic model to mathematically interrelate it with the proposed robot. Furthermore, the appropriate controller will be designed to meet the desired performance criteria.

Step 3 Trajectory Tracking: To plan for trajectory tracking of the underwater robot.

Step 4 Real time data logging and data interpretation using artificial intelligence: Development of a real time routing map from the position of In-pipe robot inside pipe and also incorporating the features of automatically calculating the shortest routing path and minimal energy consumption path using artificial intelligence for the In-pipe robot to maneuverer inside the pipe line if routing map is already provided.

Step 5 Hardware Design and System Integration: Develop the In-pipe robot hardware to validate the above concepts is the next objective. Selection of proper material, dimensions and fatigue-related properties will be done. Further component assembly, installation, electrical wiring and mechanical connection, performance Validation of proof of concept and hardware in loop simulation will be done at this stage.

Stage 6 Evaluation and Validation: Under this the test, evaluation, initial operation, documentation and reporting issues will be addressed at this stage. Finally, validation of the desired properties of the real machine and test operation on the desired application task will be the final objective.

Target_beneficiaries (500 words) [Elaborate on your proposed research objectives societal impact, national level consequences. Name 5 companies who may be interested. Are you in contact with any/all of them?]

Societal Impact: The proposed In-pipe robot has a very positive and improvised impact on society. The tasks of navigation, inspection and repair inside the industrial pipelines and nuclear reactor pipes will be possible with the proposed technological advancement. Also, with the incorporation of artificial intelligence and real time data interpretation, versatility in usage of robot will be guaranteed. Finally, with the incorporation of robot eye (vision system), the artificial intelligence will increase the robot’s capability to deal with its environment in a safer way.

National Level Consequences: The In-pipe robot can perform various tasks as listed below

- Navigation, inspection and repair inside the industrial pipelines and nuclear reactor pipes lines.
- Structural health monitoring of the pipe lines.
- Real time data interpretation and automatically generating pipeline routing.

And special focus is put on utilizing these advantages of In-pipe robot so that these robots will have national level consequences.

Interested Companies:

1. NTPC (National Thermal Power Corporation)
2. BARC (Bhabha Atomic Research Center)
3. GAIL (Gas Authority of India Limited)
4. Beverage producing Industries
5. Chemical plants
6. Amul

BARC has shown interest in the project.

Development and Analysis of Intelligent Integrated Water Habitat Robot for Surveillance, Monitoring and Cleaning

The remote/Intelligent integrated Water Habitat Robot (WHR) will gather data using various sensors (e.g. under water sonar sensor, Image sensor, Touch sensor, Gyro Sensor, Accelerometer Magnetic Sensor and DVL), mounted on the robot. The robot will be self-controlled and will perform the task as per the outlined customized application. In the project development and analysis of Intelligent Integrated water habitat robot will be carried out. The water habitat intelligent robot has got floating robotic part and under water robotic part (Fig.3.22). The robot will be used for surveillance and monitoring purpose under water and also for cleaning of trashes on the surface of the water. The floating robotic part of WHR will be used for collecting trashes on the water. The underwater robotic part of WHR will be used for surveillance of underwater creatures, underwater flora and fauna. The WHR can be used for surveillance of various coastal areas, seas, ponds, rivers and monitoring of various equipment under heavy water.

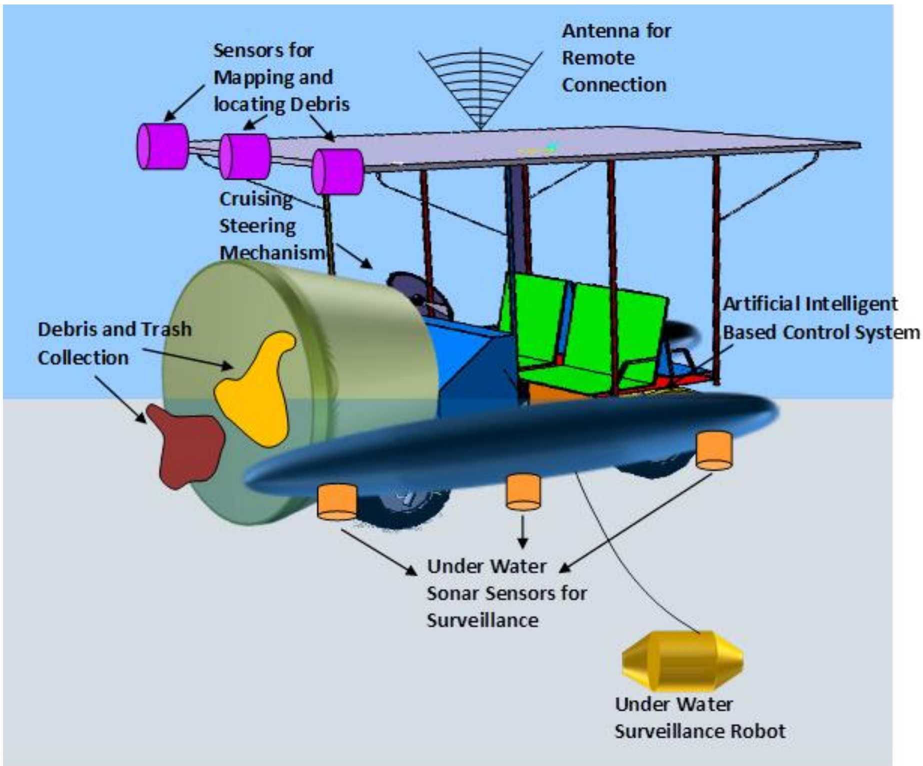


Fig. 3.22: CAD Model of Intelligent Integrated WATER HABITAT ROBOT for Surveillance, Monitoring and Cleaning

Applications and Deliverables:

The Water Habitat Robot with the help of the sensors can do surveillance and online monitoring and cleaning of various water bodies (such as ponds, rivers, coastal areas and seas).

Hence the Deliverables from the project are as follows.

- An Embedded Sensor Based Integrated Water Habitat Robot (WHR).
- A floating intelligent robotic part of WHR for cleaning purpose.
- An underwater intelligent robotic part of WHR for surveillance and monitoring purpose of various water bodies.
- An underwater intelligent robotic part of WHR can be used for surveillance and monitoring purpose of various equipment under heavy water (D_2O).

Target Beneficiaries: BARC, DAE, Govt. of India:

Development of an underwater Remotely Operated Vehicle (ROV) for bathymetric and water quality-based assessment of Barak River

The geographical location of Assam has made the goods transportation through road and rail costlier. The inland transport via Bangladesh will be comparatively cheaper. However, the current depth of the river Barak does not allow the entry of big ships. The bathymetric study of the river Barak may be a prerequisite for a successful dredging operation. Erosion of river banks is another serious issue. Monitoring of underwater river bank status may be helpful for proper planning to arrest erosion.

Flood is a regular phenomenon in Assam. The rise of a river bed may be one of the causes. The repeated bathymetric study of a particular location will be helpful to know the rate of rising of the river bed. During an emergency, an ROV fitted with a camera will be beneficial for rescue operations. One of the 17 sustainable developments demands clear water. The river is the primary source of water. Thus, maintaining the water quality of river water is of utmost importance. Many industries discharge their effluent, after treatment, to rivers. Water quality at the intake and discharge points may help to find the quality of effluent treatment.

Fish is a vital non-vegetarian dish in this region. The demand has been increasing. The fish production in the available water bodies needs to be increased to meet the demand locally. Proper monitoring and control of the required environment may be helpful for the fast growth of fish.

Aims and Objectives

The aim is to develop underwater research vehicles for a bathymetric survey of a river and monitoring of fish development in a closed environment. This fits with the objective of the hub to develop applied research on technologies for underwater exploration. The objective is "To develop an underwater Remotely Operated Vehicle (ROV) for bathymetric and water quality-based assessment of Barak River"

<u>Comprehensive analysis of the existing knowledge</u>

International status: Several commercial autonomous underwater vehicles (AUV) and Remotely Operated Vehicles (ROV) are available in the market internationally, thanks to the company like Oceaneering [#6], Hydroid etc. Oceaneering leads the market with Ocean Surveyor AUVs and their AUV pipeline inspection capabilities incorporate state-of-the-art laser micro bathymetry systems. In January 2015, the famous Savannah Harbor Expansion Project (SHEP) began to deepen the Savannah Harbor federal shipping channel to allow access to larger shipping vessels [35]. Before the project started, the water quality and bathymetric data were measured using an AUV in the study area near Hutchinson Island. Similar examples of environmental monitoring using underwater robots are abundant in the literature.

National status: Marine and Coastal Survey Division [M & CSD] of Geological Survey of India (GSI) has started coastal and marine surveys in a minuscule manner way back in the early nineteen seventies by survey and mapping of selected parts of coastal waters using country boats and other small fishing crafts [#7]. With the acquisition of one ocean-going vessel **R.V. Samudra Manthan** in 1983, 2 coastal launches **R.V. Samudra Kaustubh** and **R.V. Samudra Shaudhikama** in 1984 and **Remotely Operated Underwater robots**, GSI commenced a systematic survey of the sea bed within Exclusive Economic Zone (EEZ). The seabed mapping and environmental monitoring of GSI have led to the discovery of REE and many important minerals along the coastline of India. Also, institutions of national importance like CMERI, Durgapur, NIOT, Chennai, NIO, Goa, and various academic institutions have developed underwater vehicles for various purposes over the last two decades. However, river water quality assessment in India using underwater robots is still a dream to realise.

Statements of challenging problems

a) Design, development, control and real file implementation of a working prototype to meet the objective are challenging.
b) Calculation of hydrodynamic parameters relevant to the individual designs for modelling and precise control purpose are essential. Specific testing equipment and arrangements are required for this purpose. Without the hydrodynamic parameters, implementation of the controllers in the hardware setup is very difficult.
c) The post-processing of the data to collect the information is a challenging task.

Target Beneficiaries

a) Government of Assam, Fishery, Directorate of Fisheries
b) Government Of Assam Revenue & Disaster Management Assam
c) Government of Assam Water Resources

Design, Analysis and Development of a Low Cost Underwater Vehicle (Mini Submarine) for (a) Tourism Purpose and (b) Bio-fouling cleaning

It is aimed at designing and developing manned underwater vehicles (mini submarine) for (a) tourism purpose and (b) Bio-fouling cleaning. The following problems would be addressed:

- Design, analysis and manufacturing of an underwater vehicle.
- Identify materials for under water structures.
- Address the leakage problems in underwater vehicles.
- Fabrication and testing of vehicle.
- Identify the interested startup companies for possible business.
- Transfer of Technology to the prospective startup companies.

Methodology:

(i) Pre-design of underwater vehicle
(ii) Modification of the pre-designed vehicle
(iii) Structural analysis

(iv) Detailed design, planning and final drawing
(v) Model testing
(vi) Final product Manufacturing & testing

Expected deliverables within next 12 months

1. A mini submarine for tourism purpose

Design and development of passive high-static-low-dynamic stiffness (HSLDS) vibration isolators for underwater vehicles

Most of the vibration problems in underwater vehicles and surface ships occur in low-frequency region especially due to the low speed of engine around 10-20 Hz. Unlike the high frequency vibration, the low-frequency vibration in underwater vehicles propagates over a large distance from the source where also large-amplitude vibration arises. So, a large domain of hull is subjected to large-amplitude vibration, and thus a marine structure is vulnerable to dynamic instability and/or fatigue failure. Moreover, the built-in delicate equipment at a far distance from the source of vibration is also affected from low-frequency and high-amplitude vibration. It causes improper functionality or failure of built-in equipment. Apart from these detrimental effects, the structure-borne low-frequency noise in an underwater vehicle affects the human comfort like headaches, unusual tiredness, lack of concentration and pressure on the eardrum. Therefore, the isolation of low-frequency vibration transmitting from the engine to hull is an essential demand.

In view of this demand, the commonly known rubber vibration isolators may be used, but they are incapable of providing a good transmissibility at the low-frequency vibration as the rubber isolators have poor low-frequency anti-vibration performance. The alternatives are the active vibration isolators that can fruitfully be used for low-frequency vibration isolation in underwater vehicles. However, an active vibration isolator needs complex arrangement of its components like actuators, sensors, controller, etc. These components also need the external power supply. Moreover, active vibration isolators are expensive and less reliable. On having these disadvantages, one would prefer passive vibration isolators with the high-static-low-dynamic stiffness (HSLDS) properties. Unlike the conventional passive rubber isolators, the passive HSLDS isolators are capable of supporting high dead mass/static load along with the natural frequency in the low-frequency region. It is also possible to achieve the natural frequency of HSLDS isolators in the ultra-low frequency range. HSLDS isolators have many advantages like low cost, reliable functionality, compact configuration, simplicity in installation and durability. However, it is a relatively new technology in the past ten years and not yet fully developed in the scale of industrial product. In view of this scenario, the aim of this project is to develop a product of rubber-based low-frequency HSLDS isolator mount that will be utilized for low-frequency vibration isolation in underwater vehicles.

Objectives

Among the different products of rubber vibration isolator, AKCC mount is mostly used one for vibration isolation in submarines and surface ships. However, as the information obtained from a DRDO Laboratory, this vibration isolation mount works well above 25 Hz while the maximum frequency limit is 50 Hz. But, the vibration problems in submarines commonly appear starting from a frequency about 10 Hz. There is no other available product of similar rubber vibration isolator mount that can be used in the aforesaid low frequency range. So, the main objective of this project is to develop a product of rubber vibration isolator mount based on the HSLDS technology, where the vibration isolation would start at the frequency about 10 Hz. This product will be developed with the following target specifications, in particular, for its (present product) use in submarines.

(a) Dimensions: Length-12 cm, Width-12 cm, Height- 10 cm.
(b) Weight of isolator mount: 2-4 Kg
(c) Load capacity: 20 kg - 300 Kg
(d) Vibration isolation frequency: above 10 Hz (up to 50 Hz)
(e) Isolation efficiency: 10-20 dB/decade
(f) Rubber material: Neoprene/Nitrile (for sea environment)
(g) Metal components in the isolator mount: Steel/Aluminium
(h) Mounting mechanism: Steel/Aluminium plate with the provision of screws for fixing load.

According to this specification, the proposed product can potentially replace the AKCC mount because of the main advantage of low frequency vibration isolation starting from 10 Hz. Some potential users of this new product may be noted as Indian Navy, DRDO and other stakeholders concerned with the underwater vehicle development.

Methodology

For the development of the proposed product of rubber HSLDS isolator mount, the work methodology is detailed in the following steps.

(1) Selection of Neoprene/Nitrile rubber compound with a suitable composition especially for environmental condition in marine applications.
(2) Material characterization of rubbers through DMA test, creep test and compression-set test.
(3) Design of a special geometrical shape of rubber part of the vibration isolator to achieve HSLDS characteristic that leads to the low natural frequency of the isolator system. This

design will be carried out through finite element modelling and analysis of the isolator system.

(4) Optimization of the HSLDS isolators for the aforesaid range of load capacity.

(5) Fabrication of the rubber part of the HSLDS isolator through die preparation and compression moulding.

(6) Assembly of the rubber and metal parts of the HSLDS isolator.

(7) Vibration test of the rubber HSLDS isolator for the experimental study on its transmissibility as well as natural frequency.

Expected outcomes/deliverables

(1) A rubber HSLDS isolator mount for different load ratings at the low-frequency range (10-50 Hz).

(2) Detailed report on the technology development.

(3) Patent filing for the technology developed.

(4) Training to the M. Tech and PhD scholars in the field.

Ergonomic evaluation of the human-robot control interface and suggestions for improvement of usability

Robots or autonomous systems are ultimately controlled by human-being by their direct or indirect inputs through different control-interfaces. Human-Robot control interfaces are broadly categorized as (a) Physical human–robot interaction, and (b) Virtual human-robot interaction. Physical human–robot interactions involve physical controls (buttons, switches, joysticks etc.), haptic devices (Phantom arm), gesture based control interface, exoskeleton and wearable robots, etc. Similarly, virtual human-robot interactions involve wearable haptic interaction control, voice/ speech based interface, eye-movement based control interface, electro-biological signals (EEG, EMG), virtual reality devices, etc. Ergonomic design of the controls and displays are a common research topic in human-machine interaction. Plenty of research papers are available for user-centric design of human-machine interface. With the advancement of technology, various research work has been carried out all over the globe for sophisticated or advanced control/ display design for better control of robotic devices/ autonomous systems. Majority of these researches are mainly focused on incorporation of advanced technology to achieve the superior functionality or execution of the robotic operations. Sometimes, it is not easy to select a specific type of control that is suitable for the requirements of varied kinds of robots along with ensuring the user's convenience (Tang and Webb, 2018). To measure users' convenience, ergonomic evaluation of the human-robot control interface is very much essential (Cotter, 2014; Zang et al., 2016). The ergonomic evaluation of such interface involves postural analysis, anthropometry, biomechanics, usability, motion stereotypes and so on (Berg and Lu 2020). Ergonomic evaluation and thereby design improvements of the interface of any robot or any other autonomous/ unmanned system are of utmost necessity for ease and efficient operation by the human operators. Usability evaluations have been conducted in design of e-retailer websites (Falcão & Soares, 2013, Razza & Paschoarelli, 2015), furniture (Thamrin, & Mulyono, 2018), automobile (Bellet et al. 2021), etc. but rarely any study has been conducted for human-robot control interface. In today's scenario, technologically advanced controls/ displays are being designed for human-robot control interface from the perspective of functionality but it is lagging behind in terms of usability. Successful design of human-robot control interface design would be possible through appropriate application of ergonomic principles from the very beginning of the interface design. Users'/ operators' capabilities and limitations (both physical and cognitive) are needed to be taken in to due consideration for developing user-compatible interface design. In the context of under-water robotic explorations, there is dearth of research on human-centric or user-friendly design of human-robot control interface. Hence, it is the need of the hour to conduct pro-active ergonomic evaluation of the human-robot or any other human-autonomous system with due consideration of users' physical (anthropometry, biomechanics, behavioral aspects, etc.) as well as mental characteristics (cognitive demand/ workload, attention, memory etc.).

Aim: Evaluation of human-robot control interfaces from usability perspective and come-up with suggestions for ensuring a safe, comfortable, and intuitive interactions for robotic manipulations/ operations.

Objectives:

- To study the existing human-robot control interfaces and their advantages/ disadvantages
- To study the available standards/ guidelines of human-robot control interfaces
- To evaluate the control interfaces of the different robots/ robotic applications developed by the investigators under TIH-IIT Guwahati
- To recommend design improvement of the human-robot control interfaces from ergonomics and usability perspective
- Re-evaluation of the modified/ redesigned interfaces

Methodology:

The methodology to be followed for the proposed research has been described through the schematic diagram as shown in Fig. 3.23.

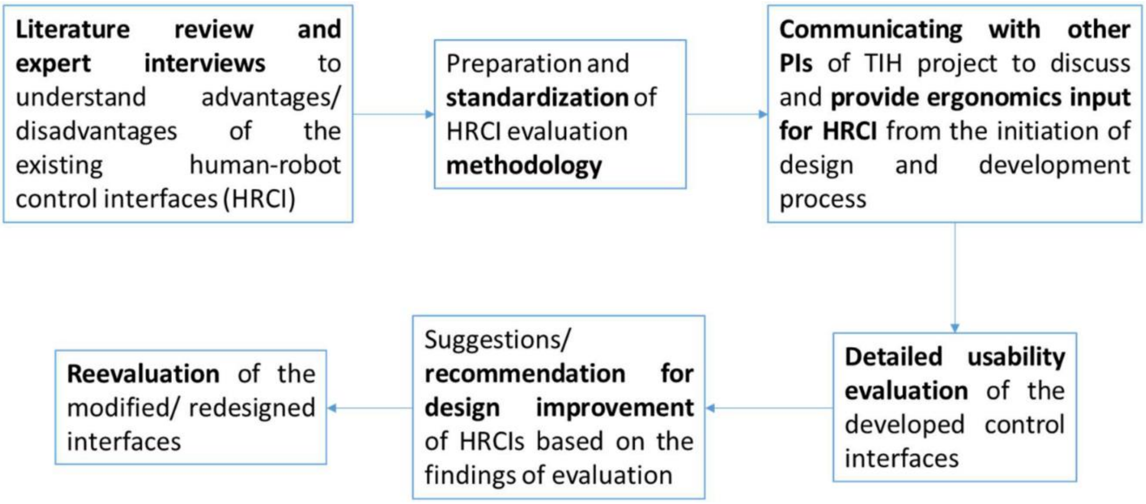


Fig. 3.23: Brief outline of the methodology to achieve the research objectives

The usability evaluation of the control interface would be done by considering following aspects:

(a) Anthropocentric and bio-mechanical compatibility (both real human trial and CAD based)

(b) Principles of control-display design,

(c) Population stereotypes,

(d) Compliance with the existing standard/ guidelines

(e) Usability evaluation (System Usability Scale)

(f) Cognitive workload evaluation

(g) Evaluation of perceived comfort during interaction with human-robot control interface

(h) Evaluation of muscular fatigue during control operation

Job Creation Methodology:

Direct recruitment of the individual is beyond the scope of the project proposal as the proposal is related to ergonomic evaluation. Workshop and training program will be conducted for developing skilled man-power (Masters students and Research scholars) for designing better human-robot control interface for under-water robotics application.

Deliverables:

- Usability evaluation of the human-robot control interfaces for different underwater RoVs developed by other teams under this TIH at IIT Guwahati. The proposed ergonomic evaluation would help in identifying the scope for design interventions and providing suggestions for improvement of ergonomics and usability aspects based on the requirement.
- Evaluation of occupant packaging of the operators/ drivers (helmsman and planesman) as well as passengers for submarine (used for tourism purpose) developed by the other team.
- Developing design guidelines/ framework for developing user-friendly human-robot control interfaces

Targeted Beneficiaries:

All the PIs/ team members who are going to develop under water RoVs/ flexible manipulator or Submarine for diverse applications will be benefitted from the proposed research. Their developed human-robot control interface (on any other control-display interface) will be evaluated from usability perspectives and accordingly suggestions will be given for implementation of required modifications/ changes for improvement. The overall evaluation and thereby design modification will ensure better human-robot/ machine.

3.2.3 Underwater Electronics & Powering

In this secondary area following work packages are identified:

1. Design and development of a digital holographic microscopic imaging system for detection and recognition of underwater microorganisms and particles
2. Real-time Scour Monitoring using accelerometers and energy harvesters

The scope, and outcome of these work packages are described in detail in the subsequent sections:

Design and Development of a Digital Holographic Microscopic Imaging System for Detection and Recognition of Underwater Microorganisms and Particles

Introduction:

Aquatic samples collected from different depths of water bodies (ponds, lakes, rivers or the sea) contain a heterogeneous mixture of microorganisms and particles. Analysis of such aquatic samples are of interest to different stake holders. Such aquatic sample analysis applications involve (a) detection and identification of different microorganisms (biologists) (Sun et al. (2008), Watson et al. (2001), Watson (2001), Moon and Javidi (2017)); (b) characterization of suspended sediments in river flow (geologists); (c) quantification of aquatic pollution through detection of contaminants like carbon particles, oil droplets, colloidal spheres, microplastics [4] etc. (environmentalists).

Identification and quantification of microorganisms or particles in homogeneous or heterogeneous fluids is a challenging problem. Microorganisms of different shapes, sizes and opacity pose challenges to imaging devices. Nowadays, water pollution is found to be having wide ranging implications on environment and consequently on public health. Plastics entering water bodies disintegrate into microplastics. These microplastics are an emerging threat to the aquatic environment (Bianco et al. (2019) and (Philips (2017)). Identification and categorization of these water pollutants is key for pollution control of such water bodies. The extent of pollution can be characterized by analysing the suspended contaminants (Dyomin (2018)). Such contaminants range from colloidal spheres, oil droplets, microplastics to carbon particles.

Traditional approaches to this problem involve conventional microscopic systems followed by manual or computer aided analysis. However, such analysis is often challenged by the intensity appearances of different kinds of samples. For example, micro air bubbles are transparent and hard to detect through such analysis. Thus, use of only intensity amplitudes limit the deployment of conventional microscopes in certain applications. On the other hand, Digital Holographic Microscopic (DHM) systems provide both amplitude and phase information of samples under analysis. The phase provides additional information that aids in identifying samples which are otherwise hard to detect using conventional microscopic imaging. This is demonstrated in (Bianco et al. (2019)) where fusion of intensity amplitude and phase has shown performance improvements of up to 38% in detection of microplastics and diatoms in aquatic samples. Recently, machine learning algorithms have been employed for the automatic identification and classification of specimens in the holographic images (Nguyen, et al. (2017), Memmolo et al. (2019) and Jo et al. (2017)).

Problems to be addressed:

The use of microscopes is imperative in the study of microorganisms and micron-sized particles. However, there are some limitations associated with the conventional microscopes are routinely used for this purpose. A) In order to image such small size objects, some form of tagging/labelling is required in most situations especially for bio-specimens. Such form of tagging can bring undesirable changes in the very properties of the objects we are interested in measuring; B) From the practical point of view, the conventional microscopes mainly involve manual focusing of images which is subjective in nature; C) Transparent objects are difficult to visualize. Phase contrast microscope needs to be used for such objects; D) In general, conventional microscopes provide only qualitative information on the object.

The DHM system, on the other hand, offers some unique features which overcome the limitations associated with the conventional microscopes. For example, the DHM involves label-free imaging. The image focusing is entirely numerical and therefore, the DHM provides a unique feature for imaging different sample depths from a single recording of the hologram without any need of moving components. In addition, since both amplitude and phase imaging is possible with DHM system, the setup can be used for imaging opaque or transparent objects. Thus, it can be believed that DHM based imaging will be able provide information on the underwater environments which hitherto was not possible.

Objectives:

The objectives of the proposed project are outlined as follows: A) Design and development of digital holographic off-axis microscopic system for the simultaneous recording of intensity and phase images; B) Optimal experimental parameter identification for the purpose of transferring the optical setup into deployable product form; C) Algorithm development and implementation for numerical reconstruction of digital holograms, phase unwrapping, object focal plane detection in 3-D space; D)Intensity and phase image segmentation and classification E) Experimental validation of the holographic microscopic for benchmarking against state-of-the art imaging techniques; F) Practical performance verification of the developed system for detection & recognition of microorganisms and particles in marine water samples; G) Generation of tagged dataset of microorganism & particles

Strategy:

Our proposal aims at the design and development of a DHM System for detection and recognition of underwater microorganisms and particles. This proposal has two main product deliverables. First, a portable Digital Holographic Microscope. Second, a holographic image analysis system capable of hologram reconstruction, machine learning based target detection for heterogeneous sample analysis. Additionally, the proposal also aims to build up an open source tagged dataset of holographic images of microorganisms and particles for the research community. Interestingly, if the developed DHM system proves to be robust enough, a submersible system can be developed in future for in-situ recording of holograms.

Target Beneficiaries: The proposed system is relevant to applications in the following domains:

- **Marine Biology** - The DHM imaging technique is equipped with desirable features such as non-invasive, non-contact, label-free and simultaneous recording of amplitude and phase images. These features will be of key interest to marine biologist to have comprehensive database of biodiversity in different water-basins across the nation. This data in association with the measurements of physical parameters such as pressure, temperature will be able to provide significant information on the effects of these parameters on the microorganisms.
- **Environmental Science –** The deployment of DHM system for water sample microscopic imaging can allow us to obtain important information on the water pollutants. The segmentation and classification of data allow us to quantitatively measure the extent of water pollution. It will allow us to take appropriate measures for reducing water pollution. Thus, the DHM system can be important part of feedback mechanism.

A comprehensive and simultaneous study on the underwater microorganisms and micro-pollutants can lead to better understanding on their mutual relationship.

Technology with suitable schematic diagram:

The schematic of Digital Holographic Microscopic setup with off-axis configuration is shown in Fig. 3.24. A coherence laser light source is divided into two beams, *reference beam and object beam*, using a beam splitter. The reference beam reaches to the CCD plane without any disturbance, whereas, the object beam passes through the microscopic slide or microfluidic channel and it is collected by a microscope object. The object beam also travels to the CCD plane where it interferes with the reference beam to create an interference pattern.

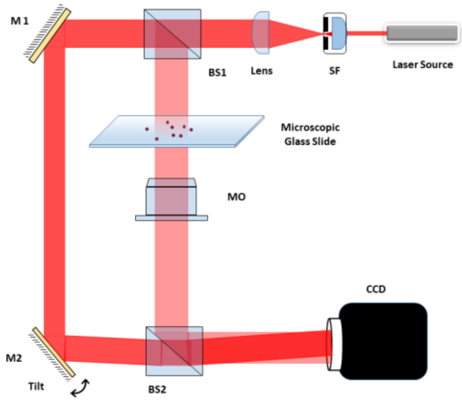


Fig. 3.24: Digital Holographic Microscopic setup with off-axis configuration.

The intensity of this interference pattern is recorded as *hologram*. This optically recorded hologram is numerically reconstructed in a computer based on the experimental parameters such as wavelength of the light source, object to camera distance, pixel pitch, hologram size, etc. The reconstructed optical field provides the amplitude (intensity) and phase images of the object under investigation. A tilt applied to mirror 2 (M2) placed on the path of reference beam allows to add required carrier frequency in the hologram recording. The numerical reconstruction basically simulates the process of optical hologram recording by multiplying the recorded hologram with numerical reference beam and propagating the computed wave field to the object plane based on Fresnel diffraction integral.

Brief methodology:

The methodology of project execution is described briefly in the following:

W1: Capital Equipment Purchase (PS-Y1.0)**; W2:** Manpower Recruitment (PS-Y1.0)**; W3:** Literature Review for Updates from Research Community (PS-Y4.5)**; W4:** Sample Collection, Manual Analysis & Tagging for Database Construction (Y0.5-Y4.5)**; W5:** Design of Digital Holographic Off-Axis Microscope (Y1.0-2.0)**; W6:** Power System Design of DHM (Y2.0-3.0)**; W7:** Algorithm Design for Numerical Reconstruction of Digital Hologram, Phase Unwrapping and Object Focal Plane Detection in 3D Space (Y0.5 – Y1.5)**; W8:** Algorithm Design for Intensity and Phase Image Segmentation (Y1.0 - Y2.5)**; W9:** Algorithm Design for

Holographic Image Feature Extraction and Visualization (Y1.0 – Y2.5)**; W10:** Algorithm Design for Target Detection & Recognition in Holographic Images (Y1.0– Y3)**; W11:** Algorithm Design for Sample Analytics Report Generation (Y3-Y3.5)**; W12:** Software Architecture Design for Digital Holographic Image Processing & Analysis (Y3-Y3.5); **W13:** Integration of DHM Imaging System and Power Module (Y4-Y5)**; W14:** Development of DHM Image Processing & Analysis Software (Y4-Y5)**; W15:** Field Deployment, Testing & Tuning of Proposed DHM Imaging System Hardware & Software (Y5.0 - PE)**.**

Risk analysis: The risks in the proposed project are associated with uncertainties in acquisition of underwater samples, quality of sample ground truth and their effect on detection performance, deviation of optical components from their specifications, unidentified effects on the system performance of environmental disturbances such as vibrations, temperature variations, etc.

Outcomes: The proposed study has the following projected outcomes:

1. **Hardware Product:** A Portable Digital Holographic Microscopic Imaging System
2. **Software Product:** A System for Digital Hologram Processing and Detection & Recognition of Microorganisms and Particles in Holographic Images
3. **Database:** An Open Source Tagged Dataset of Holographic Images of Microorganisms & Particles.
4. **Patents & Publications**

Evaluation: The detection performance of the proposed DHM system will be evaluated by using the ground truth marked aquatic samples. The performance of the hardware product will be benchmarked against commercially available DHM system and will be validated by consultants.

3.2.4 Underwater Tourism

In this secondary area following work packages are identified:

1. Study of Underwater Heritage
2. Boosting underwater tourism by 3D printed coral reef & Sustainable technologies for underwater tourism

The scope, and outcome of these work packages are described in detail in the subsequent sections:

Study of Underwater Heritage

The following points will be considered while study the underwater heritage system:

1. Digital Restoration and Reconstruction of underwater archaeological structures
2. Generating and Rendering Virtual Model of underwater archaeological structures
3. Recreating underwater archaeological structures in Augmented Reality
4. Development of framework for imaging, restoring and archiving of underwater inscription and manuscript
5. Virtual immersion in under water heritage
6. Underwater Image processing and Computer Vision
7. Intelligent data analytics architecture for the Internet of Underwater Things
8. Intelligent Control Algorithm and Dynamic Management Scheme for Underwater IoT Applications
9. Future Intelligent Underwater Network and System Architectures
10. Artificial Life and Swarm Intelligence for Underwater Applications
11. Intelligent Learning approaches for modeling of Internet of Underwater Things applications
12. AI and Big data analytics for Internet of Underwater Things
13. A Study of Intelligent Techniques for Control of Underwater Disasters
14. Intelligent prediction models for the near-future Internet of Underwater Things
15. AI Technology for Underwater Robots
16. Intelligent Search and Optimization Methods in Underwater Applications
17. Recent Advances in Intelligent Data Analytics and Internet of Underwater Things
18. Privacy-Preserving and Security Approaches for Intelligent Data Analytics
19. Intelligent Sensing, Data Interpretation, and Interpretation of Data from Multiple IoUT Sources
20. Visual inspection, ultrasonic thickness measurements, spot bio-fouling cleaning, acoustic surveys

Boosting underwater tourism by 3D printed coral reef

A coral reef is an underwater ecosystem characterized by reef-building corals. They occupy less than one percent of the ocean floor, yet it provides shelter to more than a quarter of all marine species and over 4000 species of fish make their home in coral reefs. With a global economic value of $375 billion a year, coral reefs provide food and resources for more than

500 million people in over 100 countries and territories (*web ref 29*). But tragically, coral reefs are in crisis.

Problem statement

Coral reefs are formed when each individual stony coral organism (or polyp) secretes a skeleton of calcium carbonate (limestone). Many stony corals of 1-3 mm diameter grow on top of the limestone and eventually forming massive reefs. Under favorable condition (clear and shallow water and water temperatures must ideally remain between 23˚ and 29˚ C), some species can grow as much as 4.5 centimeters (1.8 inches) per year.

Coral reefs provide us with food, construction materials (limestone) and many new medicines related to cancer drug research. Reefs offer shoreline protection, maintain water quality and draw tourist's attractions (*web ref 30*). Losing the coral reefs would have profound social and economic impacts on many countries including India that depend on coral reefs for their livelihoods. Coral reefs are endangered by a variety of factors, including natural phenomena such as hurricanes, local threats such as overfishing, destructive fishing techniques, coastal development, pollution, and careless tourism; and the global effects of climate change such as warming seas and increasing levels of CO_2 in the water. According to Reefs at Risk Revisited, a report by the World Resources Institute, 75 percent of the world's coral reefs are at risk and unless it restored, 90 percent of coral reefs will be in danger by 2030, and nearly all of them by 2050 (*web ref 31*)

Restoration of coral reefs involves a challenging rehabilitation intervention in a complex ecosystem (Allahgholi (2014)). Computer-aided design, as a tool to model and design reef like structures have been explored since the global crisis found impetus earlier this decade (Erioli and Zomparelli (2012)). However, it was architect, Enrico Dini, who the pioneered to use 3D printed structures for underwater use. Over time, though artificial printed structures have been explored as application in oceanography (Gutierrez-Heredia et al. (2016) and Mohammed (2016)) and studies are being conducted to assess the effectiveness of the same to attract habitation (Pérez-Pagán and Mercado-Molina (2018) and Ruhl (2018)), the long-term impacts of such structures are yet to be well understood, particularly from the perspective of the sustainability of the natural marine environment, beyond the marine life inhabiting it. As each ocean floor has distinct geographical and temporal behaviour, it requires specific design intervention and implementation strategies that complement the regional or national capabilities and priorities. But most importantly, any solution must be sustainable, and hence requires lifecycle planning and long-term assessment and monitoring.

Thus, this proposal aims to develop a technologically advanced, sustainable solution to boost the underwater ecosystems through the 3D printing of novel biomimetic reef structure.

Objective and scope

3D printing of new coral reefs could be a great step towards restoring under ecosystem. The main objective of the project is divided into three work packages (WP) as follows:

WP1:

- To develop a large-scale 3D printing system
- To design a novel extruder for printing fast setting material
- To formulate 3D printable materials with improved durability in marine environment
- To develop concrete or similar materials that mimic the porosity and texture of reefs

WP2:

- To design a novel reef structure that emulates a natural reef, so as to attract fish and other marine life, and is environmentally benign for the ecosystem.
- To prototype and test several concepts through simulation, that meets the above goals and supports the capabilities of the proposed large-scale 3D printing system
- To model the information and eventual performance of proposed reef structure

WP3:

- To conduct lifecycle assessment, with LCA, of the existing ecosystem as a benchmark for the proposed novel printed structure
- To devise lifecycle planning strategies and assessment for the proposed novel printed structure
- To study the long-term benefits and overall sustainability of the proposed structure with respect to the ecosystem and

WP1: In this WP, a large-scale 3D printing system will be developed to print a novel reef structure. This printer can print 3D structures of 5 m^3 volume using extrudable building material. To fulfill the objectives, a new extruder will be developed that can alter material properties at nozzle and the material should mimic porosity and texture of reefs.

In the initial stage, a small 3D printer will be used to print prototype structure and later on, the structure can be printed in 1:1 scale for field testing. The material strength optimization and durability of this structure will also be studied in this WP considering marine environment conditions.

WP2: In WP 2, a biomimetic architectural design of the novel reef structure will be conceptualised, embodied, prototyped, tested, and eventually produced/ 3D printed using the above mentioned large-scale 3D printing system. The design of the novel reef structure will consist of two broad stages: ***problem-identification*** to generate crisp requirements for the design, and ***solution-finding*** to suit the overall goal of boosting underwater ecosystem as well as supporting the cutting edge technology of 3D printing. To identify the problems and challenges, in-depth research and site study is required to; (i) concretely gather the important aspects of natural reefs that must be retained and emulated, (ii) understand the site conditions and challenges; (iii) simulate the same for laboratory testing of concepts and prototypes; and (iv) explore architectural design methods and structural engineering techniques that may be of use for the design of the novel reef structure. During the solution-finding phase of the design, several concepts will be generated and tested, and importance would be given to the following; (i) ***structural integrity*** to withstand the harsh and challenging conditions of the reefs, such as, ocean currents, temperature and pressure changes, etc. as well as attack or damage by marine life; (ii) ***material properties*** for an environmentally-benign intervention that emulates the natural ecosystem and supports the easy attachment of coral polyps leading to proliferation; (iii) the ***form, texture and porousity*** of the structure to ensure it mimics the natural coral reefs, so as to increase the acceptance by the marine life; and (iv) overall soundness for printing and assembling on the reef bed. The WP will also entail the information modelling of the novel reef structure to assess and monitor its performance through life.

WP3: In this WP, the focus is to ensure long-term sustainability and benefits of the novel reef structure to boost the underwater ecosystem, through lifecycle planning and assessment, and continued monitoring of the printed structure. This WP goes hand in hand with WP 2, as substantial inputs to the design will be derived from the lifecycle assessment (LCA) of the existing ecosystem, benchmarked to the desired state that the novel reef structure intends to imbibe. The common thread between the two WPs i.e. 2 and 3, is the outlining lifecycle thinking that will allow identification and incorporating of salient features that are required for long-term benefits. Ideally, the novel task outlined in this WP will surpass the life of the granted project.

3.2.5 Offshore Energy & Desalination of Sea Water

In this secondary area following work packages are identified:

1. Underwater compressed air energy storage system for standalone localized power generation
2. Aerodynamic studies on innovative blades of vertical axis wind turbine for harnessing offshore wind power

The scope, and outcome of these work packages are described in detail in the subsequent sections:

Underwater compressed air energy storage system for standalone localized power generation

The surge and fluctuation in energy needs, are normally resolved through an energy storage system for a particular application. Therefore, the compressed air energy storage system (CAES) is one of viable option for most promising large-scale energy storage schemes for power generating systems. In a compressed air energy storage system, the pressurized air is stored in naturally available reservoirs such as underground voids of salts, natural gas fields, porous media, hard rock layers, external surface steel piping and airbags in large water bodies.

Based on operation technique and utilization of heat generated during compression process, the CAES system are categorized as diabatic (D-CAES), adiabatic (A-CAES), advanced adiabatic (AA-CAES), isothermal CAES (I-CAES) and isobaric adiabatic (IA-CAES). Thermodynamically, all these systems work on constant volume storage except the IA-CEAS. The near isothermal CAES system maintains the pressurised air temperature almost constant by keeping the storage device in large water bodies. The main challenge associated with the near isothermal CAES system is thermal de-stratification of heat of compression in the large water bodies and its installation cost. In an IA-CAES, both the pressure and the temperature can be kept constant using flexible compressed air bags and keeping it in large water bodies besides to storage of heat of compression in a separate device. These makes it to have higher efficiency compared to other counterparts. Both these underwater CAES systems are still under research and development phase.

In underwater compressed air energy storage system (UCAES), the pressurized air is stored inside a large flexible/elastic bags or rigid tanks inside the sea bed/water bodies. In case for flexible air bags, the weight of the water column provides the required pressure to hold the compressed air inside the bags below certain depths, preventing them from blasting (like a balloon). While in case of rigid containers, the container will be made prefilled with water and at the time of energy storage, the prefilled water will be displaced through properly desired and sized pipe by the compressed air to a higher elevation. When the stored energy is needed, the compressed air inside the bag/tank is allowed to flow through a turbine-generator assembly to produce electrical power and the cycle continues in the same manner. The energy density in UCAES, is higher compared to other compressed air energy storage system because all the air mass stored in the reservoir can be fully utilized. It is mainly because the pressure remains constant in all charging conditions, even during partially filled situations. So, the turbine has no issue in exploiting it. Whereas in constant volume system, the compressed air is released during energy generation, the pressure inside the storage chamber decreases, which gradually reduces the flow to the turbine and produces less power. This condition leads to lower efficiency of the system. An UCAES can also maintains constant temperature for the stored energy.

The hydrostatic pressure is the main driving force to attain the constant pressure. As the depth increases the hydrostatic pressure also increases, at the same time the energy density of the compressed air also increase. The main application of the CAES is to store excess generated energy from any intermittent sources (such as renewable energy like wind, solar, wave energy etc.). In this regards, the tidal energy of underwater CAES has many advantages, because most of these intermittent sources of energies are generated near to the coastal areas or in the large water bodies in one or another way. Besides, it can store large energy in highly pressurized form.

Natural available mineral resources are limited and conflict of interest in limited resource will further creates scarcity. For instance, the most common known energy storage is pumped hydro storage (PHS) with battery-operated technologies (e.g. lithium-ion, lead, nickel-cadmium and nickel metal hydride and so on). The battery materials are limited and additionally, they have environmental issues. For large megawatts storage application PHS require huge battery banks at higher cost. The fate of future UCAES could be a potential power source for underwater technologies, like deep sea-mining application, which uses pneumatic power tools, battery-free underwater vehicles. It can also participate as electrical power source for future underwater entertainment homes etc. Hence, the UCAES system can be considered as a promising technology for large-scale energy storages application. Therefore, novel UCAES system is proposed in laboratory scale for localized power generation applications.

The project aims to design, develop and compare the performance of three underwater compressed air energy storage configurations in laboratory scale by constructing dual-purpose tanks and flexible air bags. It includes the following basic tasks:

1. Sizing and construction of an underwater compressed air energy storage system with flexible air bag submerged in a water tank (Fig. 3.25)
2. Performance measurement and analysis of direct storage of compressed air in to the tank without using CAES bags by displacing the water through pipe to secondary water storage tank positioned at higher elevation relative to CAES (Fig. 3.26)
3. Sizing and integration of hydro-kinetic/low-head hydraulic turbine between the lower positioned CAES and the higher positioned secondary water storage tank to enhance the power output from the system (Fig, 3.27)

The above basic tasks are shown diagrammatically as follows: Figure 3.25 indicates the application of flexible air bags as UCAES. The UCAES comprising of two tanks – one for air and other for water storage (Fig. 2). The secondary tank positioned at a higher elevation for water storage only. The representation of UCAES in Fig. 3.27, is similar with Fig. 3.26, but it comprises two hydraulic pipes between the two reservoirs. Also, it has a micro hydraulic turbine installed at low head for localized generation mode in hydraulic pipelines. The hydraulic turbine is supposed to generate electricity with the air expander to improve the overall efficiency of the system.

Approach and Methodology

A novel in-house designed UCAES system and its performance testing capability is the theme of this project. A conventional power source can be used to compress the atmospheric air to be stored as CAES and later released to generate energy through an air-expander. The important parameters (such as, amount of energy requires, amount of air mass, amount of thermal energy stored and its duration etc.) will be measured. Based on these measurements, a comprehensive thermodynamic analysis involving the energy and exergy efficiency will be performed for the three CAES system configurations to select the best configuration. Thereafter, it can be applied for any energy sources especially for intermittent renewable energy sources like wind and solar energy system.

Primarily, the CAES system is recent emerging technology applied for large-scale energy storage system. It is seen from the available components that it does not require any complex material and operation except the usual compression and expansion process. Thus, it can be applied anywhere for which water bodies are available.

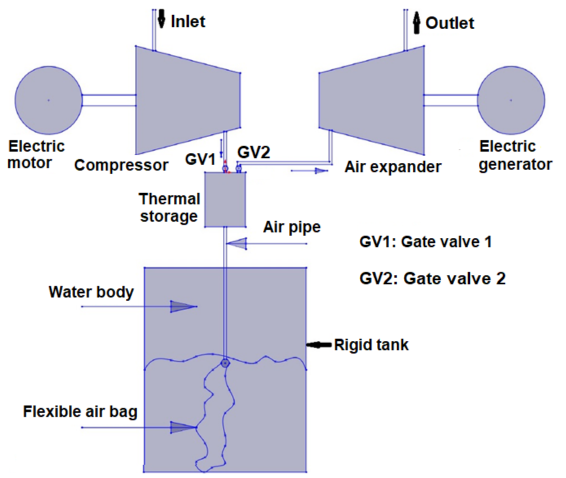


Fig. 3.25: Underwater compressed air storage system with flexible air bag.

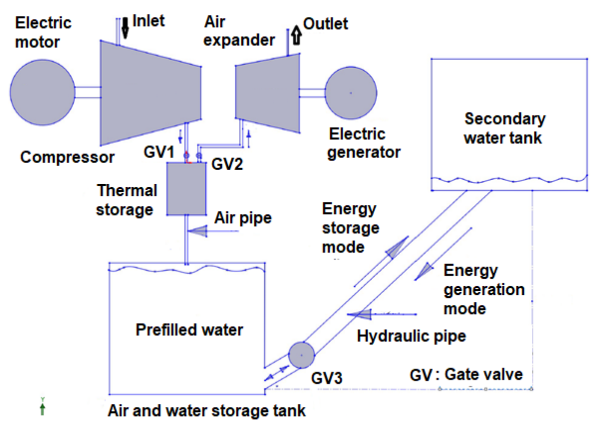


Fig. 3.26: Underwater compressed air storage system with secondary water tank.

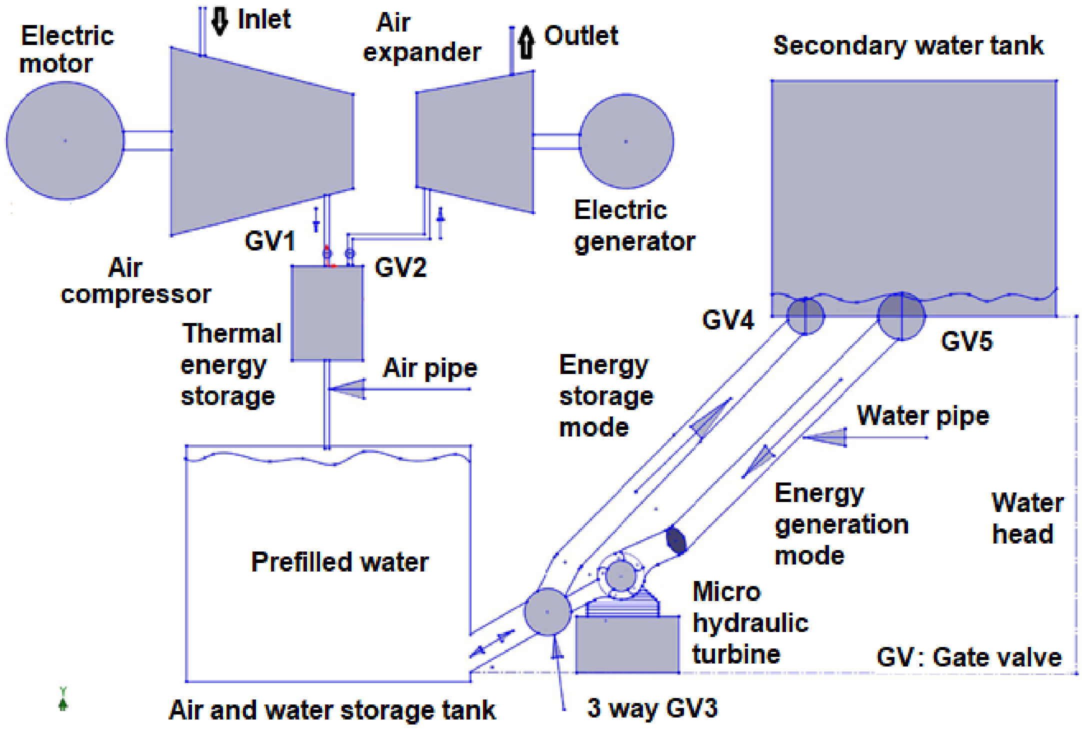


Fig. 3.27: Underwater compressed air storage system with secondary water tank and hydraulic turbine.

Aerodynamic studies on innovative blades of vertical axis wind turbine for harnessing offshore wind power

The demand on renewable energy sources are considerably increasing day by day due to the pollution in the environment, global warming and shortage of traditional fossil fuels. Wind energy is one of the potential renewable energy sources free from pollution, inexhaustible and has cheap running cost. The wind energy is used for several applications like generating power, pumping water, grinding grain, etc. Many countries have primary ambitious target to generate electricity these days from renewable energy sources and for this, wind energy could contribute immensely if addressed properly. The evolution of harnessing wind energy from offshore is crucial research in the current days since the growing need of wind bazaar requires significant onshore/land space. Offshore wind energy harnessing is one such arrangement of wind farms that can be positioned in water bodies (Fig. 3.28). Offshore wind farms generate more electricity than onshore due to the higher wind speed.

A wind turbine is a device, which is used to produce electricity by harnessing wind energy. Generally, wind turbines are classified into two types according to the rotational axis wind rotors: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). In HAWT, the rotor shaft is mounted parallel to the ground, whereas the rotor shaft of the VAWT is mounted perpendicular to the ground. The ongoing research on VAWTs is attracting the current researcher intent due to its several advantages. VAWTs can capture wind independently in any direction and offer a more considerable reduction in cost across various segments, particularly operations and maintenance, support frame, establishment, and electric foundation costs. The VAWTs can be implemented offshore coastal areas/water bodies where the wind speed will be much higher with strong offshore breezes in the afternoon time than onshore. Further, offshore VAWTs are technically feasible to install in deep water as well as shallow water because they can handle the large turbulence effect. These offshore VAWTs can also be placed near the load centres along the coasts, for which there is no need to employ long-distance transmission lines for providing electricity to the big cities. One of the prime disadvantages of VAWT is it provides lower efficiency than HAWT even if it is providing several advantages. The above issue is mainly due to the implementation blades of VAWT. Further, the VAWTs face a self-starting problem. These shortfalls can be managed by addressing innovative blades through advanced fabrication methods such as 3D printing technology. Moreover, aerofoil shapes of wind turbine blades are gaining importance because they can be designed as lift/drag based methods with respect to wind directions. The innovative design of aerofoil shape and its material selection, will be a significant contribution in the area of VAWT. The prime points of research is to quantify power coefficient and torque coefficient in laboratory based simulation. In addition, innovative approach on power augmenting techniques can also be another domain of research. These new blade designs can be used in the offshore VAWT for the long-life span and higher efficiency of wind turbines. The prime goal of this project is to design an innovative aerofoil shaped wind turbine blade (suitable thickness, materials, number of blades) and quantifying aerodynamic parameters (torque and power coefficients) through wind tunnel experiments, for a VAWT towards offshore wind energy applications.

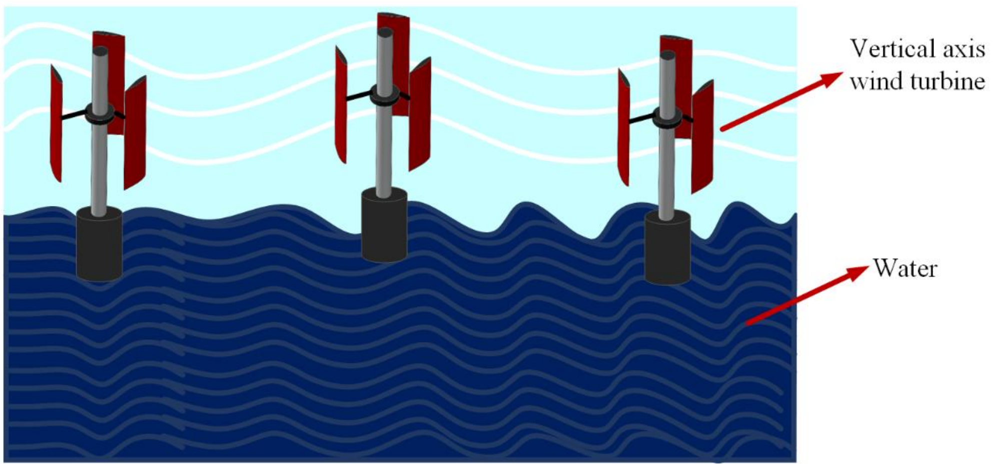


Fig. 3.28: Schematic representation of an offshore vertical axis wind farm.

Objective of the project:

This project aims to design a new airfoil blade for offshore VAWT and investigate its aerodynamic parameters on a laboratory scale for power augmentation. This goal will be achieved by following tasks:

- Design and development of blades (symmetric or nonsymmetric) by using polymer material
- Investigation of the performance of offshore VAWT by the effect of blade numbers, shape and thickness of the blades
- Effect of performance parameters such as solidity, TSR, aspect ratio on offshore VAWT performance
- Understanding the complex flow field around the surface of blades of offshore vertical axis wind turbine
- Augmenting the performance of the offshore VAWT by the effect of power augmentation techniques

Approach and Methodology:

The aerodynamic performance of the offshore vertical axis wind turbine is the theme of investigation. The initial phase of the study (through high performance computing) will examine the flow field around the blades by velocity/pressure contour and vorticity magnitude. Additionally, the torque coefficient and power coefficient results can be found from this numerical simulation. The prototype model of the VAWT will be mounted and tested on a Wind Tunnel Laboratory of the Mechanical Engineering Department, IITG. The rotor performance will be measured in this wind tunnel by adjusting several design factors such as the blade geometry, blade profile, velocity, solidity, aspect ratio, and pitch angle.

The onshore VAWTs are already available and routinely used for fulfilling the energy needs (such as electricity generation, pumping water, grinding grain etc.). Offshore energy generation is a new idea and it will be more beneficial than onshore energy generation due to the lack of available space of onshore and its low wind speed. The energy generation from the offshore VAWTs can be used in naval ships and submarines and the big cities near offshore. This facility will provide higher efficiency as the offshore wind speed is higher compared to onshore. Further, these offshore wind firms have potential address the surge demands to reduce the load on prime source of electricity generation as fossil fuel, which is diminishing day by day. Additionally, it will boost researchers/entrepreneur to explore more offshore energy generation by through VAWTs. The local fabrication wind turbine blades through 3D printing technology can be explored under “Made in India Scheme” for budding startup companies.

3.2.6 Underwater Aquaculture

In this secondary area following work packages are identified:

1. Dolphin monitoring Internet of Things (IoT) Network in River Brahmaputra
2. Exploration of the aquatic ecosystem of river Brahmaputra

The scope, and outcome of these work packages are described in detail in the subsequent sections:

Dolphin monitoring Internet of Things (IoT) Network in River Brahmaputra

The Ganges river dolphin (Platanista gangetica gangetica) is a subspecies of river dolphin. Commonly it is known as Susu or Hihu. The Ganges dolphin is found in the Ganges, Meghana, and Brahmaputra Rivers in India, Nepal and Bangladesh. These are recognized by the Government of India as the National Aquatic Animal (*web ref 26*) and Official Animal of Guwahati, Assam. The Ganges river dolphins are one of the four fresh river dolphin species in the world.

Unfortunately, these river dolphins are experiencing the adverse effects of human environmental impacts and are highly endangered as per International Union for conservation of Nature (IUCN) (*web ref 27*). In all, their population of not more than 2000 has been estimated (Mohan et al. (1997)) all over the world.

This project aims to provide an autonomous method to find out the population status and distribution pattern, which will be helpful for the conservation of the river dolphins.

Objectives:

- Implement an IoT network to detect the presence of dolphins in river Brahmaputra
- Monitoring dolphin density in a given area
- Counting dolphin population in a given area
- Make the system energy efficient to improve its lifetime.

Present State-of-the arts:

<u>National Scenario:</u>

First population assessment of Gangatic dolphins in River Brahmaputra was conducted in the year 1993 (Mohan et al. (1997)). After 12 years, a population assessment survey of the endangered Ganges river dolphin was made between February and April 2005 in the Brahmaputra River starting from Assam–Arunachal Pradesh border to the India– Bangladesh border (Wakid (2009)), In both the surveys, the population assessment was done on the basis of manual field verification. There are many activities taken up, which are based on these assessments (Wakid (2006) and web page dolphin),

A major issue connected to river dolphin visual surveys is the erratic and brief surfacing behavior, many individuals could be missed or others double-counted (Vidal et al. (1997), Reeves (2000) and Richman (2014)).

International Scenario:

River dolphin monitoring is proposed to be done by counting them manually by either visual counting or aerial surveys (Fürstenau et al. (2017), Hodgson (2017), Sugimatsu et al. (2018) and Oliveira-da-Costa et al. (2019)). Dolphins come to the water surface for few seconds and in turbid waters, typical in Brahmaputra River, it is difficult to monitor their activities.

To improve the accuracy, the monitoring and counting of dolphins is proposed to be done with the help of passive acoustic monitoring (PAM) technique (Zimmer (2011)). The dolphins make a distinct sound in low frequency region. In PAM technique one hydrophone is either fixed at a place or towed through the water. Based on the number of audio signals generated by the dolphins, their density or counts are measured.

Drawbacks of the standalone PAM system is limited accuracy of the measurements. The data collected is at the local unit. Which has limited processing power and data storage capacity. The moving PAM systems are usually implemented by mounting sensors on a moving vehicle. Therefore, these may become very expensive, especially for large-scale monitoring activities that last over weeks or months.

Proposed approach:

In the proposed system, a large scale network of sensors will be implemented. In this autonomous system, each sensor data will be transmitted to a central server wirelessly. At the server the collective data processing will give us better accuracy.

To account for the limited energy-supply available to the sensors, we will implement techniques to reduce the energy consumption while transmitting the data to the server.

The advantages of the proposed system are-

1. It can monitor data for a long period.
2. It can cover a larger geographical area, including difficult terrains.
3. It will provide a low-cost system and accuracy of the system will be better.
4. The data collected by the system can also be utilized to monitoring /understanding the behavior of the dolphins.

Challenges:

1. How to interpret data.
2. How to identify and remove duplicate data received by multiple sensors.

3. How to use the setup to count the number. Static sensors are used to measure the density in a given area but not the number in the whole river, as dolphins will move from one location to another over the time.
4. Using PAM system at depth, say 100m or at 1000m, either requires a pressure housing capable of withstanding 10 or 100 atmospheres. Surface sensors are vulnerable to the ship/boat strike.
5. How to improve the network lifetime.

Expected Outcomes:
1. An autonomous network to monitor river dolphins.

Exploration of the aquatic ecosystem of river Brahmaputra

The Brahmaputra River is one of the largest river systems in the world. Yet it is also one of the most under-investigated, underdeveloped basins. The valley consists of the western Brahmaputra valley covering the regions of Goalpara and Kamrup, the central Brahmaputra valley region covering Darrang, Nagaon, and the North Bank and Eastern Brahmaputra Valley comprising districts of Sonitpur, Lakhimpur, Dibrugarh, and Sibsagar (Jurewicz (1976)). There is a lot of potential for underwater exploration in this river.

The Brahmaputra River is braided and unstable in its entire reach in the Assam Valley except for a few places. The instability of the river is attributed to high sediment charge, steep slope, and transverse gradient. The silt brought in the process gets deposited as the river descends into the plains with a sudden reduction in slope, with the consequent decrease in the flow velocity and its sediment carrying capacity.
The flood in Brahmaputra Valley is a recurring phenomenon and has been causing large scale damages every year. The reasons for a flood can be summarized as below:

- Inadequate capacity of the river channel due to braided nature, thereby spilling of floodwater over the banks
- Drainage congestion at the outfall of tributaries during the high stage of the main river
- Excessive silt load in the river due to soil erosion and large scale slides in the hilly catchments (*web ref 28*)

Objective and scope:
The main objective of the project is to develop underwater robots (drones) to carry out the following tasks:

- Mapping of the riverbed of Brahmaputra

- Surveillance of the aquatic animals and plants
- Online quality assessment of the water at different locations
- Search and rescue operations

Mapping of riverbed: The deposition of the slit is one of the main reasons for flooding. The objective is to map the riverbed to identify the areas of slit deposition. In the suspected areas, removal of slit and debris could be done to avoid flooding of water. Later on, it can be used for underwater bed level survey for installation of micro-turbines for power generation.

Surveillance of aquatic animals and plants: River Brahmaputra is the home of many species of marine animals. Among them, it is the kind home for the largest Gangetic dolphins or freshwater dolphins. Although the number of dolphins is highly decreasing, surveillance of such aquatic animals can be done and suitable measures can be adopted to increase their population. Similarly, different types of plants can also be studied.

Online quality assessment of the water: Livelihoods of many people depend on the banks of the river. It is known that the hot, warm, polluted discharge from industries greatly harms the water quality and the surrounding biodiversity. Through this program, a quick online assessment of the temperature and quality of the water can be done. This approach would significantly help in reducing water pollution by taking corrective measures.

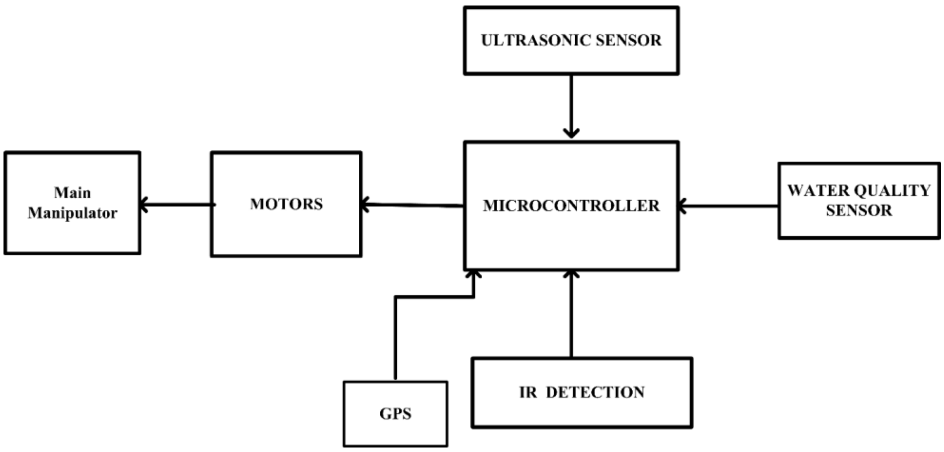


Fig. 3.29: Block diagram of underwater drone.

Search and rescue operations: The primary objective is to aid in the rescue and search services. In the past, several accidents of drowning of boats and human beings occurred, and it took several days to recover the bodies. With the help of underwater drone search operation can be carried out in less number of time. It can also be used in rescue by providing quick search and information. Figure 3.29 shows a typical block diagram of underwater drone.

3.2.7 Underwater Healthcare and Monitoring

In this secondary area following work package has been identified:

Design and development of different life supporting, monitoring, safety, assisting and communicating devices for divers to prevent and management of diving accidents during underwater exploration

In order to explore the resources available at underwater, divers perform the required activities for their exploration. However, the health issues being faced by them such as decompression sickness, oxygen toxicity, breathing difficulties, lung over-expansion injury, nitrogen narcosis, and others are the major issues among the divers, which are required to be addressed in order to save their lives. The diagnosis of the divers' conditions at an early stage could save lives of them. Thus, continuous storing, monitoring of key physiological parameters such as heart rate, ECG, respiration rate, body temperature, volatile organic compounds in the respiratory air, blood pressure, oxygen and CO_2 pressure in the blood, dehydration level and microbubble formation, and transmitting the same through the wireless mode without any data loss and timely communication of health status will be very much crucial to prevent the loss of humans. The data received from the device will be monitored, analyzed and the required feedback or alarm will be passed to concerned authorities for necessary follow up action. A methodology for adaptive error control scheme will be developed for reliable wireless underwater acoustic wireless communication. Any equipment having waterproof and pressure-proof is very much essential for its exploration of the proposed application. In addition, locating the divers and bring them back to sea level are also important in order to save their life in case of any emergency. Thus, it is proposed to design and develop a system which could be potentially used for life supporting, monitoring, assisting and communicating devices for divers to prevent the diving accidents and management of the same during underwater exploration. In addition, it is proposed to develop a low frequency integrated transceiver for wearable devices enabling underwater-to-terrestrial communication. A preliminary study will be conducted using an underwater acoustic bed.

Diving for both recreational and commercial purposes has increased. But there are many dangers associated with diving, including fatality, which may be due to pre-existing or sudden onset health issues, and equipment failures cause many such unfortunate events. Monitoring of various physiological parameters is routinely used to monitor, predict, and treat health-related issues. Not many studies have been carried out to monitor such parameters in divers. The need for an `umbilical` to transmit data from the diver pose as a limitation for continuous monitoring of health-related parameters. Thus, devising remote health monitoring in divers is needed. Worldwide, Divers Alert Network (DAN) received notification of 169 deaths involving recreational scuba diving during 2016, Buzzacott et al. (2018). There are 47 deaths for every 1000 emergency department presentations for scuba related injuries in the USA alone, Buzzacott et al. (2018a). The leading cause of drowning being hypoxia, triggered by different events, such as problems with equipment, insufficient gas supply, loss of consciousness, nitrogen narcosis. Unfavorable sea conditions, trauma, preexisting diseases, and stress/anxiety are some other events that lead to drowning, Lance et al. (2017) and Valter et al. (2013). Divers may present with signs such as confusion, abnormal posture control, muscle spasm, speech problem, blank stare, unresponsiveness, low amount of oxygen in blood depending on the severity of hypoxia, Lindholm (2007). Though peripheral oxygen saturation (SpO_2) is a reliable sign of hypoxemia, the clinical signs may not be consistent with changing SpO_2 values. Altered mental status, even with a normal SpO_2 value, will render the diver incapable of performing a life-saving task. Wireless communication in underwater is in many ways different than the terrestrial wireless communication. Mandar et al. (2008) developed an ocean surveillance using underwater communication. Though different kinds of technology are available for the underwater communication, acoustic communication is found to be more suitable because of its inherent advantages in the salt water environment for long range underwater communication, Lawrence et al. (1999) and Lanzagorta (2012).

Due to extreme environmental conditions under the water, human survival becomes very much difficult. The health problems such as decompression sickness, oxygen toxicity, breathing difficulties, lung over-expansion injury, nitrogen narcosis, and others are the major issues among the divers, Yehuda Melamed et al. (1992). Thus, continuous monitoring of key physiological parameters and transmitting the same will be very much helpful to prevent and management of diving accidents and the loss of human. Due to extreme environment at the underwater condition, bringing the divers to the sea level within the shortest span of time is also very much critical. Apart from monitoring, wireless transmission of those collected data without any data loss and time delay will be crucial to take a call on their health behaviour. The equipment used in underwater conditions are required to be tested under high pressure and waterproof. It is required to incorporate the physiological health monitoring device. The existing model by Teledyne Benthos, Green (2010) showed only the depth and pressure. He also incorporated the monitoring of diver location and condition. As the normal breathing becomes toxic when the diver moves beyond 30 m, Albert et al. (2010], it led to oxygen toxicity, Albert et al. (2010a). The other problem of nitrogen narcosis caused due to anesthetic effect of some gases at high pressure, Freudenrich (2020), noble gages are mixed with gas mixture. Val Jones et al. (2019) reported that monitoring of the cardiovascular system by measuring ECG, oxygen saturation and blood pressure will help to safeguard the divers from meeting any accidental death. It is to be noted that due to remote monitoring of physiological parameters gives freedom to both divers and operators to control the situations to prevent any kind of accident and emergency. Thus, it is proposed to design and develop a system which could be potentially used by the divers for safeguarding them during underwater exploration without a loss of human life.

a) Problems to be addressed:

During underwater exploration, the divers expected to get many life-threatening problems including exposure and hypothermia, reduction of vital capacity of the respiratory system, over expansion of lungs, other aspects of barotrauma (pressure injuries) and various manifestations of decompression sickness, Val Jones et al (2006). Apart from medical illness of the divers, heart attacks occur during diving with higher frequency than on land. Statistics on accidents and deaths show that cardiovascular events (heart attacks) cause 20 to 30 % of all deaths which occur during scuba diving (source: Divers Alert Network). Thus, early detection of cardiovascular related problems could save the life of the divers. The physiological parameters of the divers such as heart rate, respiration rate, body temperature, oxygen and CO_2 content in the respiratory air, oxygen saturation of haemoglobin and pressure, and CO_2 pressure in the blood are to be measured. In addition, blood pressure, dehydration level and microbubble formation would be very much required. If the diver makes an unnatural pause between each breath, it leads to hypercapnia, i.e. an abnormal high level of CO_2 in the blood and the body tissue leading to unconsciousness and death. In case of involuntary hyperventilation, i.e. breathing more than is necessary to keep the body's carbon dioxide tensions at the minimum level—can be triggered by fear experienced during stressful situations, the anxiety of the first few dives or the discomfort caused by the safety equipment, the increase in static lung loading, or the increase in breathing resistance. Thus, a device monitoring the frequency of breathing can save lives. Underwater acoustic channels vary with diver's movement. On changing channel conditions, the energy optimal ECC configuration needs to be found. None of the today's wearable electronic devices are capable of underwater-to-terrestrial communication. As the market for wearable electronics is growing, we believe that this feature is crucial for future generations of wearable devices.

b) Objectives:

The major objectives of the proposed research activities are the design and development of different kinds of life supporting devices, measurement and monitoring units for key physiological characteristics, safety devices, different kinds of assisting devices in the extreme environmental situation, communication devices in under water conditions from shallow depth to deep section, studies on abnormal posture of different joints in underwater conditions, exploring neuromonitoring, mental fatigue and early diagnosis of different activities. The proposed activities will help the divers to prevent and management of diving accidents during the underwater exploration. It can be categorized into 6 sections, which are as follows: Health monitoring device, protective Equipment systems, breathing gas storage Equipment, biomedical safety devices, mechanical devices for rescue and biomedical devices for marine life.

c) Strategy:

Different sensors and devices required for different kinds of activities will be designed and developed. Data from this study will be used to device remote monitoring systems that have the potential of decreasing diving related incidents and fatality. The existing pulse oximetry and NIRS will be modified in order to make it capable to be used in underwater conditions. In case of low frequency (HF band) radio for wearable personal devices, an attempt will be made to finalize the topology of antenna and others components and parts of the devices. The optoelectronic system fabricated in the smart textiles coupled with diver's suite to assess the physiological parameters.

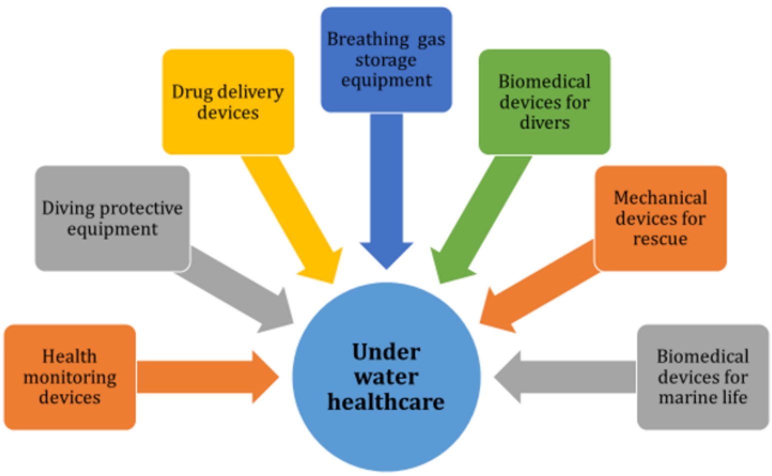


Fig. 3.30. Different domains to be explored under the underwater healthcare scheme for divers

d) Target Beneficiaries:

Divers who are exploring the underwater environment for recreational or occupational purposes. Health monitoring devices can be used for different kind of people including divers. Diving protective equipment and sensor embedded suits will be used by divers. Gas carrying unit of divers will be developed to reduce the active load on the divers to reduce their effective weight of the same. The proposed biomedical devices will be useful for the divers and rescue members.

e) Methodology:

The scope of our project for underwater health care can be as shown in Fig. 3.30. There are seven different sections under which the healthcare devices for the divers will be developed for safeguarding them with life supporting devices, monitoring key physiological parameters, different safety equipments, assisting them in different difficult situation, storing the data and communicating the same through wireless mode, studies on abnormal posture of human in underwater conditions, and the schematic diagram of the proposed system is shown in Fig. 3.31.

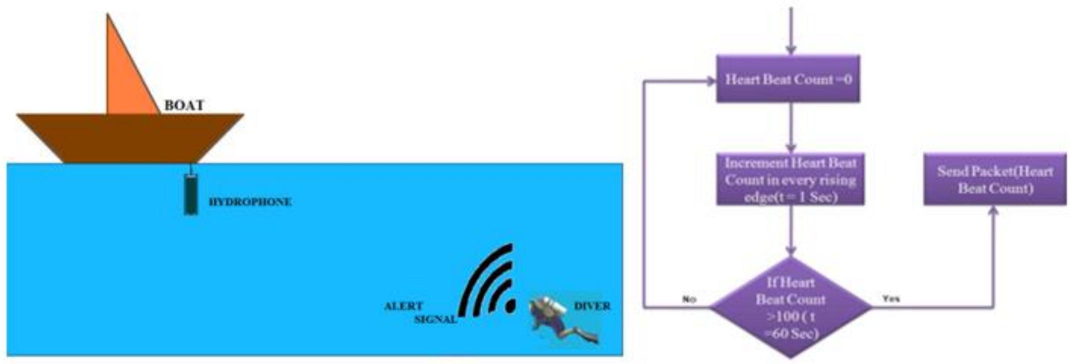


Fig. 3.31: Proposed system and the data analysis (Chitre and Shahabudee 2008)

In this work, it is proposed to select adaptive FEC for data transmission from the diver to the receiving station, making sure to achieve the desired BER or less to ensure reliability. While doing so computational complexity, energy consumption of transmitter-receivers, channel conditions will be considered. For this purpose, evaluation of various FEC schemes proposed for underwater acoustic communication will be done. The desired BER at the receiver can be achieved using optimal ECC with optimal transmit power at the transmitter. The choice of ECC with the target BER is linked with many factors, e.g., channel conditions, distance between transmitter-receivers, depth of the diver, transmit power level, frequency of operation, and available bandwidth. Some of these factors, e.g., frequency of operation, bandwidth, are known a priory at the transmitter. While for a moving diver some factors keep changing, for example, distance between diver and the receiver, channel conditions between both.

The physical distance and apparent distance between transmitter-receiver may differ significantly, depending on the channel condition between the two. For example, for the same distance, a clear channel between transmitter and receiver appears closer than a more cluttered channel. To estimate the channel conditions or channel state information (CSI), it is proposed to periodically transmit known pilot sound signal from the receiver. It is also proposed to receive it by the passive hydrophones at the diver's end. Using these pilots, the diver equipment can estimate the CSI. To adaptively choose an optimal ECC, the proposed methodology is shown in Fig. 3.32.

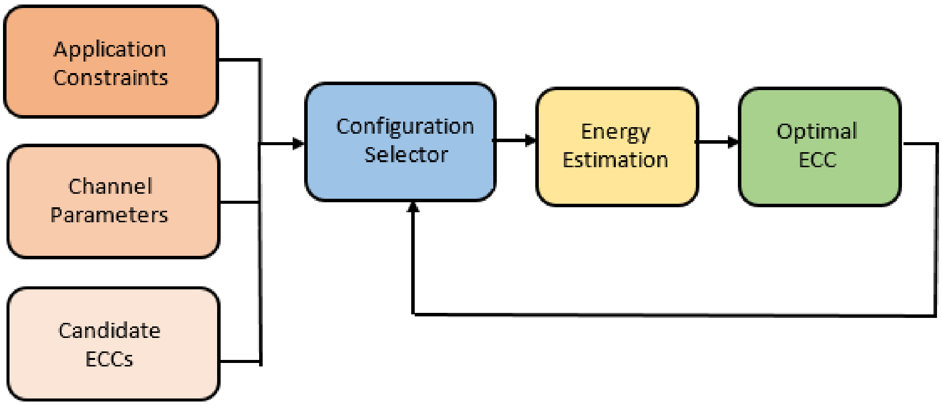


Fig. 3.32: Methodology for adaptive energy optimal ECC selection.

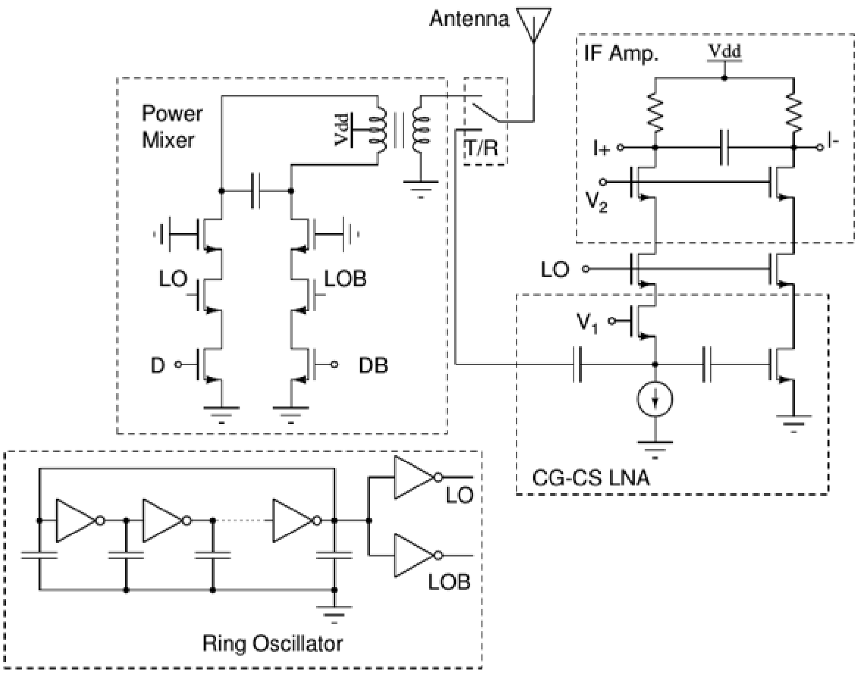


Fig. 3.33: A possible realization of the proposed low frequency radio

A possible architecture of the radio is shown in Fig. 3.33. A ring oscillator will be used to generate the LO signal required for up-converting the message signal. A power mixer will be used as a transmitter. A transmit-receive switch will be used to connect the CMOS transceiver with the antenna. An IF-to-RF current reuse receiver will be used to reduce the power consumption of the receiver. The common-source common-gate low noise transconductor will receive the incoming RF signal and amplify it. The amplified RF current signal will be switched using active current mixer transistors. A common-gate TIA will amplify and filter the IF signal. The IF output will be converted to a digital code using an ADC.

Based on the rich concentration of partial oxygen pressure, the problems such as muscle spasms and convulsions, nausea and dizziness, breathing problems and issues with the eyes and ears are generated. It will lead to oxygen toxicity in the central nervous system (CNS)

f) Risk analysis:

All the devices are required to be protected from water leakage and pressure at underwater level. Safe use of the devices, Equipments and reliability of the devices are more important. Data transmission without loss of information through water at different conditions will be a great challenge**.**

g) Outcomes:

Different biomedical devices, safety equipments, monitoring devices, data transfer facility, flexible devices, acoustic wireless communication, and others suitable for safeguarding the divers are proposed.

h) Evaluation:

The products being developed by the research team will be tested at each and every stages of their development. All testing as per the ASTM/ISO standard will be followed. Initially, it will be tested in a water tank, swimming pool, river with low current and high current location, where the effect of different depth, pressure, wave nature and other conditions will be studied.

i) National and International Collaboration:

As part of national collaboration, a research team from IIT Bhubaneshwar and IIT Delhi will be included. In addition, **ESAD-IDEA (Escola Superior de Artes e Design -Idea)** will participate in the project to develop the driver's suite incorporating sensors and sensing the system. **INESC TEC** will develop sensors to monitor the key physiological parameters, and transmitting the same through the wireless mode.

The objective of the collaboration is to study and develop an optoelectronic sensing system (optoelectronics in synthesis; which has been already developed for smart textiles) coupled to a customized diver's suite to readily assess in loco physiological parameters. It relies on the integration of such a system with of a properly designed suite. The system will address the measurement of key parameters like heart rate, ECG, respiration rate, body temperature, blood pressure, oxygen and CO_2 pressure in the blood, through the combination of electrical and optical sensing principles and transmitting the same through wireless.

The measurement of the physiological parameters implies the investigating the possibility to integrate a miniaturized temperature sensing element in the suite, energized externally at a proper wavelength, with the objective to get a re-radiation profile from such element with information compatible with the identification of its temperature. A possible solution for this proposal is semiconductor-based temperature sensor located on integrated circuits. They offer a linear response but have the lowest accuracy of the basic sensor types at 1 °C to 5 °C. They also have the slowest responsiveness (5 s to 60 s) across the narrowest temperature range (-70 °C to 150 °C). It is also expected to conduct a study on determining the lifetime of this technology. For the successful development and implementation of the sensors and their location in the suit, this task will interact with the suit design task.

3.2.8 Underwater Vision & Communication

In this secondary area following work packages are identified:

1. Under water computer vision
2. Design and development of shape memory alloy actuated soft jelly fish robot towards inspection of intricate structures and surveillance with IOT based health monitoring system
3. Design and analysis of RF Section for Ka-band vacuum electronics devices & Design of a portable remote operated underwater video surveillance vehicle with robotic arm
4. Investigation of Interaction Model of Cyber-Physical System(s) for Underwater Applications
5. Smart underwater Monitoring System
6. Design and Implementation of AI powered Autonomous Underwater Vehicle (AUV) and IoT Enabled Underwater Acoustic Sensor Networks
7. Development of hardware setup and real time implementation of cooperative motion control algorithm for autonomous underwater vehicle under communication constrain
8. Measurement diagnostics of saline water sloshing behavior through shockwave impingement

The scope, and outcome of these work packages are described in detail in the subsequent sections:

Under water computer vision

The problem of underwater image enhancement has been given considerable importance in recent times due to its vast application area in marine engineering and aquatic robotics. There are few core areas where underwater vision techniques are more prominent, namely image restoration, image and video analytics such as semantic segmentation, object detection to get some meaning information, robotic vision etc. Underwater image and video restoration become an important research topic, as underwater image and video are in general visually degraded due to light scattering and absorption. Color distortion, low contrast, and detail (edge information) loss are also the important problems of underwater images. Another important task is to analyze the underwater image and video to predict or detect some meaning full information out of them. This information is useful for a diverse range of application including riverbed monitoring, understanding of eco-hydrology, pollution and debris control, different automatic underwater vehicle (AUV) based real-time applications etc. In this task, image segmentation and object detection in underwater environment with inhomogeneous intensity turns out to be one of the most challenging topics these years. In ocean investigations, underwater image segmentation and object detection are the most fundamental and vital tasks. Finally, there is an incremental need for extending conventional computer vision algorithms for robotic vision. For AUV like underwater robotic devises require a real time analysis and incremental learning based machine learning approach for efficient robotic vision applications. In this project, the above vision issues are handled using state-of-the-art deep learning models such that the conventional vision methods can be extended for underwater images and videos.

Objectives:

In this project, we are handling the different aspects of underwater image and video processing and analytics. There are three major verticals of this work, namely image and video restoration, image and video analytics such as segmentation and object detection, and robotic vision for AUVs in underwater scenarios. To achieve these goals the following steps will be carried out throughout the project:

- Underwater image or video restorations

In this part, mostly image and video de-noising algorithms will be developed. In general, there are few intrinsic visual artifacts are presented in underwater images or videos mainly due to scattering of light, light absorption, color distortion, low contrast, and loss of edge information etc. Although, there are few works are reported in recent literature, there are lots of scope of improvement, mainly using modern deep learning architecture. Therefore, in this part of the project, different restoration algorithms will be developed which will be required for different underwater exploration tasks for example AUV etc.

- Underwater Image and Video Analytics: Segmentation and object detection

In this part of the project, image and video are analyzed to predict or detect some meaning full information out of them. Image or video segmentation and object detection are two major areas of this domain. In this task, it is required to understand the difficulties for usual segmentation algorithm when used for underwater images or videos. In addition to the underwater noise in the images or video, there are some temporal noise due to water flow etc. Therefore, segmentation and object detection in presence of such spatio-temporal artifacts is the main challenge of this part where recent deep learning-based segmentation algorithms are tuned for such constrained environments.

- Robotic Vision for AUVs:

In the final part of this project, we will explore some aspects of robotic vision for underwater automatic vehicles or robots. There are some generic differences between conventional computer vision and robotic vision. For example, for conventional computer vision, both training examples and object classes are known where are in robotic vision they may not always be. To meet this gap, some work based on incremental learning will be proposed work so that convention CV applications can be used for under water robot vision.

Underwater Image Restoration

Underwater images often suffer from severe visual quality degradation due to the absorption and scattering of light in the water medium. Song et al. (2020) first proposed a manually annotated background light (MABLs) database. Concerning the relationship between MABLs and the histogram distributions of several underwater images, a robust statistical model of background light estimation is then proposed. Next, the transmission map of the Red color channel is roughly estimated based on the new underwater dark channel prior (NUDCP). Later a scene depth map based on the underwater light attenuation prior (ULAP) and an adjusted reversed saturation map (ARSM) are applied to compensate and modify the coarse transmission map of Red color channel. Next, transmission maps of Green-Blue color channels are estimated. Finally, to improve the color and contrast of the restored image with a dehazed and natural appearance, a variation of white balance is introduced as post-processing. Mandal et al. (2020) observed that the attenuation becomes wavelength-dependent in the underwater scenario, causing undesired color cast along with the hazy effect. Therefore, they reformulate the local haziness in the underwater images and estimate the de-hazed images by exploiting the similarity in the local neighborhood of the image. It is based on the assumption that the depth of the scene gradually changes in the local neighborhood, which can be approximated by local patch similarity.

Ancuti et al. (2020) observed that under such adverse underwater conditions, the data comprised in at least one color channel among RGB is close to completely lost, thereby causing the traditional restoration techniques subject to noise and color shifting. In such cases, their proposed scheme can be used to restore the lost color channel, which is based on the subtraction of local mean from the opponent color channel. Yang et al. (2019) adopted the conventional single image outdoor dehazing model, which has also been used in other underwater image dehazing methods. However, they have proposed a novel background light estimation technique that can enhance the underwater image quality. It first recovers the red channel information of the background light using the dark channel of the underwater images by using a deep learning-based model. Then, an adaptive color deviation correction is used to recover the background light. Later, the dark channel prior is used to enhance the quality of underwater images using the estimated background light. Zhou et al. (2019) first extract the hazy image patches that exhibit the characteristics of the color-line prior and recover the color line of the patches. Later, the local transmission map for each patch is estimated based on the offsets of the color lines along the background-light vector from the origin. To obtain the solution in the underwater scenario, they proposed an optimization function to derive the local transmission maps.

Most of the underwater image dehazing methods adopt atmospheric dehazing model, which does not take wavelength into account, thus produces severe visual artifacts in the underwater scenarios. Akkaynak and Treibitz (2019) use oceanographic measurements to derive the physically valid space of backscatter. Further, show that the wideband coefficients that govern backscatter are different than those that govern direct transmission, even though the current model treats them to be the same. Later they proposed a revised equation for underwater image formation that takes these differences into account, and validate it through in situ experiments underwater.

Problem formulation for Underwater Image Restoration

It can be observed from the above literature that a majority of the existing schemes either adopt an outdoor atmospheric image restoration and dehazing model or takes wavelength into account for carefully drafting the attenuation coefficient. While the earlier approach has its drawback of neglecting wavelength of the water medium and inducing poor color contrast, the later is difficult in estimating the depth that gradually changes across the scene as we go deeper into the water.

Underwater Image and Video Analytics: Segmentation and Object Detection

The scene understanding of the underwater environment is an appealing topic among marine researchers and the public too, as underwater and especially undersea domains highly capture its attention. Many applications benefit from underwater scene information such as seafloor survey and marine object detection (Everingham et al. 2015). Conventional methods for underwater scene understanding fall into multi-sensor data fusion. Castellani et al. (2002) proposed to reconstruct 3D underwater environment with the aid of multiple acoustic views given by underwater acoustic sensors, but the trade-off between speed and accuracy limits this method for the realtime use. Moroni et al (2012) instead proposed to use both acoustic and stereo camera sensors, but the additional data fusion process for mapping has to be carefully considered.

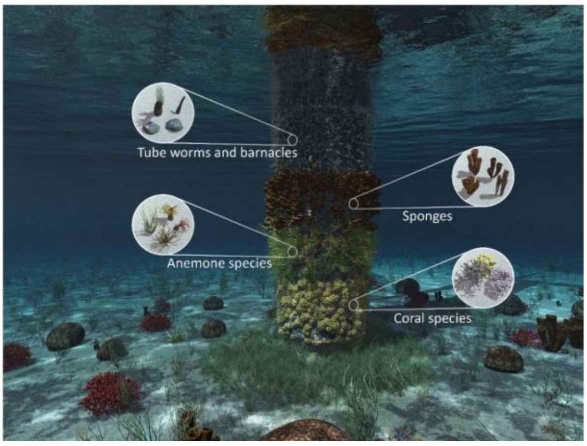


Fig. 3.34: Underwater Image and Video Analytics: Segmentation and Object Detection

Problem formulation

It has been observed in the literature that it could be difficult to calibrate a stereo camera in underwater environment because the refractive effects lead to non-linear distortion effects that depend on the seawater density and incidence light rate. Furthermore, depth image only cannot provide the straightforward information for object recognition task in the current camera view. Considering above facts, firstly it has been planned to extend the existing the deep models for semantic segmentation and object detection methods in underwater scenario.

Robotic vision

A robot is an inherently active agent that perceives, decides, plans, and executes actions in order to interact with the real world. Since the underwater ecosystem is vast and unsuitable as an exploration workspace for humans in general, many underwater tracking operations are done using autonomous underwater vehicles (AUVs), which are controlled and maintained by human operators. These tasks require the operators to have good knowledge and expertise about the AUVs, as well as the exploration zone, in order to maneuver the AUVs properly to extract desirable information from the expedition. Robotic vision plays a significant role here because it acts like the eyes of the operator, and helps the robotic vehicle take important *physical actions* on behalf of the human operator, based on its understanding of the visual feedback, which mimics the conscience and judgments of a human expert. Hence, the operators can be reasonably confident about the decisions made by the AUVs, and about the success of the mission.

Although several core areas of underwater exploration such as restoration, segmentation and object detection fall under the umbrella of computer vision, robotic vision has an overlapping with these areas, but demands a different end-result. While computer vision refers to extracting information from input images (or sequences of image frames, i.e . a video) to make sense of them, robotic vision takes in input images, incorporates aspects of robotics into its techniques and algorithms, such as kinematics, reference frame calibration and others, and translates them into physical actions that affect the environment of the robot. Deep learning has grabbed the attention of the robotic vision community in four broad application areas: Object detection and categorization, Object grasping and manipulation, Scene representation and classification, and Spatiotemporal vision.

Object detection and categorization is a fundamental task in robotics, and in underwater surveys, it is highly desirable for the AUVs to be efficient in detecting the countless objects it comes in contact with. For detection, pose estimation of the AUV and localizing the objects in its workspace are two important tasks, and although multisensor systems along with Global Positioning Devices (GPS) are widely used for this purpose Antonelli (2006), they show low performance in an underwater environment. A vision-based localization system for an AUV with limited sensing and computation capabilities was presented in Burguera et al. (2015), where the vehicle pose is estimated using an Extended Kalman Filter (EKF) and a visual odometer. In yet another work Pérez-Alcocer et al. (2016), a visual-based controller to guide the navigation of an AUV in a semi-structured environment using artificial marks was presented. The main objective of this work was to provide to an aquatic robot the capability of moving in an environment when visibility conditions are far from ideal and artificial landmarks were placed with an approximately known distribution. But even this approach could be more realistic if natural landmarks were used. Hence alternative methods are required. Moreover, the current state-of-the-art methods for object detection and classification using deep neural architectures involves feeding the deep neural networks (DNNs) with a huge amount of data to train on, and then classifying them using the trained DNN. This approach fails for underwater explorations, as there might be a number of object categories beyond the existing knowledge of the trained classifier, and hence its predictions will falter. We shall need to use different learning approaches than the conventional neural learning.

The ability to grasp objects and visual serving directly, without the need of hand-crafting the intermediate processes like detecting features, then objects, and then using the gripper has been achieved by deep learning paradigms. *Object grasping and manipulation* for underwater explorations is therefore a direct application of robotic vision, but again, the paradigms must generalize over the several objects that exist in underwater environments. Although recent works have shown that using self-supervision techniques to learn to grasp objects (concept extended to learn the state-of-the-art eye-hand coordination in robots) works pretty well in real-time using GPUs (Pinto and Gupta (2016)), bringing down the failure rate to 20%, the approach has not been considerably tested in underwater scenarios. Underwater situations are dramatically worse and increase the level of difficulty of the physical interaction of the AUV with the environment. Unmodeled underwater currents introduce continuous and unexpected motion disturbances, which have an adverse effect on any manipulation action of the AUV; hence it is quite challenging to grasp and manipulate. With millions of images of the sea floor and the underwater environment collected using AUVs, their manual annotation by experts is a very repetitive and time-consuming job. Hence, it is necessary to automate the analysis of largely available AUV imagery by developing deep learning tools for rapid and accurate annotation – this is what falls under scene representation and classification, and some work has been done on this in Mahmood et al. (2019).

The processing of video and other spatiotemporal sources of data are detrimental in robotic vision. A lot of work has been done in the area of visually detecting and tracking human motion using underwater robots. For example, in Sattar and Dudek (2009), a system has been developed to allow a robot to detect, track and follow a scuba diver by using frequency domain detection of biological motion patterns, wherein the detection and tracking of the human operator is done using the spatiotemporal signature of human motion. In another work Doherty (2018), a novel algorithm has been proposed for multi-robot approximate-distributed real-time online spatiotemporal topic modelling (AD-ROST), wherein, given a set of images, the goal is to predict for each image, the distribution over a latent set of categories that generated the data, in a multi-robot setting. The challenge was to let each robot build a model that discovers the structure of the image stream that coincides well not only with the human semantics, but also consistent with the models of other robots in the expedition, and this was achieved by consistent online spatiotemporal topic modelling.

Problem Formulation:

Since the AUVs are expected to work in an unstructured environment, they might encounter thousands of different objects. Thus, we cannot assume full prior knowledge of the environment, or the objects. As a result, although deep learning techniques have shown commendable performance on the above-mentioned tasks, their applications on robotic vision has been limited, mainly because they most use batch learning methods to train – once new classes of data are introduced, the models need to be re-trained. So, an object classifier like an AUV should be able to adapt to new data and incorporate new classes on the fly. This is where incremental learning of real-world objects could prove to be useful.

Major application areas:

The underwater computer vision has received considerable attention due to its immense and diverse applications such as marine engineering, eco-hydrology based analysis and predictions, aquatic robotics etc. The river Brahmaputra has been the lifeline of northeastern India since ages. This mighty river runs for 2880 kms through China, India and Bangladesh. In recent times, there have been a diverse range of research going on River Brahmaputra in different hydrological aspects. A few have been listed below. The proposed work on underwater computer vision may facilitate such underwater exploration-oriented research and technological works.

a) Underwater Ecosystem for Brahmaputra River and Majuli Islands: The Brahmaputra changes its course and pattern along with its current flow very frequently especially in its upper stretches and this has a strong bearing on its hydrobiology. For efficient understanding of such diverse eco-hydrological features, proposed methods can help.
b) Riverbed monitoring: The River Brahmaputra naturally has heterogeneous riverbed pattern, which is an important information for many hydrological applications. The proposed vision based underwater exploration makes it much easier to monitor and analysis the underwater demography of the river.
c) Agriculture i.e. salient aspects of fisheries of the river system in the state: River Brahmaputra is a trans-boundary major river flowing through the northeastern state of Assam, India and is the lifeline of its natural fisheries.
d) Health: Pollution, debris etc. in the Bramhaputra River and Majuli Islands: Pollution control and debris management become one of the major task nowadays. Proposed project on vision based underwater exploration makes it easier this task.
e) Disaster management: The river Brahmaputra is a big river and a river of such magnitude has problems of sediment erosion-deposition attached with it; the Brahmaputra is no exception. The problems of flood, erosion and drainage congestion in the Brahmaputra basin are gigantic. The Brahmaputra river is characterized by its exceedingly large flow, enormous volume of sediment load, continuous changes in channel morphology, rapid bed aggradations and bank line recession and erosion

Image and video restoration:

The problem of underwater image enhancement has been given considerable importance in recent times due to its vast application area in marine engineering and aquatic robotics. The two foremost reasons that make the underwater image restoration difficult are scattering and color distortion. Similar to the problem of single image dehazing, underwater image dehazing also consists of two major phases:

(1) Removal of haze, followed by the post-processing step,

(2) Color correction. Mathematically, the phenomenon of underwater image dehazing based on the transmission-based haze segmentation can be written as

$$H(x) = C(x)T(x) + L(x)(1 - T(x))$$

where H, C, T, and L denote Hazy, Clean, Transmission map, and Atmospheric light map, respectively.

<u>Proposed architecture:</u>

A hypothetical architecture is given in the Fig. 3.35: This is a typical de-hazing architecture for normal scenario. In this work, we will fine-tune this architecture to make it suitable for underwater images and videos.

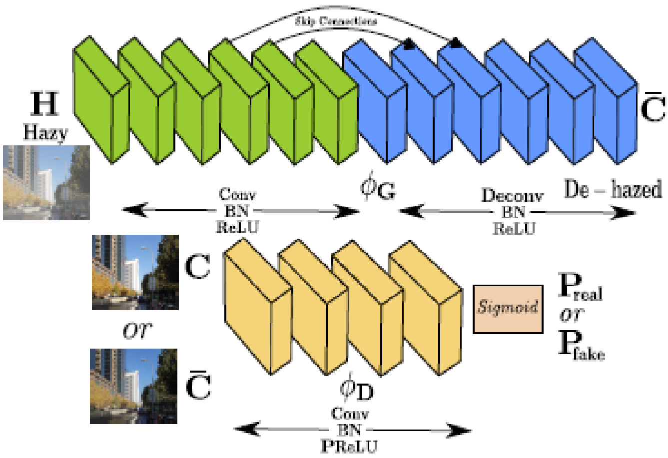


Fig. 3.35: Illustration of proposed architecture for underwater images and videos

<u>Database and some initial results:</u>

Some useful dataset are as follows:

- TURBID Dataset: TURBID (Duarte et al. (2016)) is a online available dataset to evaluate the underwater image restoration.
- Underwater image Dehaze dataset: Skinner and Roberson (2017) dataset contains - Ground truth target imaged in air, underwater raw image, and dehazed image. This dataset can be used to evaluate underwater image dehazing methods.

The deep learning-based method proposed in Duarte et al. (2016) can be used to generate the de-hazed images in the underwater scenario, as shown in the following Fig. 3.36.

(Hazy Image) From author's work (Sharma et al. (2020)) Existing (Li et al. (2019))

Fig. 3.36: Proposed deep learning based method to generate the de-hazed images.

Underwater image and video analytics: Segmentation and Object Detection

Proposed architecture:

It may be good idea to start with an existing semantic segmentation algorithm and then to propose some improvement to get better accuracy in the desired results. In this line of thought, UNet (Ronneberger and Brox (2015)) architecture may be used as this architecture performs better for similar kind of semantic segmentation tasks. This architecture contains two paths. Contraction (also known as an encoder) and Symmetric expanding path (also known as a decoder). Hence it is also known as Encoder-Decoder (Fig. 3.37).

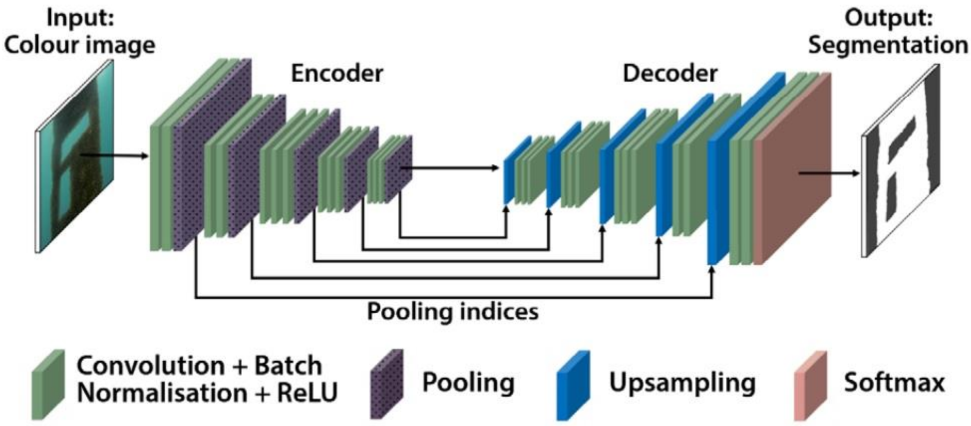


Fig. 3.37: Encoder-Decoder segmentation algorithm.

Contraction path: It is used to capture the context of the image. The encoder contains a stack of convolution and max-pooling layers.

Expanding path: It is symmetric to contraction path (but with opposite work). It is used to enable precise localization using transposed convolutions.

Dataset: The SUIM dataset has over 1500 natural underwater images and their ground truth semantic labels; it also includes a test set of 110 images. The images are of various spatial resolutions, e.g., 1906 × 1080, 1280 × 720, 640 × 480, and 256 × 256, etc. These images are carefully chosen from a large pool of samples collected during oceanic explorations and human-robot cooperative experiments in several locations of various water types (Fig. 3.38).

TABLE I: The object categories and corresponding color codes for pixel annotations in the SUIM dataset.

Object category	RGB color	Code
Background (waterbody)	000	BW
Human divers	001	HD
Aquatic plants and sea-grass	010	PF
Wrecks or ruins	011	WR
Robots (AUVs/ROVs/instruments)	100	RO
Reefs and invertebrates	101	RI
Fish and vertebrates	110	FV
Sea-floor and rocks	111	SR

Sample Results from Existing Literature:

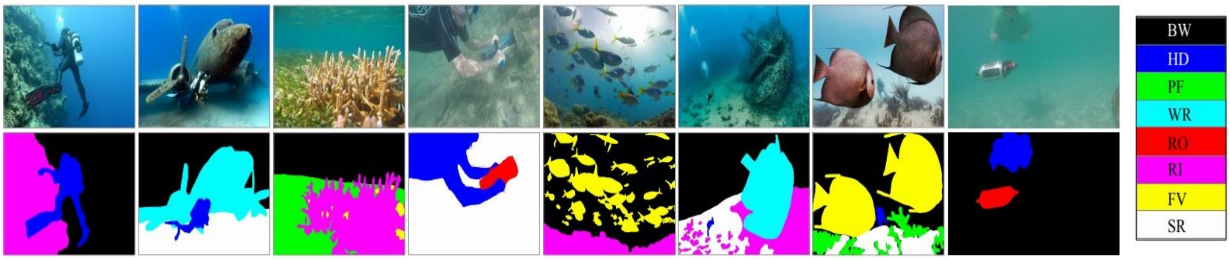


Fig. 3.38: Sample results

Design and development of shape memory alloy actuated soft jelly fish robot towards inspection of intricate structures and surveillance with IOT based health monitoring system

Bio inspired underwater robot plays a major role in the surveillance and monitoring of marine life. Conventional robots and machines are made of rigid materials that limit their ability to elastically deform and adapt their shape to external constraints and obstacles. Although they have the potential to be incredibly powerful and precise, these rigid robots tend to be highly specialized and rarely exhibit the rich multifunctionality of natural organisms (Majidi (2014)). The natural creatures are made of soft materials – polymers. Soft robots contain little or no rigid material and are instead primarily composed of fluids, gels, soft polymers, and other easily deformable matter. Soft robots have the potential to change the way we construct intelligent systems. By using highly deformable and stretchable materials, we can build robots that safely interact with human operators and function in unstructured environments. Soft robots are composites of flexible materials that together give rise to entirely new modes of function and behavior, in many ways not unlike natural biology (Lipson (2014)).

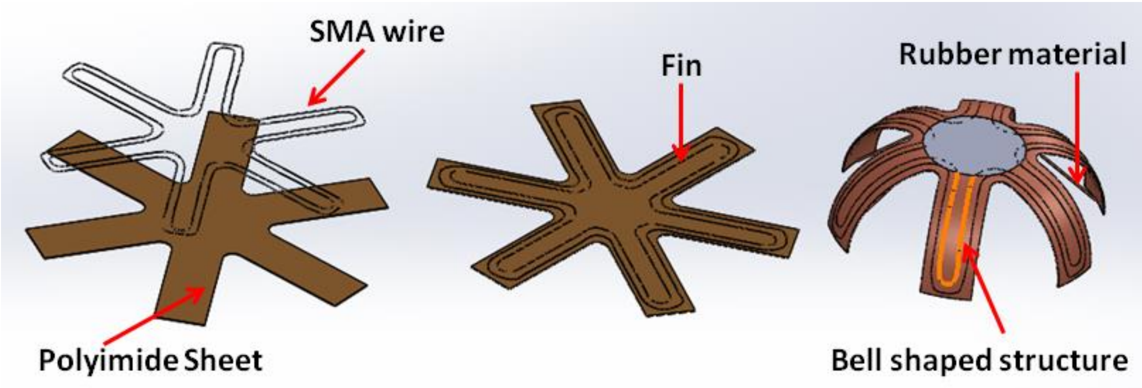
Dielectric elastomer (silicon), Shape Memory Alloy (SMA), pneumatic muscle, Ionic Polymer–Metal Composite (IPMC), ferromagnetic polymers and piezoelectric polymers are the established soft robotic actuator technologies (Coyle et al. (2018)). Recently, smart material-based bio-inspired soft robots have attracted much interest among researchers. Different bio-inspired robots such as fish (Shintake et al. (2018), Wang et al. (2008), Rossi et al. (2011) and Robert (2018)), Inchworm (Sangok et al. (2013), Wang (2014), Umedachi (2016)), Turtle (Kim et al. (2012)), Jelly fish (Xiao et al. (2013), Ko et al. (2012), Godaba et al. (2016), Shintake et al. (2016), Yeom et al. (2015), Yeom and Oh (2009), Villanueva et al. (2011), Hu et al. (2016) and Frame et al. (2018)) have been developed in recent years. SMA actuators are able to generate large displacements with simple mechanisms. Shape memory alloys are a class of material that can memorize a shape, undergo a semi-permanent deformation, and revert back to its memorized shape on heating. From having a very high energy density and being usable in a variety of shapes, including rods, plates, ribbons, springs, and wires (Hugo et al. (2017)). SMA elements attached externally to a soft polymer or wire mesh, or SMA elements directly embedded into a polymeric matrix. Each of these structures presents good and diverse capabilities such that they have all been used in a wide range of robotic applications. Various designs of robotic jellyfish has been developed using different actuators to mimic the shape and motion of common jellyfish using Digital Servos (Xiao et al.(2013)), Electromagnetic actuation (Ko et al.(2012)) Dielectric elastomer based jellyfish (Godaba et al. (2016) and Shintake (2016)), IPMC based jellyfish (Yeom et al. (2015), Yeom and Oh (2009), Shape Memory Alloy (Villanueva et al. (2011) and Hu et al. (2016)), Pneumatics based jellyfish (Frame et al. (2018)). Polyimides are a group of thermally stable polymers that exhibit excellent chemical resistance and good mechanical properties, mainly owing to their ability to withstand temperatures up to 500 °C. It is known to be strongly heat resistant and has excellent electrical properties as an insulator. It is ideal for use as an insulator under adverse environmental conditions such as those encountered in outer space applications of extremes of heat and vibration (Sharma and Pillai (1982), Sessler et al. (1986)) and DuPont (DuPont™ Kapton® Technical Bulletin). Globally, many researchers have developed Smart material based bio-inspired robot. In India, researchers have developed the rigid underwater vehicles for underwater observations. Recently, our group has developed and demonstrated a SMA based robotic fish. However, nobody has attempted to develop smart material based bio-inspired soft jelly fish robot. Further, NiTi SMAs are subjected to a cyclic loading, and then the cyclic deformation. Therefore, fatigue failure, assessing the fatigue life and reliability are key issues need to be addressed for SMA based robotic fish. Fatigue of these SMAs can be categorized into two types, one is structural fatigue and another is functional fatigue. Fatigue due to cycling loading is known as structural fatigue and represents the physical failure (or fracture) of NiTi SMAs; while the deterioration of properties like super-elasticity and shape memory effect occurred during the cyclic deformation of NiTi SMAs is called the functional fatigue (Eggeler et al. (2004)). In this proposal, a SMA based soft robotic jellyfish towards noise less underwater surveillance and marine life monitoring using smart and soft materials has been proposed with IOT based health monitoring system.

Objectives:

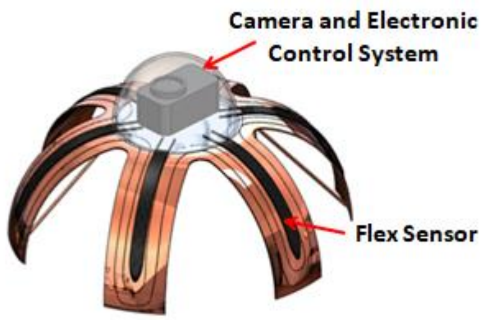
- Design and Fabrication of Shape memory alloy/Smart material based Soft jelly fish robot and optimization of the robot design.
- To develop an experimental setup for performing accelerated life testing and estimating life of the SMA based actuators and electronic components like electric circuit boards, electronic interconnects etc.
- To identify and investigate the causes of major failures in SMA structure and electronic components of SMA based robotic fish.
- Integration of Camera, Battery and Electronic interfaces in the fabricated robot with IOT based health monitoring system.
- Hydrodynamic analysis under different depths in water channel at laboratory.
- Investigations on the object detection using on board camera in water channel.

Methodology:

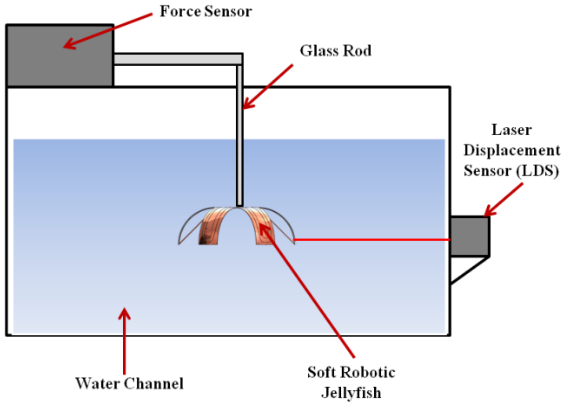
Fig. 3.39 and Fig. 3.40 show the schematic of the proposed methodology. Fabrication of the proposed design uses Nitinol SMA wires attached to polyimide sheets of symmetric structure. A rubber string is attached between the fin ends and centre of the body to achieve the recovery motion. At rest the jelly fish remains in bell shape. The SMA wire is actuated through Joule heating which creates flapping motion of the fin. During cooling, the jellyfish returns to the bell shaped structure due to the elasticity of rubber string. The continuous heating and cooling of the SMA wire based polymer structure subjected to expansion and contraction of its body with tentacles which generate thrust to make the jelly fish robot to move in water. Flex sensors will be attached to individual fins of the jellyfish for obtaining radius of curvature and bending angle for control.



Fabrication of the proposed Jellyfish



Proposed Jellyfish with Camera, Sensors and Electronic Control System



Experimental Setup for Force and displacement measurement

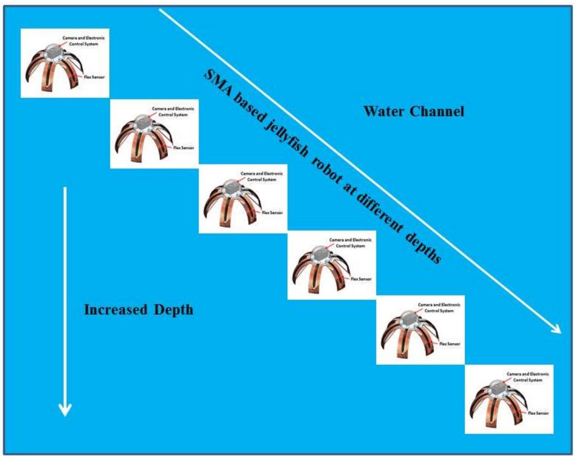


Fig. 3.39. Methodology of the proposed work

The camera, electronic interfaces and battery can be attached on the top of the robot as watertight leak proof mechanism. A waterproof high-resolution camera can capture the objects in the water channel and stores the images in the on board memory. Experimental investigation on the thrust force generation and displacement of individual fin can be measured using a force sensor and laser displacement sensor arrangement attached within the water channel to study the speed of the proposed robot. The SMA wire diameter can be varied and its effect on the thrust force can be investigated. The proposed robot performance can be tested underwater with different depths. The conceptual design of the proposed SMA based jelly fish robot for underwater surveillance is shown in Fig.3.40. The framework for prognostics and health management is shown in Fig.3.41.

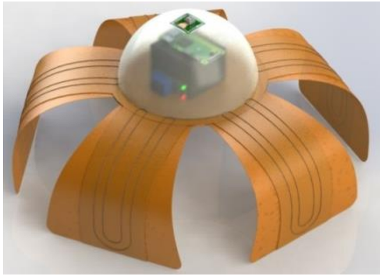


Fig. 3.40: Conceptual Design of the proposed SMA based jelly fish robot for underwater surveillance

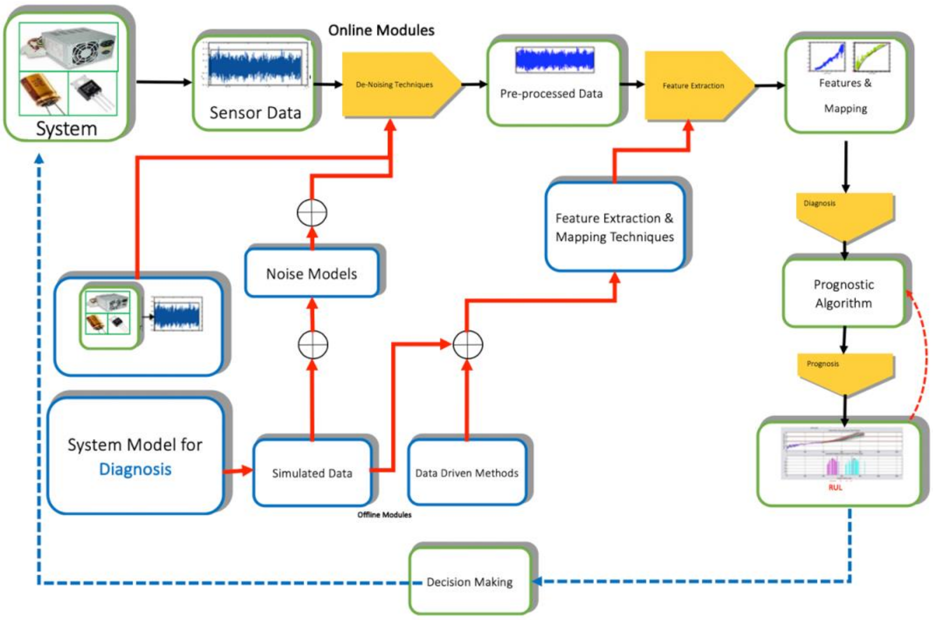


Fig.3.41: Framework for prognostics and health management

Design and analysis of RF Section for Ka-band vacuum electronics devices for Defence purpose

The Navy, with its water-based operations, has always depended on electromagnetic communications. The medium-data-rate satellite communications services (1.5 to 45 Mb/s) and high-data-rate services (>155 Mb/s) now being demonstrated offer the potential of new and innovative capabilities to the Navy. These naval communication satellites are highly integrated terminals that are compatible with any type of satellite. They have X, Ku, and Ka-band terminals, and few terminals need to be installed inside the ship to establish a network. The proposed design helps to develop RF Section of vacuum electronic devices in Ka-band with higher power and wide bandwidth which will be used in the satellite terminal.

Problems to be addressed: In Navy defence SATCOM terminal in Ka-band as communication equipment is required. Presently UHF and S-band terminals have been sourced indigenously. Efforts are required to indigenously develop SATCOM terminals in the C and Ku bands also. In the proposed proposal, the design and analysis of RF Section for Ka-band vacuum electronics devices will be addressed. The proposed RF section will be used in the SATCOM terminal that is installed in the ship to establish a high data rate wireless communication.

Aims and Objectives: It is proposed to carry out design and simulation of RF section for Vacuum Electronics Devices in Ka-bands for higher power and wide bandwidth. To support the high data rate wireless communications (e.g. 5G mm-wave comm.) like person-to-person and machine-to-machine (M2M) communication networks with wide coverage area with uniform/ reliable connectivity, high power amplifiers are needed. The designed RF section of vacuum electronic devices in the Ka-band can be used in the SATCOM terminal as an RF Module. The SATCOM terminal can be installed inside the ship.

Strategy: Klystron tubes are high power and high gain RF sources that have long been used as microwave amplifiers or oscillators for scientific, industrial, business and military applications, including radars, transmitters, accelerators, plasma heating, count-measure systems, and SATCOM (Ren (2006)). In general, re-entrant RF cavities are used as RF interaction structure. The re-entrant square cavity formed by keeping a gap in the central conductor of an RRC is shown in Fig. 3.42. A strong electric field is created in the gap region (through which the electron beam moves) by carefully adjusting the cavity dimensions.

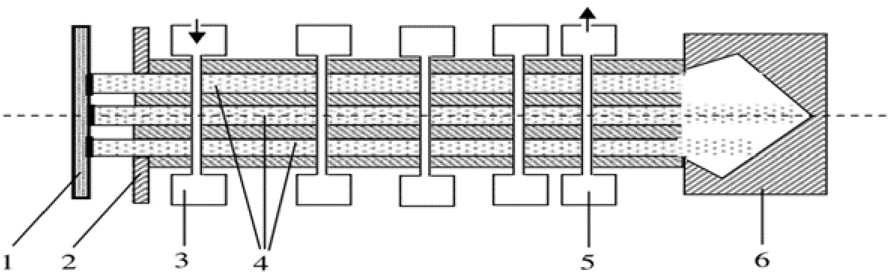


Fig. 3.42. Five-cavity three-beam klystron. 1) Cathode, 2) Anode, 3) Input resonator, 4) Beams, 5) Output resonator, 6) Collector.

Klystrons use a re-entrant cavity as their interaction structure (Ren (2016), Sirtori (2002) and Sherwin (2002)). As the frequency of operation increases beyond X-band, the dimensions of a circular cylindrical re-entrant cavity become too small to assemble with greater accuracies and align with the electron beam and the magnetic focusing structure. Hence, rectangular re-entrant cavities are preferred at higher frequency klystrons due to ease of component fabrication as well as ease of assembly and alignment (Li et al. (2016)). Analyses for a circular cylindrical re-entrant cavity based on an equivalent circuit approach and method of moment have been well documented in the published literature (Li et al. (2014), Song et al. (2015), Tsimring (2007), Lau et al. (1990), Wu et al. (2013), and Zhao et al. (2015)). The micro re-entrant square cavity (Mineo and C. Paoloni (2012)) was proven as the best solution for the design of klystrons at mm-wave frequencies. It handles a high order mode with an electric field distribution on the cavity gap similar to the one of the basic mode. Moreover, its dimensions are suitable to be realized by multi-layer micro-fabrication processes and simultaneously interact well with cylindrical beam (Paoloni (2014)). Microwave transitory mode cavities are usually made up of a cylinder and rectangle with a central post and have been investigated extensively. The central post acts as a capacitor. A tiny gap ‘g’ mid of top of the post and cavity ceiling is responsible for a huge capacitance. This capacitance creates high electric field captivity within the gap, whereas B field circulates around the post composing the inductive space of the cavity. In this order, a capacitive post that is introduced at the center helps to reduce the size and resonant frequency of the structure. By manipulating the gap spacing between the top of the post and cavity upper wall, this cavity can be adopted as a highly tunable or displacement sensitive resonator thus making such a device predominant for a wide range of applications (Murugkar et al. (2016)).

To achieve efficient beam-wave interaction, RF cavities with high R/Q values and Q factor (unloaded) are desired. To achieve high Q (greater than 1000) and R/Q up to 150 Ω, re-entrant cavities are used. In the case of a cavity with low R/Q value, the interaction of the electric field with the beam at the gap degrades (Chang et al. (2018)) In this case, it may not be enough to establish the proper level of beam modulation to attain the gain and output power specifications. Re-entrant cavities with special shapes that ensure a strong electric field in the direction of the beam are preferred to ensure a strong coupling between the electron beam and radio frequency (RF) wave. A re-entrant cavity can support a greater number of resonant frequencies or modes of oscillation, of which only the modes (in general, fundamental TM mode) with the desired axial electric field profile is chosen as the operating mode.

The gain-bandwidth product of klystrons depends on the R/Q values of the RF cavities. In vacuum microwave devices either re-entrant cavities or slow-wave structures are used to achieve overall high gain over a broad bandwidth. In klystrons, to improve the beam-wave interaction, RF cavities with higher R/Q values are required. Some solutions to improve the performance using different topologies of cavities to provide higher R/Q have been proposed in the past (Chodorow and T. Wessel-Berg (1961) and Symons and Vaughan (1994)). Attaining high power at a higher frequency is still an active area of research in microwave tubes. It is focused on the Design and Analysis of RF Section for K_a-band vacuum electronics devices with higher power and wide bandwidth for SATCOM terminals which is installed inside the ship to support the high data rate wireless communications. The Navy defence is focused on the development of the SATCOM terminal in the K_a-band for higher power and wide bandwidth recently.

Target Beneficiaries: The main objective of this project is to design and analysis of RF Section for K_a-band vacuum electronics devices. The design is a part of the SATCOM terminal which will support the high data rate wireless communication in the Navy.

Technology: To achieve the objective, the following steps will be followed:

a) The designing and studies of individual resonant cavity for the higher frequency applications will be started first.
b) Then performance improvement of the individual resonant cavity in terms of bandwidth, shunt impedance, quality factor, and fabricability will be studied.
c) After that, the design and studies of cavity with coupler (input and output cavity) will be completed.
d) Then the combination of the input cavity, intermediate cavity, and output cavity to make the RF section will be done.
e) After that, the design and studies of focusing system to keep the beam abstain from spreading as it traverses through the tube.
f) Finally, the beam wave interaction will be studied to predict the performance and optimize the position of the cavities for performance improvement.

Outcomes: With the successful development of this project, we can design and analysis of RF Section for K_a-band vacuum electronics devices with higher power and wide bandwidth for SATCOM terminals that will be used in the Navy defence applications.

Design and Implementation of AI powered Autonomous Underwater Vehicle (AUV) and IoT Enabled Underwater Acoustic Sensor Networks

The aim of this WP is to design and develop energy-efficient reliable underwater sensor networks by considering the key challenges in deployment of wireless sensor networks in underwater environments. The underwater wireless sensor networks (UWSNs) enable a wide range of application, including environment monitoring, oceanographic data collection, pollution monitoring, offshore exploration, disaster warning, assisted navigation and tactical surveillance applications. The major objectives of the project proposal are:

- Design and develop AI powered autonomous underwater vehicles (AUVs)
- Design and develop IoT Enabled underwater sensor networks (UWSNs) hardware with multiparameter sensing and communication modules
- Design and develop network-coding-based MAC protocols with scalable and efficient data gathering routing protocol
- Develop an energy-aware scheduling of surveillance
- Design and implementation of a topology reorganization scheme for reliable acoustic communications in UWSNs affected by shadow zones.
- Develop localization algorithms, including stationary localization algorithms, mobile localization algorithms and hybrid localization algorithms
- Underwater acoustic channel characterization in man-made noise, ambient noise, multi-path and Doppler spread
- Design of vision-guided navigation and tracking system

The product to be delivered and its relevance to the Nation's SECURITY and DEFENCE

- ***IoT Enabled Underwater sensor networks*** **(UWSNs)**
- ***AI powered Autonomous underwater vehicles*** **(AUVs)**
- ***Distributed Tactical Surveillance System*** that employs autonomous underwater vehicles and fixed underwater sensors can collaboratively monitor areas for surveillance, reconnaissance, targeting and intrusion detection systems
- ***AI powered Environmental Monitoring System*** using UWASNs that can perform pollution monitoring (chemical, biological and nuclear)
- ***IoT Enabled Disaster Warning Systems*** using UWASNs that can measure seismic activity from remote locations to provide tsunami warnings to coastal areas and study the effects of submarine earthquakes

Significance and Innovation: Underwater sensor nodes employ acoustic communications to realize wireless functionality in water. As compared with existing radio transmissions in wireless sensor networks (WSNs), the key developmental challenges of acoustic transmissions include: high bit error rate, long propagation delay, lower transmission rate, power consumption, limited bandwidth and noise. To reduce the energy cost of UWSNs, the periodic wake-up and sleep concept was employed in several medium access control (MAC) protocols. The underwater sensor node data is meaningless without location information. Multiple autonomous underwater vehicles (AUVs) are equipped with underwater wireless sensors are used in exploration of natural undersea resources, marine surveillance, river and sea pollution detection and monitoring and gathering of scientific data in collaborative sensing and monitoring strategies. The underwater channel is severely impaired, especially due to multi-path and fading. The battery power is limited and usually batteries cannot be recharged because solar energy cannot be exploited. The underwater sensors are prone to failure due to corrosion and aquatic organisms. The UWSNs of an underwater monitoring system require greater levels of water resistance. The amount of data that can be sensed during the monitoring by every sensor node is limited by the storage capacity.

Key parameters determining AUV characteristics are: maximum working speed, depth of operation, payload capacity and mission time, which are highly interrelated. The various issues considered during design are as follows:

- Configuration and Modularity
- Degrees of freedom, and Stability
- Near neutral buoyancy and Hydrodynamic modeling
- Pressure Hull design and Energy system
- Navigational Sensors and Communication
- Navigation and control and Payload Sensors

The AUV is equipped with a number of navigational (Inertial Navigation System, Depth Sensor, Altimeter, Doppler Velocity Log, Forward Looking Sonar, Global Positioning System, APOS) and payload sensors (Side Scan Sonar, camera, CTD) for execution of its operation successfully.

Participating Industry with an explanation of why they are interested and where does this product fit into their roadmap.

<u>Pentagon Rugged Systems Pvt Ltd, Hyderabad</u>

Pentagon Rugged Systems started in the year 2003 with main focus on rugged mil grade systems, Industrial Automation and total solution serving all the wings of Indian Armed Forces. PRS is one of the leading system integrator and solution providers and working with R & D Establishments and the DRDO laboratories in the country. Also, PRS closely associated with various public and private sectors for various defense projects.

Pentagon Rugged System are primarily focused in extending service to the major research and development where there is more scope to challenge the environment there by meeting military standard and Pentagon Rugged Systems are associated with the worldwide leader in art and science of the ruggedization of electronic equipment for harsh environments.

The major projects and R&D activities are: Autonomous underwater vehicles (AUVs), Portable Target System for Field Training, Unmanned Ground Vehicle, Pick and place robotic arms for various hazardous material, Stage Separation monitoring system in Rocket and Missiles, On Board and on line Video Transmission using rugged Cameras. Trauma Care Training Simulator, Customization of Ruggedized Computer Systems with Consoles, Tank Driving Simulators, Global Positioning System and simulators, Sub-System for Weather Warning Systems, Simulator for Various missile applications.

Role and Responsibilities of Members of Research Institutions

- Design and implementation of the following functional modules.
    - Underwater sensor networks (UWSNs) hardware with multiparameter sensing and communication modules.
    - Network-coding-based MAC protocols with scalable and efficient data gathering routing protocol.
    - Energy-aware scheduling of surveillance.
    - A topology reorganization scheme for reliable acoustic communications in UWSNs affected by shadow zones.
    - Localization algorithms, including stationary localization algorithms, mobile localization algorithms and hybrid localization algorithms.
    - Underwater acoustic channel characterization in man-made noise, ambient noise, multi-path and Doppler spread.
- Testing and validation of underwater sensor networks (UWSNs) based environment monitoring, oceanographic data collection, pollution monitoring, offshore exploration, disaster warning, assisted navigation and tactical surveillance systems.

Role and Responsibilities of Participating Industry

- Design of autonomous underwater vehicles (AUVs)
- Embedded Software
- Hardware and Software Integration
- Software Testing & Maintenance Services
- Field Testing and Validation

3.2.9 Offshore Bio & Mineral-resources

In this secondary area following work packages are identified:

1. Smart Pond Monitoring System for Aquaculture Farming, Wetland monitoring System, and Flood Monitoring System.
2. Drones for underwater resource surveillance and monitoring.

This project aims at the development of an autonomous aerial transport system for monitoring the large water bodies. The drones will be launched from a mother vessel to explore the remote areas. These drones will be equipped with the appropriate cameras and sensors for monitoring the water bodies. The data collected by these drones will be useful for NIOT, MPEDA, and CIFRI. In this proposal the proven battery/hybrid drones will be deployed in conjunction with swarming & docking features, the swarming enhancing the payloads beyond 100 kg, and the docking enhancing the range beyond 100 km.

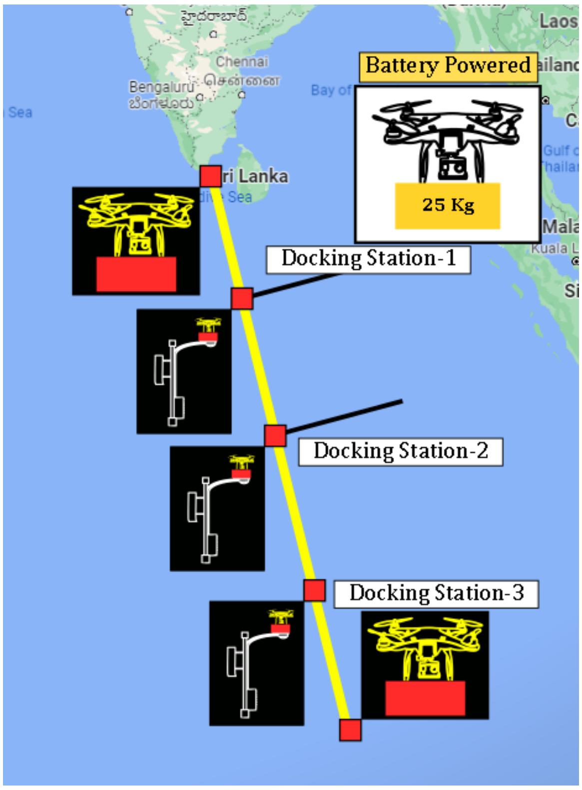


Figure 3.43: Illustration of the proposed autonomous aerial transport system

An open call will be made to attract the experts from throughout the nation to join the team of the areas mentioned in this chapter

Chapter-4

TIH Finance

4.1 Finance

The budget of the TIH has been divided into six sub-missions viz., (i) Technology Development (ii) Centers of Excellence (iii) HRD & Skill Development (iv) Innovation, Entrepreneurship, and Start-ups Ecosystem (v) International collaborations and (vi) TIH Management Unit. The details of the budget distribution have been provided in tables 4.1 to 4.4. The budget under the recurring, non-recurring, and capital head for all six proposed sub-missions has been summarised in table 4.1.

Table 4.1: TIH Cost Analysis (in Rs. Crore)

S No	Sub-Missions	Budget Head	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
1	Technology Development	Recurring	2.40	5.70	6.40	2.70	0.00	17.20
		Non-Recurring	0.60	7.60	10.22	3.58	0.00	22.00
		Capital	0.00	0.00	0.00	0.00	0.00	0.00
		Sub-Total	**3.00**	**13.30**	**16.62**	**6.28**	**0.00**	39.20
2	Centers of Excellence	Recurring	3.40	1.30	3.00	0.10	0.00	0.00
		Non-Recurring	2.40	5.03	10.59	0.00	2.00	0.00
		Capital	0.05	0.00	1.60	0.35	0.50	0.00
		Sub-Total	**5.85**	**6.33**	**15.19**	**0.45**	**2.50**	30.32
3	HRD & Skill Development	Recurring	4.15	7.15	4.37	5.40	2.91	23.98
		Non-Recurring	1.20	0.17	0.10	0.07	0.04	1.58
		Capital	0.00	0.00	0.00	0.00	0.00	0.00
		Sub-Total	**5.35**	**7.32**	**4.46**	**5.47**	**2.95**	25.55
4	Innovation, Entrepreneurship, and Start-ups Ecosystem	Recurring	1.05	7.14	10.47	1.55	1.05	21.26
		Non-Recurring	0.00	1.98	0.58	0.00	0.00	2.55
		Capital	0.00	2.98	1.73	0.00	0.00	4.70
		Sub-Total	**1.05**	**12.09**	**12.77**	**1.55**	**1.05**	28.51
5	International collaborations	Recurring	0.00	0.52	0.52	0.00	0.00	1.03
		Non-Recurring	0.00	0.20	0.20	0.00	0.00	0.40
		Capital	0.00	0.00	0.00	0.00	0.00	0.00

		Sub-Total	**0.00**	**0.72**	**0.72**	**0.00**	**0.00**	1.43
6	**TIH Management Unit**	Recurring	1.25	1.25	1.25	1.25	1.25	6.25
		Non-Recurring	0.00	0.00	0.00	0.00	0.00	0.00
		Capital	3.75	0.00	0.00	0.00	0.00	3.75
		Sub-Total	**5.00**	**1.25**	**1.25**	**1.25**	**1.25**	10.00
	Total	Recurring	**12.25**	**23.05**	**26.00**	**11.00**	**5.21**	77.51
		Non-Recurring	**4.20**	**14.98**	**21.68**	**3.65**	**2.04**	46.55
		Capital	**3.80**	**2.98**	**3.33**	**0.35**	**0.50**	10.95
	Grand Total in Rs Crore		**20.25**	**41.01**	**51.00**	**15.00**	**7.75**	**135.007**

The project will utilize 57.41% of the budget for recurring, 34.48% of the budget for non-recurring, and 8.11% of the budget for the capital. Table 4.2 summarized the year-wise distribution of the recurring, non-recurring, and capital budget head.

Table 4.2: Budget Head wise & year-wise estimated costs (Rs Crore)

S. No.	Budget Head	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total	%
1	Recurring	12.25	23.05	26.00	11.00	5.21	77.51	**57.41**
2	Non-Recurring	8.0	17.96	25.01	4.00	2.54	57.5	**42.59**
	Grand Total in Rs Crore	**20.25**	**41.01**	**51.00**	**15.00**	**7.75**	**135.007**	**100**

Table 4.3: Year-wise estimated costs (Rs. Crore)

S No	Sub-Missions	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total	%
1	**Technology Development**	3.00	13.30	16.60	6.30	0.00	39.20	29.04
2	**Establishment of CoEs**	5.85	6.33	15.19	0.45	2.50	30.32	22.46
3	**HRD & Skill Development**	5.352	7.32	4.464	5.466	2.95	25.552	18.93
4	**Innovation, Entrepreneurship and Start-up ecosystem**	1.05	12.09	12.77	1.55	1.05	28.51	21.11
5	**International collaborations**	0.00	0.72	0.72	0.00	0.00	1.43	1.06
6	**TIH Management Unit**	5.00	1.25	1.25	1.25	1.25	10.00	7.41
	Total Mission cost in Rs Crore	20.25	41.01	50.98	15.02	7.75	135.01	100.00

The six sub-missions viz., Technology Development, Centers of Excellence, HRD & Skill Development, Innovation, Entrepreneurship, and Start-ups Ecosystem, International Collaborations, and TIH Management Unit use 29.4%, 22.46% 18.93%, 21.11%, 1.06% and 7.02% of the total budget respectively. The year-wise distribution of the total budget for all six proposed sub-missions has been summarised in table 4.3.

In the first year of the project, a center of excellence will be established. Several technologies are intended to be developed in five years of this project. The HRD sub-mission will support more than 500 individuals during the project. There will be 20 skill development programs in this project; those will help in developing the skill of around 700 participants. Several programs are intended under the sub-mission 'Entrepreneurship, Innovation, and Start-ups' to provide temporary support at the initial stage.

Table 4.4: Year-wise Physical and Financial targets (Rs. Crore)

S No	Sub-Missions	Year 1		Year 2		Year 3		Year 4		Year 5		Total	
		Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial
1	Technology Development	6	3.00	9	13.30	10	16.60	3	6.30	0	0.00	28	39.20
2	Center of Excellences	0	5.85	0	6.33	0	15.19	0	0.45	0	2.50	0	30.32
3	HRD & Skill Development	54	5.35	231	7.32	147	4.46	178	5.47	162	2.95	772	25.55
4	Entrepreneurship, Innovation and Start-ups	16	1.05	29	12.09	29	12.77	21	1.55	16	1.05	110	28.51
5	International collaborations	0	0.00	1	0.72	1	0.72	0	0.00	0	0.00	2	1.43
6	Mission management Unit	1	5.00	0	1.25	0	1.25	0	1.25	0	1.25	1	10.00
	Grand Total	**77**	**20.25**	**270**	**41.01**	**187**	**50.98**	**202**	**15.02**	**178**	**7.75**	**913**	**135.0**

The international collaboration will be taken forward, particularly after the first year of the project. For the smooth functioning of all the sub-missions, a mission management unit will be established in IITG. A feasible target has been assigned for each sub-mission. These targets, along with the budget, are summarised in Table 4.4. The details on the budget under each sub-mission have been provided in the following sections.

Justification: Technology Development

Three schemes are identified for the technology development viz., (i) expert-driven new knowledge generation /discovery, (ii) development of products/ prototypes from existing knowledge (by experts or teams), and (iii) technology /product delivery in specific sectors. The details of the number of projects to be considered under these schemes along-with the budget are summarised in Table 4.5.

Table 4.5: Estimated Expenditure (Rs crore) for Sub-Mission -Technology Development

			Targets						Budget					
S. No.	**Major Components**	**Unit Cost**	**Yr1**	**Yr2**	**Yr3**	**Yr4**	**Yr5**	**Total**	**Yr1**	**Yr2**	**Yr3**	**Yr4**	**Yr5**	**Total**
1	Expert Driven New Knowledge Generation /Discovery	0.5	6	6	7	1	0	20	3.00	3.00	3.50	0.50	0.00	10.00
2	Development of products/ prototypes from existing Knowledge (By experts or teams)	4.3	0	1	2	1	0	4	0.00	4.30	8.60	4.30	0.00	17.20
3	Technology /product delivery in specific sectors	3	0	2	1	1	0	4	0.00	6.00	4.50	1.50	0.00	12.00
	Total	**7.8**	**6**	**9**	**10**	**3**	**0**	**28**	**3.00**	**13.30**	**16.60**	**6.30**	**0.00**	**39.20**

Table 4.6. EXPERT DRIVEN RESEARCH

S No	**Budget Head**	**ESTIMATED COST IN Rs LAKHS**			
		Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
A.	**Recurring**				
	1. Project Staff	9	8	8	25
	2. Domestic Travel	1.5	2	1	4.5
	3. Contingencies	0.5	0.5	0.5	1.5
	4. Consumables	1	0.5	1	2.5
	5. Miscellaneous	0.5	0.5	0.5	1.5
	6. Over Heads	1.5	1.5	2	5
	Sub-Total	**14**	**13**	**13**	**40**
B.	**Non-Recurring**				0
	1. Equipment	3	3	4	10
	Sub-Total	**3**	**3**	**4**	**10**
C.	**Capital**	0	0	0	0
	Grand Total	**17**	**16**	**17**	**50**

The duration for an expert-driven new knowledge generation /discovery will be three years. An amount of 50,00,000 will be provided under the recurring and non-recurring heads. The details on the budget for expert-driven research is provided in Table 4.6.

The duration for the **development of products/prototypes from an existing knowledge** will be five years. An amount of 4,30,00,000 will be provided under the recurring and non-recurring heads. Approximately 70% budget will be provided for equipment (non-recurring) head. The details on the budget for the development of products/ prototypes from existing knowledge are provided in Table 4.7.

Table 4.7. DEVELOPMENT OF PRODUCTS/ PROTOTYPES FROM EXISTING KNOWLEDGE

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		Ist Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	**Recurring**						
	1. Project Staff	10	10	20	10	10	60
	2. Domestic Travel	4	4	4	4	4	20
	3. Contingencies	2	2	2	2	2	10
	4. Consumables	3	3	3	3	3	15
	5. Miscellaneous	3	3	3	3	3	15
	6. Over Heads	2	2	2	2	2	10
	Sub-Total	**24**	**24**	**34**	**24**	**24**	**130**
B.	**Non-Recurring**						
	1. Equipment	200	100	0	0	0	300
	Sub-Total	**200**	**100**	**0**	**0**	**0**	**300**
C.	**Capital**						
	Grand Total	224	124	34	24	24	430

The duration for the **development of technology/product in specific sectors** will be five years. An amount of 3,00,00,000 will be provided under the recurring and non-recurring heads. Here, a 67% budget will be provided for equipment (non-recurring) head. The details on the budget for the development of technology/product in specific sectors are provided in the following Table 4.8.

Table 4.8. DEVELOPMENT OF TECHNOLOGY/ PRODUCT DELIVERY IN SPECIFIC SECTORS

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		Ist Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	**Recurring**						
	1. Project Staff	10	10	20	10	10	60
	2. Domestic Travel	3	3	2.5	2	2	12.5
	3. Contingencies	2	3	2	2	1	10
	4. Consumables	2	2	2	2	2	10
	5. Miscellaneous	0.5	0.5	0.5	0.5	0.5	2.5
	6. Over Heads	1	1	1	1	1	5
	Sub-Total	**18.5**	**19.5**	**28**	**17.5**	**16.5**	**100**
B.	**Non-Recurring**						
	1. Equipment	100	100	0	0	0	200
	Sub-Total	**100**	**100**	**0**	**0**	**0**	**200**
C.	**Capital**	**0**	**0**	**0**	**0**	**0**	**0**
	Grand Total	**118.5**	**119.5**	**28**	**17.5**	**16.5**	**300**

Justification: Center of Excellences

A center of excellence entitled "**Center of Excellences on Manufacturing of Cyber-Physical Systems (CEMCPS)**" will be developed in this project. The primary focus of the CEMCPS will be on providing the manufacturing facility of different products useful for a CPS. The crucial products such as motors, electronics devices, mechanical devices, controllers, actuators, sensors, etc. will be in-house designed and manufactured. The CEMCPS will have a workshop equipped with the cutting edge technologies such as 5-axis CNC machines, Polymeric & Metal 3D Printers, Lasers, Welding units, Robotic arms, and CAD/CAM/CAE software.

The COE will consist of eight different laboratories viz., (i) Product Development Laboratory, (ii) Reverse Engineering Laboratory (3) Fabrication Laboratory (4) Virtual & Augmented Reality Laboratory (5) E-Mobility Laboratory (6) Internet of Things Laboratory (7) Product Testing Laboratory and (8) Sensor & Actuator Fabrication Laboratory. The budget for the CEMCPS will be 30.50 cr, and it will be established in first two year of the project, as shown in Table 4.9.

Table 4.9: Estimated Expenditure (Rs crore) for the Sub-Mission Center of Excellences

Major Components	Unit cost	Targets						Budget					
		Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
Center of Excellences on Manufacturing of Cyber Physical Systems	30.30	0.19	0.21	0.50	0.01	0.08	1	5.85	6.33	15.19	0.45	2.50	30.32
Total		0.19	0.21	0.50	0.01	0.08	1	5.85	6.33	15.19	0.45	52.50	30.32

The budget of CEMCPS will be distributed among different heads as 8.0 cr. For recurring, 20.0 cr. For non-recurring and 2.5 cr. for capital, as shown in Table 4.10.

Table 4.10. Center of Excellence on Manufacturing of Cyber-Physical Systems

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	**Recurring**						
	1. Project Staff	100	100	100	100	100	**500**
	2. Domestic Travel	15	15	15	15	15	**75**
	3. Contingencies	10	10	10	10	10	**50**
	4. Consumables	15	15	15	15	15	**75**
	5. Miscellaneous	10	10	10	10	10	**50**
	6. Over Heads	10	10	10	10	10	**50**
	Sub-Total	160	160	160	160	160	**800**
B.	**Non-Recurring**						
	1. Lab R&D Infrastructure & Equipment	240	505	1055	0	200	**2000**
	Sub-Total	1000	750	250	0	0	**2000**
C.	**Capital**						
	1. Furnishing, Tables, Chairs, Cubicles, Electrical works, and other Capex items	50	50	50	50	50	**250**
	Sub-Total	50	50	50	50	50	**250**
	Grand Total	**1210**	**960**	**460**	**210**	**210**	**3050**

Table 4.11: Estimated Expenditure (Rs crore) for HRD & Skill Development

	Major Components	Unit cost	Targets						Budget					
			Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	**Schemes for UG courses**													
	(i) Graduate Internships	0.005	8	98	50	56	88	300	0.04	0.49	0.25	0.28	0.44	1.5
	(ii) Development Fund (For Projects done under Graduate Internships)	0.01	0	47	56	44	15	162	0	0.47	0.56	0.44	0.15	1.62
	(iii) CPS Infrastructure development fund	1	0	0	1	0	0	1	0	0	1	0	0	1
2	**Schemes for PG courses**													
	(i) Post-Graduation Fellowships	0.03	0	10	10	10	20	50	0	0.3	0.3	0.3	0.6	1.5
	(ii) Development Fund (For Projects done under PG Fellowships)	0.02	0	6	6	7	14	33	0	0.12	0.12	0.14	0.28	0.66
	(iii) CPS Infrastructure development fund	1	0	0	1	0	0	1	0	0	1	0	0	1
3	**Doctoral Fellowships**	0.17	12	12	0	7	0	31	2.04	2.04	0	1.19	0	5.27
4	**Post-Doctoral Fellowships**	0.22	5	7	0	3	0	15	1.1	1.54	0	0.66	0	3.3
5	**Faculty Top-up**	0.024	28	40	16	44	20	148	0.672	0.96	0.384	1.056	0.48	3.552
6	**Faculty Fellowship**	0.3	0	2	1	2	1	6	0	0.6	0.3	0.6	0.3	1.8
7	**Chair Professor**	0.3	0	1	1	2	2	6	0	0.3	0.3	0.6	0.6	1.8
8	**Professional Skill Development Workshop**	0.05	0	6	5	2	2	15	0	0.3	0.25	0.1	0.1	0.75
9	**Upgrading PG Programme**	1.5	1	0	0	0	0	1	1.5	0	0	0	0	1.5
10	**Advanced Skill Training School**	0.1	0	2	0	1	0	3	0	0.2	0	0.1	0	0.3
	Total		54	231	147	178	162	772	5.352	7.32	4.464	5.466	2.95	25.552

Justification: HRD & Skill Development

In HRD & Skill Development sub-mission, following activities are identified:

- Providing fellowships for UG, PG, Doctoral, Post-Doctoral, Faculties and Chair professors,
- Setting up groups of faculty members and students in association with organizations like IEEE etc.
- Offering temporary research and development positions for industrial engineers
- Organizing the preliminary and advanced skill development workshops,
- Conducting seminars, short term courses and conferences periodically
- Contests and competitions shall be organized, and prizes/awards shall be given to winners of these contests.

Table 4.11 shows the distribution of the budget of HRD & skill development under different components.

Schemes for UG courses
Graduate Internships (for 10 months): UG fellowship for a period of 10 months, i.e., during the final year project duration. The fellowship will be Rs. 5,000/- per month for 10 months. The total estimated cost per unit is Rs 50,000-00 under Recurring cost. No Non-Recurring and Capital expenditure involved in this component. The Btech Student will be engaged with the regular course work also.
Development Fund (For Projects done under Graduate Internships): When needed, a grant of Rs. 1,00,000 per two students can be given for Projects done by UG Students Undergoing the CHANAKYA-GI. The total estimated cost is Rs 1,00,000-00 per unit under Recurring cost. No Non-Recurring and Capital expenditure involved in this component.
CPS Infrastructure development fund: One time Grant of Rs. 1,00,00,000 for infrastructure support for Under-graduate labs in CPS and Allied areas to the institution where GI is offered. The total estimated cost per unit is Rs 1,00,00,000-00 under Non-Recurring and no Capital expenditure involved under this component.

Schemes for PG courses
PG Fellowships (for 2 years): PG fellowship for a period of 2 years, i.e., during M. Tech./ M.S./ M.E. The fellowship will be Rs. 12,400/- per month for 2 years. The total estimated cost per unit is Rs 2,97,600-00 under Recurring cost. No Non-Recurring and Capital expenditure involved in this component.

Development fund for Projects done by PG Students undergoing the CHANAKYA-PG Fellowships: When needed, a grant of Rs. 2,00,000 can be given for Projects done by UG Students Undergoing the CHANAKYA-GI. The total estimated cost is Rs 2,00,000 per unit under Recurring cost. No Non-Recurring and Capital expenditure involved in this component.
Infrastructure Support linked to CHANAKYA- PGF: One time Grant of Rs. 1,00,00,000 for infrastructure support for Post-graduate labs in CPS and Allied areas to the institution where GI is offered. The total estimated cost per unit is Rs 1,00,00,000-00under Recurring cost. No Non-Recurring and Capital expenditure involved in this component.

Doctoral Fellowships
Doctoral Fellowships (duration 3 years to 4 years): Doctoral fellowship for a period of 4 years i.e., during PhD. The fellowship will be Rs.35,000/- per month. The total estimated cost per unit is Rs 17,,00,000/- Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

Post-Doctoral Fellowships
Doctoral Fellowships (duration 3 years to 4 years): PD fellowship for a period of 2 to 3 years i.e., during Post Doctoral research. The fellowship will be Rs.60,,000/- per month. The total estimated cost per unit is Rs.22,00,000.00 under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

Faculty Top-Up
Faculty Top-Up: A top-up of Rs. 20,000/- per month will be awarded to the active faculty members of CPS. The total estimated cost per unit is Rs 2,40,000/- under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

Faculty Fellowship
Faculty Fellowships (for 3 years) (On the lines of INSPIRE faculty award Scheme): In line with INSPIRE Faculty fellowships, faculty/ young researchers with Ph.D. will be awarded a fellowship for a duration of 3 years and could be attached to CoEs or research/ academic institutes. The fellowship will be Rs.80,000-00 per month, with all-inclusive. The total estimated cost per unit is Rs.30,00,000-00 under Recurring cost. No Non-Recurring and Capital expenditure involved in this component.

Chair Professor
Chair Professor Fellowships (for 3 years) (On the lines of National Geospatial Chair Professor Scheme): Chair Professor Fellowship for a period of 36 months, i.e., during the duration of guidance of project in CoEs. The fellowship will be an honorarium for Max. Rs.80,000/- per month for 3 years, the annual contingencies/ Travel/ Miscellaneous costs of Rs.1.20 Lakh for travel to various institutions for attending conferences; review meetings, etc. and to propagate the technologies in CPS and institutional overhead @ of 10% subject to a maximum of Rs.1.00 lakh per annum. The total estimated cost per unit is Rs.30,00,000-00 under Recurring cost. No Non-Recurring and Capital expenditure involved in this component.

15 Professional Skill Development Workshops will be conducted in the five years of the project. Each workshop will have 20 participants and hence a total of 300 participants in 15 workshops. It will be a 5 days' workshop with an average expenditure of 5000/- per candidate. Therefore, for each workshop Rs 5,00,000/- will be required with Rs 3,10,000/- recurring cost and Rs 1,90,000/- non-recurring cost. There will be no capital cost involved in this workshop.

Table 4.12: Professional Skill Development Workshop

S No	Budget Head	Amount in Rs Lakhs
A.	**Recurring**	
	1. Contingencies	0.4
	2. Travel, honorarium to experts etc	2.5
	3. Miscellaneous	0.2
	Sub-Total	**3.1**
B.	**Non-Recurring**	
	1. Teaching Material	0.9
	2. Used case studies, Books, Journals, etc	1
	Sub-Total	**1.9**
C.	**Capital**	**0**
	Grand Total	**5**

For upgrading the PG program, one-time Grant of Rs. 1,50,00,000 will be required. The distribution of the budget in recurring and non-recurring cost has been summarized in Table 4.13.

A training institute will be established, which will offer an advance skill development programs in the CPS. As 100 candidates are intended to provide the advance skill development, a grant of a total Rs 10.00 lakhs will be required for two years. The budget of this training institute has been summarized in Table 4.14. This program will be conducted four times therefor it will provide training to 400 candidates.

Table 4.13. Upgrading the PG Programme

S No	Budget Head	Amount in Rs Lakhs
A.	**Recurring**	
	Contingencies	20
	Miscellaneous	10
	Sub-Total	**30**
B.	**Non-Recurring**	
	Equipment	100
	Teaching Material	10
	Books, Journals, etc	10
	Sub-Total	**120**
C.	**Capital**	**0**
	Grand Total	**150**

4.14. Advanced Skill Training Institute

S No	Budget Head	Amount in Rs Lakhs		
		Year-1	Year-2	Total
A.	**Recurring**			
	Contingencies	0.5	0.5	1
	Travel, honorarium to experts, etc	2	2	4
	Miscellaneous	1	1	2
	Sub-Total	**3.5**	**3.5**	7
B.	**Non-Recurring**			0
	Equipment	**2**	**0**	2
	Teaching Material	0.3	0.3	0.6
	Used case studies, Books, Journals etc	0.2	0.2	0.4
	Sub-Total	**2.5**	**0.5**	3
C.	**Capital**	**0**	**0**	0
	Grand Total	**6**	**4**	10

Justification: Innovation, Entrepreneurship & Start-ups Ecosystem

Start-ups and other corporate ventures in the domain area of the CPS, initiated by students at IIT Guwahati and other reputed institutes, shall be provided temporary support at the initial stages. Several activities are identified under this submission. The budget allocated for each activity has been summarised in Table 4.15.

Table 4.15: Estimated Expenditure (Rs crore) for Innovation, Entrepreneurship & Start-ups ecosystem

Major Components		Unit cost	Targets						Budget					
			Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	Grand Challenges and Competitions	3.825	0	1	0	0	0	1	0.00	3.83	0.00	0.00	0.00	3.83
2	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS	2.5	0	1	0	0	0	1	0.00	2.50	0.00	0.00	0.00	2.50
3	Entrepreneur In Residence	0.04	10	10	10	10	10	50	0.40	0.40	0.40	0.40	0.40	2.00
4	Start-up	0.1	5	15	15	10	5	50	0.50	1.50	1.50	1.00	0.50	5.00
5	Technology Business Incubator (TBI)	7.43	0	0.5	0.5	0	0	1	0.00	3.72	3.72	0.00	0.00	7.43
6	Dedicated Innovation Accelerator	2	0	0	1	0	0	1	0.00	0.00	2.00	0.00	0.00	2.00
7	Seed Support System	5	0	0	1	0	0	1	0.00	0.00	5.00	0.00	0.00	5.00
8	Social Entrepreneurship Program	0.15	1	1	1	1	1	5	0.15	0.15	0.15	0.15	0.15	0.75
Total			16	28.5	28.5	21	16	110	1.05	12.09	12.77	1.55	1.05	28.51

Grand Challenges and Competitions (GCC) will be conducted to motivate several ambitious entrepreneurs to convert their ideas into viable enterprises by the exploration of innovations. The competitions will be conducted at all India level. It is a pre-incubation activity targeted mainly at scouting of innovations for building a pipeline for successful TBI. There are 100 participants envisioned for this activity. The budget required for this one-time activity will be Rs. 3.82 cr. and it will be conducted in the third year of the project. The distribution of the budget for GCC in the recurring, non-recurring, and capital head has been summarized in Table 4.16.

Table 4.16. Grand Challenges and Competitions (GCC)

S No	Budget Head	Amount in Rs Lakhs
A.	**Recurring**	
	I. All India Competitions (Operating Costs for 20 challenges under 1 GCC)	
	1. Human Resources	75
	2. Travel, honorarium to experts etc	100
	3. Miscellaneous	10
	4. Marketing, promotion and publicity	10
	5. Networking and training programmes	25
	6. Other administrative expenses including consumables, printing, publications, books, journals etc	25
	II. Awards	
	1. Reward @ Rs 2.50 lakhs per winner for 5 ideas	12.5
	Sub-Total	**257.5**
B.	**Non-Recurring**	
	I. Prototyping Grant/ Seed Fund @ Rs 20.00 Lakhs each for 5 winners	100
	Sub-Total	**100**
C.	**Capital**	
	1. Competitions location-specific arrangements like furniture, tables, chairs, dashboards, product development, and demonstration arrangements, etc	25
	Sub-Total	**25**
	Grand Total	**382.5**

There is a definite need to address the gap in the very early stage idea/ proof of concept funding. The *Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)* program focuses on addressing the idea to prototype funding gap. This program would attract a large number of youngsters to come forward to try out their ideas without actually worrying about failure.

Eventually, such an approach would bring in a large number of potential ideas into the incubation programs, thereby increasing the flow of quality incubate to the incubators. Academic Institutions and/or B-Schools/ Existing STEP/TBI will be the potential participants in this activity. The total budget for this activity will be Rs. 2.5 Cr. and it will be conducted in the second year of the project. The distribution of the budget for PRAYAS in the recurring, non-recurring, and capital head has been summarized in Table 4.17.

Table 4.17. Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)

S No	Budget Head	Amount in Rs Lakhs
A.	**Recurring**	
	1. Prototyping Grant/ Seed Fund @Rs 10.00 Lakhs each for 10 ideas	100
	2. Travel, honorarium to experts etc	5
	3. Miscellaneous	3
	4. Other administrative expenses including consumables, printing, publications, books, journals etc	2
	Sub-Total	**110**
B.	**Non-Recurring**	
	1. Raw material, Spare parts, consumables, etc	20
	2. Fabrication/ Synthesis charges of working model development or process that includes design engineering/ Consultancy/ Testing/ Experts costs etc	20
	Sub-Total	**40**
C.	**Capital**	
	1. Establishment of PRAYAS Center, Fabrication LAB, location-specific arrangements like furniture, tables, chairs, dashboards, product development, and demonstration arrangements, etc	50
	2. Operation and maintenance of Fab lab @ Rs 10.00 lakhs per year for 5 years	50
	Sub-Total	**100**
	Grand Total	**250**

Entrepreneur In Residence

This activity is to inspire the best talents to be entrepreneurs, minimize the risk involved in pursuing start-ups, and to partially set off their opportunity costs of high paying jobs. A grant of maximum Rs. 33,333.33 per month for a period of 12 months. The total estimated cost per unit is Rs 3.60 Lakhs under recurring.

Start-up

This activity is intended to promote student start-ups, accelerate the journey of idea to prototype by providing initial funding assistance, and take forward student innovations to the commercialization stage. A one-time grant of Rs 10.00 Lakhs to each selected student start-up. The total estimated cost per unit is Rs 10.00, Lakhs under recurring.

A Technology Business Incubator (TBI) is intended to enhance the prospects of success of technology-based new enterprises. Business incubation has been globally recognized as an important tool for job creation and economic development. The expected outcome of this TBI will be Start-ups, new products/technologies developed/ innovations, commercialization. The budget for the proposed TBI is Rs. 7.43 Cr. and it will be established in the 2nd year of the project. The distribution of the budget for TBI in the recurring, non-recurring, and capital head has been summarized in Table 4.18.

Table 4.18 TBI

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A	**Recurring**						
	1. Human Resources**(Core Management Team /Mentors and Tech Support Persons /Business Development Professionals)	25	25	25	25	25	**125**
	2. Travel (@ Rs. 40,000 pm)	3.6	3.6	3.6	3.6	3.6	**18**
	3. Utility and maintenance	5	5	5	5	5	**25**
	4. Marketing, networking & publicity	5	5	5	5	5	**25**
	5. Training Programmes, Events, and Start-up-Resonators	10	10	10	10	10	**50**
	6. Other Administrative Expenses including consumables, printing, publications, books, journals, etc.	5	5	5	5	5	**25**
	7. Miscellaneous and Contingencies	3	3	3	3	3	**15**
	Sub-Total	**56.6**	**56.6**	**56.6**	**56.6**	**56.6**	**283**
B	**Non-Recurring**						
	1. D&D Rooms (Dies & Designs, FAB lab)	15	15	15	15	15	**75**
	2. Office Equipment including state-of-the art communication network, Video Conferencing Facilities	5	5	5	5	5	**25**
	3. Contingencies for non-recurring expenditure and other items	3	3	3	3	3	**15**
	Sub-Total	**23**	**23**	**23**	**23**	**23**	**115**
C	**Capital**						
	1. Renovation/furnishing of space for CPS-TBI ; (20,000 sf ; @ 600 psf);(Furniture / Test Benches / Installations; Incubation Cubicles and Spaces /Interaction Centers) excluding the cost of land & building	36	24	24	24	12	**120**
	2. Thrust Area Equipment (Equipment /Machineries; Clean Rooms / Test Rigs / IT Systems; Instruments/Tools & Dies/Measuring Devices, etc)	50	50	50	50	25	**225**
	Sub-Total	**86**	**74**	**74**	**74**	**37**	**345**
	Grand Total	**165.6**	**153.6**	**153.6**	**153.6**	**116.6**	**743**

Dedicated Innovation AcceLerators (DIAL)

The budget includes Human resources, logistics, travel, mentoring, infrastructure, training, etc. The overall budget for running accelerators shall be Rs 1.5 crore per year with the participation of 10-15 start-ups. Rs 1.00 crore as soft loan and Rs.2.00 lakh per technology as project handling charges, as a grant to DIAL. The total estimated cost per unit is a maximum Rs 2.00 crore under recurring.

Seed Support System (SSS)

Given to eligible TBI's under the recurring head with a maximum cap of Rs 5.00 crore. However, the support should be utilized in 2-3 years. It is given as investment or debt to incubate with maximum support of Rs 1.00 crore. The total estimated cost per unit is Rs 5.00 crore under recurring.

Justification: International Collaborations

International collaborations dedicated to Cyber-Physical Systems will be built at the levels of researchers and thematic domain areas to leverage international best practices in India. It will be required to gain global competitiveness and international visibility. It will connect Indian research with global efforts in frontier areas in addressing global challenges. Through this activity, participation and access to international projects and advanced facilities will be encouraged. At-least 2 international collaborations are intended during this project. The details on the budget and target for international collaboration has been summarised in table 4.19.

Table 4.19: Estimated Expenditure (Rs crore) for International Collaborations

Major Component	Unit cost	Targets						Budget in Rs Crore					
		Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
International collaborations	0.72	0	1	1	0	0	2	0.00	0.72	0.72	0.00	0.00	1.43
Total		0	1	1	0	0	2	0.00	0.72	0.72	0.00	0.00	1.43

Each international collaboration required a budget under the recurring and non-recurring head. The budget for each international collaboration will be Rs. 0.72 Cr. The distribution of the budget for each international collaboration in the recurring and non-recurring head has been summarized in Table 4.20.

Table. 4.20 INTERNATIONAL COLLABORATIVE RESEARCH PROGRAMME

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS			
		Ist Yr	2nd Yr	3rd Yr	Total
A.	**Recurring**				
	1. Project Staff	5	5	5	15
	2. Contingencies	1	1	1	3

	3. Consumables	1	1	1	3
	4. Miscellaneous	1	1	1	3
	5. International travel/ exchange programmes	0	10	0	10
	6. International workshops/conferences/meetings	0	10	0	10
	7. Over Heads	2.5	2.5	2.5	7.5
	Sub-Total	**10.5**	**30.5**	**10.5**	51.5
B.	**Non-Recurring**				
	1. Equipment	10	10	0	20
	Sub-Total	**10**	**10**	**0**	20
C.	**Capital**	0	0	0	0
	Grand Total	**20.5**	**40.5**	**10.5**	71.5

Justification: TIH Management Unit

A TIH management unit will be established in the first year of the project. The budget for the TIH Management unit is Rs. 10 Cr. which has been summarised in Table 4.21.

Table 4.21: Estimated Expenditure (Rs crore) for TIH Management Unit

Major Components of Sub-Missions	**Unit cost**	**Targets**						**Budget**					
TIH Management Unit	10	0.5	0.125	0.125	0.125	0.125	1	5.00	1.25	1.25	1.25	1.25	10.00
Total	**10**	1	0	0	0	0	1	5.00	1.25	1.25	1.25	1.25	10.00

TIH management unit will consist of 5 rooms in the new research building of IIT Guwahati, which will occupy an area of nearly 34,000 square feet. The rent for this facility will be Rs 35/sqf/month; therefore, *approximately* the total rent will be 1.25 Cr./year. Also, capital investment such as office furniture, conference rooms, meeting expenses will be required. The distribution of the budget for the TIH management unit under recurring and capital cost has been summarised in Table 4.22.

4.22 TIH Management Unit (TIH-MU)

S No	Budget Head	ESTIMATED COST IN Rs Crore					
		Ist Yr	2nd Yr	3rd Yr	4th yr	5th yr	Total
A.	**Recurring**						
	Rent	1.25	1.25	1.25	1.25	1.25	6.25
B.	**Capital**						
	Office Furniture	3.25	0	0	0	0	3.25
	Meeting Expenses	0.5	0	0	0	0	0.5
	Grand Total	**5**	**1.25**	**1.25**	**1.25**	**1.25**	**10**

4.2Time Frame

Activity plan: Targets, Milestones on Timeline / GANTT Chart

First Year (Shown Quarterly)

Milestone	1st Q.	2nd Q.	3rd Q.	4th Q.
Purchase and installing of R & D infrastructure and equipment				
Initiate process of hiring Project Staff				
Setting up of Center of Excellence in Manufacturing of Cyber Physical Systems				
Initiate a periodic process of holding seminars, short-term courses, tutorials and workshops				
Setup Consultancy service centre at TIH, IITG				
Conduct first student and Industrial contest in Technologies for Underwater Exploration				
Setup Technology Business Incubator at IIT Guwahati				
Apply for R & D projects in domain area of Technologies for Underwater Exploration				
Conceptual Design of Technologies proposed by TIH				
Initiation of Setting up Manufacturing Facility				

Second Year (Shown Quarterly)

Milestone	1st Q.	2nd Q.	3rd Q.	4th Q.
Continue, if required, with purchase and installing R & D infrastructure and equipment				
Continue process of hiring Project Staff (if required)				

Continue periodic process of holding seminars, short-term courses, tutorials and workshops				
Continue Consultancy service centre at TIH, IITG				
Conduct second and third student and Industrial contest in Technologies for Underwater Exploration				
Continue Technology Business Incubator at IIT Guwahati				
Apply for R & D projects in domain area of Technologies for Underwater Exploration				
(Continuation) - Conceptual Design of Technologies proposed by TIH				
Prototype Development of Technology Design(s) made in first year				
Continuation of Setting up Manufacturing Facility				

Third Year (Shown Quarterly)

Milestone	1st Q.	2nd Q.	3rd Q.	4th Q.
Continue periodic process of holding seminars, short-term courses, tutorials and workshops				
Continue Consultancy service centre at TIH, IITG				
Conduct with student and Industrial contests in Technologies for Underwater Exploration				
Apply for R & D projects in domain area of Technologies for Underwater Exploration				
Initiation of Training programs for Industrial Engineers				
(Continuation) - Conceptual Design of Technologies proposed by TIH				
Prototype Development of Technology Design(s) made in second year				
Manufacturing and Commercialization of technologies/products developed in first two years				

From the fourth and fifth year onwards, the major modes of revenue generation shall be specifically targeted as given below

(a) Continuation of research in domain area of Technologies for Underwater Exploration, Technology development and commercialization.
(b) Participating in Research in domain area of Technologies for Underwater Exploration by participation in National and International Collaborative efforts.
(c) Obtaining advanced R & D grants from various funding agencies for development of cutting-edge technologies
(d) Periodic continuation of consultancy, education services and Industrial training programs.
(e) Engaging in large scale mass manufacturing of various products, developed within and outside the TIH.
(f) Continuation of student and industrial contests and increased involvement of students and researchers in domain area of Technologies for Underwater Exploration.
(g) Conducting of research in related areas of the Cyber-Physical Systems in the NM-ICPS list of domain areas.

4.3 Cost-Benefit Analysis

These will be carried out by the Project evaluation committee, from time to time, depending upon the specific projects taken by the Hub. As the Hub operate like section 8 company, it shall ensure that all profits shall be redirected towards further development of the Hub and societal benefit.

4.4 Risk Analysis

As the TIH deals with underwater exploration, where the team members will have continuous interaction with the environment and society, there are several risks which have to be faced by the TIH. These risks have to be analysed depending upon the aims and targets of the Hub and the activities that the Hub undertakes. These risks shall be dealt with by the Program Directorate listed in Chapter 5 of this document, depending upon the projects being dealt with by this Hub.

Chapter 5

TIH Management

5.1 The Activities of the TIH

The activities of the Hub shall be performed by a TIH team having six wings. The structure of these wings is given below.

1) Coordination Wing (CW) – The project director (PD) shall be the head of this wing. It shall comprise a financial co-ordinator and the heads of each of the other wings. The primary objective of this wing is to coordinate all activities between other wings of the Hub and also the activities of the Hub with all its collaborators and Industry partners. This wing shall also be responsible for the setting up and administration of world class facilities for R & D and development of effective Human Resource in the Hub. All communication between the other wings of the Hub and the HGB (Hub Governing Body) shall be done by the CW.
2) Basic Research Wing (BRW) – This wing shall be headed by Faculty members from IIT Guwahati who are part of the TIH team. It shall comprise faculty members at IIT Guwahati and any collaborators dealing with fundamental research on Technologies for Underwater Exploration (mentioned in chapter 1 of this document).
3) Applied Research wing (APRW) – This wing shall be headed by Faculty members from IIT Guwahati who are part of the TIH team. It shall comprise faculty members at IIT Guwahati, collaborators, Industry partners dealing with activities of BRW (mentioned in part 1. (iii) of this document).
4) Advanced Research Wing (ARW) – This wing shall be headed by Faculty members from IIT Guwahati who are part of the TIH team and shall comprise Faculty members, collaborators (both national and international) and members from Industry, conducting research on advanced topics that require super-specialization in the given domain area of Technologies for Underwater Exploration (mentioned in part 1. (iii) of this document).
5) Technology Incubation and Entrepreneurship Wing (TIEW) – This wing shall be headed by a Faculty member from IIT Guwahati who is a part of the TIH team. The primary objective of this wing shall be to seek out modes for revenue generation. Firstly, this wing shall identify and seek out potential collaborators and funding agencies who would provide research grants for conducting basic/applied research as per the mandate of this Hub. Secondly, this wing shall also identify budding entrepreneurs and venture capitalists who

have/wish to setup firms in the domain area of Technologies for Underwater Exploration. Thirdly, this wing shall seek out new products that have a respectable market, and communicate the same to other wings to consider for research/analysis & design/manufacture. Fourthly, this wing shall be responsible for Technology Transfer, Patenting and other works relating to commercialization.

6) Education and Training Wing (ETW) – This wing shall be headed by a Faculty member from IIT Guwahati who is a part of the TIH team. The objective of this wing shall be to generate mechanisms for transfer of knowledge about the various fields of research activity in Technologies for Underwater Exploration to person(s) who may not be traditionally associated with such a field. The tasks of this wing shall be
   (a) Identify organizations involved with education and awareness programs on Technologies for Underwater Exploration, apply for and acquire seed grants from such organizations and utilize the same for the Education activity of this Hub.
   (b) To conduct workshops, short-term courses and seminars for the purpose of knowledge dissemination.
   (c) Development of Certificated Courses
   (d) Development of course structure and syllabi for formal education in Technologies for Underwater Exploration, video/audio/books
   (e) Skill Development in Technologies for Underwater Exploration
   (f) Tinkering Lab for UG/PG students. Certain PhD students shall also be encouraged to conduct research on various projects of the Hub.

A schematic of the structure of the TIH is as shown in Fig 5.1.

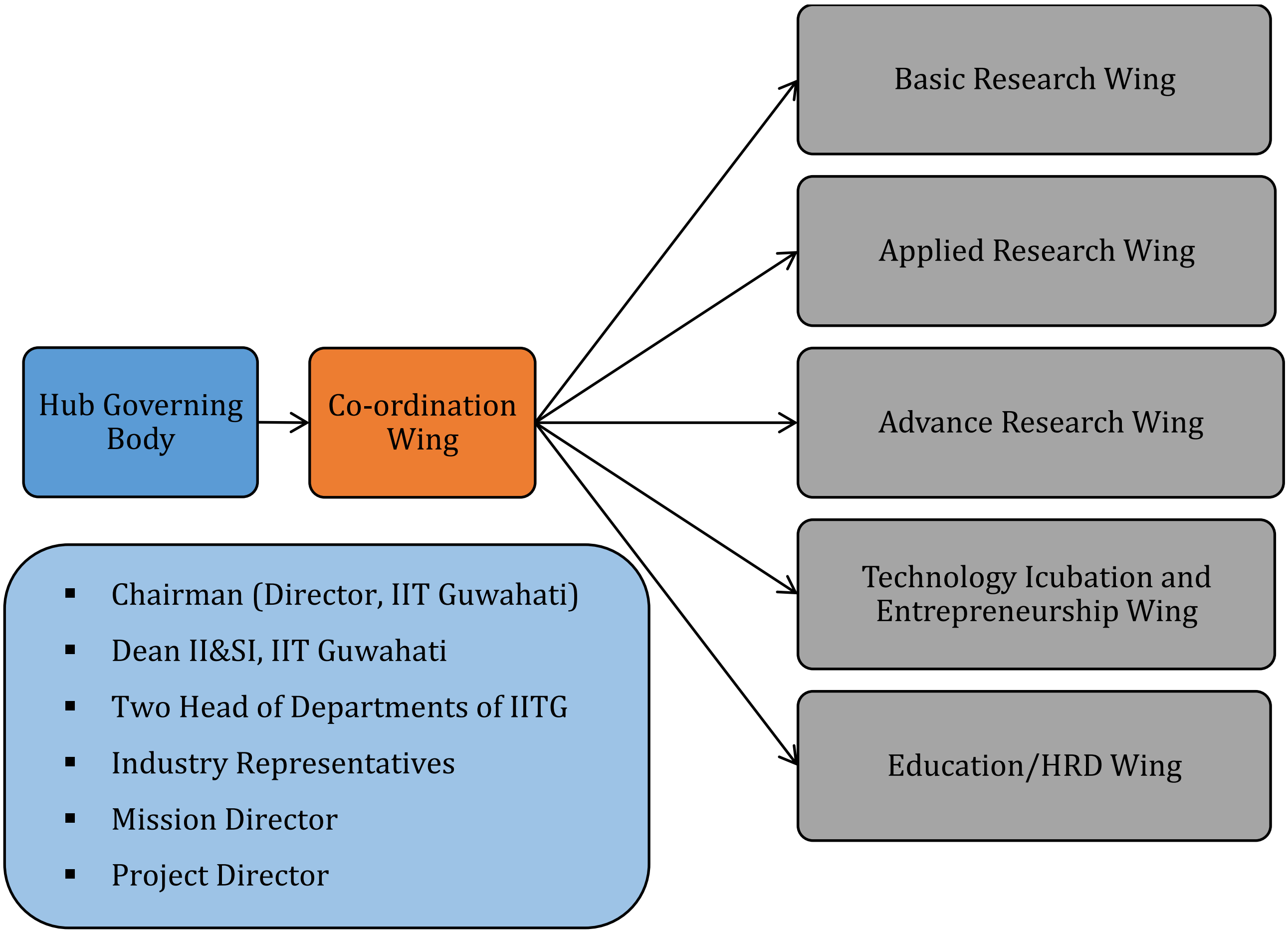


Fig 5.1 Overall TIH Management Structure

Project Advisory and Monitoring Committee

An advisory body will be setup to monitor the progress of all the projects in the TIH.

5.2 Team members with specialization

S. No,	Name of Team Member with Dept.	Area of Expertise
1.	Santosha Kumar Dwivedy (Professor), Department of Mechanical Engineering, IIT Guwahati	Design and Robotics
2.	P.S. Robi, Professor (Mechanical Engineering), IIT Guwahati	Coating, Fracture Mechanics, Materials Processing, Metal Matrix composite, Metal Casting, P/M Processing
3.	S. Kanagaraj (Professor), Department of Mechanical Engineering, IIT Guwahati	Biomaterials, Biomedical devices and implants, Materials characterization
4.	Harshal B Nemade (Professor), Department of Electronics & Electrical Engineering, IIT Guwahati	Electronic instrumentation, Systems design, Electronic product design, MEMS
5.	Subashisa Dutta (Professor), Department of Civil Engineering, IIT Guwahati	Satellite Remote Sensing and GIS for Water resources Management, Irrigation And Hydraulics Engineering

6.	Samarendra Dandapat (Professor), Department of Electronics & Electrical Engineering, IIT Guwahati	Signal Processing, Machine Learning, Speech Processing
7.	Sukumar Nandi (Professor), Department of Computer Science & Engineering, IIT Guwahati	Networks (Specially: QoS, Wireless Networks), Computer and Network Security, VLSI
8.	Pradip Kr. Das (Professor), Department of Computer Science & Engineering, IIT Guwahati	Man-Machine Intelligence Systems, Mobile Robotics
9.	Shivashankar B. Nair (Professor), Department of Computer Science & Engineering, IIT Guwahati	Artificial Intelligence, Intelligent Internet of Things, Cyber-Physical Systems,
10.	U.S. Dixit (Professor), Department of Mechanical Engineering, IIT Guwahati	Neural Network and Fuzzy Set Application; Mechatronics, FEM
11.	N Sahoo (Professor), Department of Mechanical Engineering, IIT Guwahati	Shock Wave based Analysis
12.	Karuna Kalita (Professor), Department of Mechanical Engineering, IIT Guwahati	Coupled Dynamics of Electro-Mechanical Systems, Vibration
13.	Srikrishna N. Joshi (Associate Professor), Department of Mechanical Engineering, IIT Guwahati	Mechatronics, Web based manufacturing, Process modelling and optimization of manufacturing processes,
14.	Satyajit Panda (Associate Professor), Department of Mechanical Engineering, IIT Guwahati	Nonlinear vibrations, Smart materials and structures, FEM, FGMs and structures, Micromechanics, Composite
15.	B. Hazra (Associate Professor), Department of Civil Engineering, IIT Guwahati	Control Theory, Stochastic Systems
16.	Arijit Sur (Associate Professor), Department of Computer Science & Engineering, IIT Guwahati	Computer Vision, Machine Learning
17.	Sonali Chouhan (Associate Professor), Department of Electronics & Electrical Engineering, IIT Guwahati	Wireless Sensor Networks, Coding Theory, Wireless Communications.
18.	Manoj Majhi (Associate Professor), Department of Design, IIT Guwahati	Animation, Special Effects, Cartooning, Animation Movie history, Creation of Traditional Animation
19.	Sougata Karmakar (Associate Professor), Department of Design, IIT Guwahati	Virtual Simulation (CAD and Digital Human Modeling), Ergonomics
20.	B. Sandeep Reddy (Assistant Professor), Department of Mechanical Engineering, IIT Guwahati	Robotics and Control, Nonlinear Dynamics
21.	Sajan Kapil (Assistant Professor), Department of Mechanical Engineering, IIT Guwahati	Rapid Manufacturing (3D Printing), Welding/Cladding Processes, CNC, Manufacturing Automation
22.	Prithwijit Guha (Assistant Professor), Department of Electronics & Electrical Engineering, IIT Guwahati	Computer Vision, Pattern Recognition, Signal Processing, Robotics
23.	Rishikesh Bharti (Assistant Professor), Department of Civil Engineering, IIT Guwahati	GIS, Unmanned Aerial Vehicles, Advance remote sensing (hyperspectral, thermal and microwave) and GIS
24.	Abhishek Shrivastava (Assistant Professor), Department of Design, IIT Guwahati	Research in Interaction Models of Cyber Physical Systems
25.	Charu Monga (Assistant Professor), Department of Design, IIT Guwahati	Visual communication, Visual Ethnography, Craft clusters, Film-making, Animation, Illustration
26.	Rashmi Dutta Baruah (Assistant Professor), Department of Computer Science & Engineering, IIT Guwahati	Evolving Intelligent Systems, Computational Intelligence, Online Machine Learning, Learning from Data streams
27.	Amit Awekar (Assistant Professor), Department of Computer Science & Engineering, IIT Guwahati	Data Mining, Machine Learning

28.	Biranchi Panda, Assistant Professor, Department of Mechanical Engineering, IIT Guwahati	Additive Manufacturing and Robotics
29.	Atul K. Soti, Assistant Professor, Department of Mechanical Engineering, IIT Guwahati	CFD and Heat Transfer, Fluid-Structure Interaction, Renewable energy, High Performance Computing
30.	Pankaj Biswas, Professor, Department of Mechanical Engineering, IIT Guwahati	Computational weld mechanics, Solid state welding, Soft computing modeling of welding processes, FEM
31.	R. Ganesh Narayanan, Professor, Department of Mechanical Engineering, IIT Guwahati	Material Forming and Joining
32.	Nelson Muthu, Assistant Professor, Department of Mechanical Engineering, IIT Guwahati	FEM, Fracture Mechanics, Composites, Structural Health Monitoring, Medical Device Innovation
33.	Nagarjuna Nallam, Asaistant Professor, Department of Electronics & Electrical Engineering, IIT Guwahati	Circuits for SDR and cognitive Radios, Wirelessly powered RF and analog circuits,
34.	Shubhadeep Mandal, Assistant Professor, Department of Mechanical Engineering, IIT Guwahati	Microswimmers, Complex Fluids, Droplet Microfluidics, Electrohydrodynamics
35.	Shakuntala Acharya, Assistant Professor, Department of Design, IIT Guwahati	Bio-3D Printing
36.	Mahima Arrawatia, Asaistant Professor, Department of Electronics & Electrical Engineering, IIT Guwahati	Energy Harvesting, RF Circuit Design, Microstrip Antennas
37.	Dr. Praveen Kumar, Professor, Department of Electronics & Electrical Engineering, IIT Guwahati	E-mobility
38.	Prof. Parameswar K. Iyer, Professor, Department of Chemistry, IIT Guwahati	Designing and fabricating functional material with controlled composition and architecture
39.	Deepak Sharma, Associate Professor, Department of Mechanical Engineering, IIT Guwahati	Optimization and Soft Computing Techniques for Design and Manufacturing
40.	Rishikesh Dilip Kulkarni, Assistant Professor, Department of Electronics & Electrical Engineering, IIT Guwahati	Optical Metrology, Digital Optical Signal Processing, Digital Holography, Speckle Interferometry, Fringe Projection Profilometry

Collaborators from Other Institutes

41.	Abinash K. Swain, Assistant Professor, Department of Mechanical and Industrial Engineering, IIT Roorkee	Product Design and AI
42.	P.M. Pathak, Professor, Department of Mechanical and Industrial Engineering, IIT Roorkee	Robotics, Dynamics, Control and Design
43.	Pavan Kumar Kankar, Associate Professor, Discipline of Mechanical Engineering, IIT Indore	Fault Diagnosis of Mechanical Components, Condition Based Maintenance, Machine Learning, Signal Processing
44.	I.A. Palani, Associate Professor, Discipline of Mechanical Engineering, IIT Indore	Optical instrumentation, Mechatronics System Design, Laser assisted synthesis and characterization
45.	P.K. Mohanty, Assistant Professor, Department of Mechanical Engineering, NIT Arunachal Pradesh	Design and Development of Robots, Motion Planning of Autonomous Agents, Soft-computing Approaches,
46.	Sahadev Roy, Assistant Professor, Department of Electronics and Communication Engineering, NIT Arunachal Pradesh	Mechatronics, Electronics and communication
47.	Sangamesh Deepak R, Assistant Professor, Department of Mechanical Engineering, IIT Dharwad	Robotics and Optimization

48.	Dayal R. Parhi, Professor, Department of Mechanical Engineering, NIT Rourkela	Robotics, Machatronics, Machine Design and Vibration
49.	Ravi Kant, Assistant Professor, Department of Mechanical Engineering, IIT Ropar	Laser based Manufacturing
50.	Santhakumar Mohan, Associate professor, Department of Mechanical Engineering, IIT Palakkad	Robotics and Control
51.	Ekta Singla, Associate Professor, Department of Mechanical Engineering, IIT Ropar	Modular Manipulators, Assistive devices
52.	Barun Pratiher, Assistant Professor, Department of Mechanical Engineering, IIT Jodhpur	Nonlinear Dynamics
53.	Chaitali Koley, Assistant Professor, Electronics and Communication Engineering, NIT Mizoram	Microwave Devices, Communication Systems
54.	Basil Kuriachen, Assistant Professor, Mechanical Engineering, NIT Mizoram	Micro-Manufacturing, CAD/CAM, Additive Manufacturing, Modeling and Simulation
55.	Arnab Bandyopadhyay, Associate Professor, Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology.	Hydrological Modelling
56.	Rupak Sarkar, Associate Professor, Regional Research Station (TERAI Zone), UTTAR BANGA KRISHI VISWAVIDYALAYA	Agricultural Engineering and Water Management
57.	Lokesh K. Sinha, Director, DTRL, DRDO	Underwater Robotics, Hyper-spectral Remote Sensing
58.	Binoy Krishna Roy Professor, Electrical Engineering, NIT Silchar	Control Systems, Fault Detection and Diagnosis, Industrial Automation, Process Control
59.	Dr. P. R. Sahu Associate Professor, School of Electrical Sciences, IIT Bhubaneswar	Interests: Digital Communications, Mobile Communications, Receiver performance in fading channels
60.	Dr. Barathram. Ramkumar , Assistant Professor, School of Electrical Sciences, IIT Bhubaneswar	Wireless Communications, Statistical Signal Processing, and Cognitive Radios
61.	Dr. M. SabarimalaiManikandan Assistant Professor, School of Electrical Sciences, IIT Bhubaneswar	Signal Processing, Embedded System, Wireless Sensor Networks
62.	Lerrel Pinto, Assistant Professor, Computer Science, New York University, USA.	Robotics
63.	Liang Gao, Professor, Huazhong University of Science and Technology (HUST), Wuhan, China	Product Design, Optimization
64.	Akhil Garg, Associate Professor, Mechanical Science and Engineering, Huazhong University of Science and Technology (HUST),Wuhan, China	Additive Manufacturing, Robotics, CAD-CAM
65.	Jian Zhang, Associate Professor, Mechanical Engineering, Shantou University	Adaptable Design, Robust Design, Interface Design, Design of Electric Vehicle.

5.3 Legal Framework

The BoD of the section – 8 company IIT Guwahati TI&DF will ensure that the activities of the Hub are within the legal framework of the Institute and the Government of India. The IITG TI&DF will have an IPR cell, which shall ensure that the Hub is within the National Intellectual Property Rights Policy of the Government of India. IITG TI&DF shall document and encourage patent production for various technologies developed by the Hub and provide for financial assistance for the same. The IITG TI&DF shall follow all Indian and International standards for product development.

a. Procurement Policy

This policy has been framed for purchase of items from recurring and non-recurring funds generated from sponsors and self-efforts and other funds allocated to the company. These rules and regulations for purchase and accounting of different expenses of setting-up and running the organization and thereby provide a conducive working environment for employees, partners and associated entities to promote excellence expected from IITG TIDF and as such should be interpreted in the same context, so that the procurement of the needed equipment/other items is done in time and without procedural wrangles, which permits the desired task to be pursued with greater vigour.

The authority delegated with the powers of procuring goods in public interest shall have the responsibility and accountability to bring efficiency, economy, and transparency in matters relating to procurement and for fair equitable treatment of suppliers and promotion of competition in procurement. The procedure to be followed in making procurement must confirm to the following yardsticks.

- The specification in the terms of quality, type etc. and quantity of goods to be procured, should be clearly spelt out keeping in view the specific requirements of the procuring entity without including non-essential features, which may result in unnecessary expenditure.
- Quotes should be invited following a fair, transparent and reasonable process.
- The procuring authority should be satisfied that the equipment(s)/item(s) / material selected offer adequately meet(s) the requirement in all respects.
- The procuring authority should satisfy itself that the price of the selected offer is reasonable and consistent with the quality required.

- At each stage of procurement of concerned procuring authority must place on record, in precise terms, the considerations which weighed with the while making the procurement decision.
- Purchase should not be split to avoid obtaining approval of appropriate competent authority.

b. The role of stores and purchase section

The role of stores and purchase sections

- Processing and clearance of purchase
- E-Procurement, E-Publishing, E-Auction
- Maintenance of Central Asset Registers for all items
- Conducting physical annual stock verification

c. Types of Purchases

Direct Purchase: Purchase of goods, in case of urgency/ to complete installations/running experiments/ chemicals/ some specific needs of time-bound research projects (e.g. electronic components, capacitors, inductors, etc.)/ machine parts/ liveries or miscellaneous items etc. duly recorded, on each occasion may be made on the recommendations of a duly constituted purchase committee. The committee will survey the market including online ascertaining the reasonableness of rate, quality and specifications and identify the appropriate suppliers and certify the same. The committee will collect minimum one valid quote. The benefit of warranty and other clauses as available must be availed.

Limited Tender: IITG TIDF will invite quotes under Limited Tender from the potential vendors identified by the indenter. In addition, IITG TIDF may also invite the quote from the additional vendors.

Open Tender: Invited through publication of tender notice on GOI website (eprocure.gov.in) and tendering may be through e-procurement.

Single Tender: Purchase up to 30 lakhs can be done by sending an enquiry letter to a single firm under the following circumstances:

a. It is in the knowledge of the user department that only a particular firm is the manufacturer/ supplier of the required goods i.e. proprietary item(s) shall produce proprietary certificate.

b. The required goods are to be purchased from a particular source and the reason for such decision is to be recorded in the form of PC Report.

c. For standardization of machinery or spare parts to be compatible to the existing sets of equipment, the required item is to be purchased only from a selected firm.

d. The notice regarding the purchase of item(s) of propriety in nature must be uploaded on company's Website giving a minimum time of 7 days (excluding National Holidays) to submit quotation. However, in other cases of single source purchases e.g. a compatible spare part from manufacturer of the equipment, order can directly be placed without publishing the requirements on the website.

Rate Contract: If the purchase is proposed on the basis of rate contract approved by Central Government Company, or on rate Contract approved by TIH/IITs/GeM/DGS&D, orders for purchase up to Rs. 5 Lac, may be approved by the competent authority, without inviting any type of tender as per terms and conditions of the Government/ Public Sector Undertaking/ Organization as the case may be.

Government e-Market place (GeM): Government of India recently initiated online Government e-Marketplace (GeM) for common use Goods and Services. The GeM portal may be utilized by the company for direct on-line purchases as under:

a) Up to ₹ 2,50,000/- through any of the available suppliers on the GeM, meeting the requisite quality, specifications and delivery period.

b) Up to ₹ 10,00,000 through the GeM seller having lowest price amongst the available sellers, of at least three different manufacturers, on GeM, meeting the requisite quality, specifications and delivery period.

c) Above ₹10,00,000 through the supplier having lowest price meeting the requisite quality, specifications and delivery period after mandatorily obtaining bids, using online bidding or reverse auction tool provided on GeM.

4. Bidding systems

I. Single-bid system: For purchases with estimated cost of up to ₹10 lakhs under single bid system (technical and financial bid together and opened at single instance).

II. Two-bid system: For purchase with estimated cost of more than ₹30 lakhs two bid system (Part A: Technical Bid and Part B: Financial Bid in separate sealed envelopes to be opened at different instances) shall be followed. Technical bid will be opened by first. Technical comparative statement will be prepared by the Indentor/ PI. If required, the concerned PI/ indenter may obtain clarification/ document from bidders at the time of technical evaluation regarding any technical aspect(s) as per the enquiry letter/ tender document. After approval of the technical comparison statement by the competent authority, the financial bid of the technically qualified vendor(s) will be opened.

5. Performance bank guarantee

In case of purchase of special/ sophisticated equipment, costing above ₹15 lakhs, a performance bank guarantee or FDR pledged in favour of the company for an amount equal to or more than 10 % of the cost price for the duration of the warranty period plus sixty days will be taken from the supplier/ Indian Agent.

d. Financial Delegation of Power of Authority

The Financial Delegation of Power of Authority in IIT Guwahati Technology Innovation and Development Foundation are summarised in this section

1. Sanctioning authority for purchase of Technical/Research/Other than office items

Amount (INR)	Process/Guideline	Applicant	Recommendation	Forwarding	Sanctioning Authority
Up to 25k	Need to accompany actual invoices/ Quotes	Employee/PI	CEO		Project Director (TIH)
Up to 2.5 Lac	Direct Purchase: Minimum one valid quote	Employee/PI/ PD/(Project Director(TIH)	Three members purchase committee	Project Director (TIH)	Vice Chairperson, BoD
Up to 10 Lac	Limited tender: Minimum 3 technically valid quotes	Employee/PI/(Project Director(TIH)	Three members purchase committee	Project Director (TIH)	

Above 10 Lac	Open Tender: Invited through publication of tender notice on GOI website (eprocure.gov.in) and tendering may be through eprocurement.	Employee/PI/(Project Director(TIH)	Three members purchase committee from EC (Project Director(TIH)	Vice Chairperson, BoD	Chairperson, BoD

2. Sanctioning authority for purchase of Office items

Amount (INR)	Process/Guideline	Applicant	Recommendation	Forwarding	Sanctioning Authority
Up to 25k	Need to accompany actual invoices/ Quotes	Employee	CEO		Vice Chairperson, BoD
Up to 2.5 Lac	Minimum one valid quote	Employee	Three members purchase committee	CEO	
Up to 10 Lac	Minimum 3 technically valid quotes	Employee	Three members purchase committee	CEO	
Above 10 Lac	Minimum 3 technically valid quotes	Employee	Three members purchase committee (with CEO as convener)	Vice Chairperson , BoD	Chairperson,

CEO issues the purchase order for the sanctioned purchases. For all purchases above Rs. 25,000/- the indentor has to obtain prior approval from the sanctioning authority with proper justification.

3. Sanctioning authority for TA/DA and honorarium

Amount (INR)	Process/Guideline	Applicant	Forwarding	Sanctioning Authority
Upto 1 Lac	Need to accompany actual invoices for travel and prerequisite approval for travel from CEO/ Project Director (TIH)	Employee/ PI	CEO	Vice Chairperson, BoD
Above 1 Lac	Need to accompany actual invoices for travel and Prerequisite approval for travel from Chairperson, BoD	Employee/ PI	CEO	Chairperson, BoD on recommendation of the Vice Chairperson, BoD

For CEO/ Project Director(TIH) prerequisite approving authority is Vice Chairperson, BoD

4. Employees salary and related expenses

Amount (INR)	Process/Guideline/ Initiator	Recommendation	Sanctioning Authority
Any amount	HR person to initiate the process basis employee records and contractual obligations	CEO	Vice Chairper

5. Financial power to write-off the assets

Same as the purchase. For any financial approval above 10 Cr and any exception to the above requires approval of the board of directors (BoD).

Delegation of power leave of staff Nature of Position	Nature of leave	Recommending authority	Approving Authority
CEO	Casual leave/ Earn Leave	Project Director (TIH)	Vice chairperson, BoD
Administrative	Casual leave/ Earn Leave		CEO
Research	Casual leave/ Earn Leave	Project Director (TIH)	CEO

e. Recruitment Policy

Board of Directors (BoD) may create positions of following nature depend upon the need.

1. Leadership positions

Leadership positions would include roles reporting to BoD or its chairperson or vice chairperson or Project Director (TIH) such as CEO.

2. Administrative Positions

Administrative positions would include positions required for smooth functioning for administrative requirement including (but not limited to) sales, marketing, finance, HR, IT, etc. and not including research/consultancy related activities of TIDF.

3. Research Positions

Research positions would include positions required for smooth functioning of research/consultancy projects etc. of TIDF.

Nature of Position	Selection and/or shortlisting Committee	Approving Authority
CEO	Chairperson, BoD (Chairperson) Vice chairperson BoD (Convener) Project Director (TIH)	BoD

4. Contractual Position for 11 months (renewable on performance basis)

Nature of Position	Selection and/or shortlisting Committee	Recommendation	Approving Authority
Administrative	Nominee of the Vice Chairperson, BoD (Chairperson) CEO (Convener) Two Experts (Members)	Vice Chairperson, BoD	Chairperson, BoD
Research	Nominee of the Vice Chairperson, BoD (Chairperson)	Vice Chairperson,	Chairperson,

5. Adhoc appointment for 89 days

May be approved by Vice-chairperson, BoD on recommendation of CEO for administrative position or Project Director (TIH) for scientific/technical position.

i. For administrative position

The CEO will request to the Vice Chairperson, BoD seeking approval for initiating the process of appointment stating/enclosing:

- the position(s) to be filled
- educational qualifications required and
- scale of pay
- a committee with at least three members examining the candidates' suitability for the post. (with the himself/herself as the convener)
- a draft of the advertisement/circular.
- After approval the advertisement shall be placed on the company's website (If needed with prior approval it may be advertised in the newspaper).

ii. For research position

The Project Director (TIH) will request to the Vice Chairperson, BoD seeking approval for initiating the process of appointment stating/enclosing:

- the position(s) to be filled
- educational qualifications required and
- scale of pay
- a committee with at least three members examining the candidates' suitability for the post. (with the himself/herself as the convener)
- a draft of the advertisement/circular.

After approval the advertisement shall be placed on the company's website (If needed with prior approval it may be advertised in the newspaper).

6. Selection and Appointment

The candidates will be interviewed by the selection committee. After the interview, selection committee report (in prescribed format) on the selected and waitlisted candidates along with the recommendation of Vice Chairperson, BoD will be submitted to the Chairperson, BoD for approval. Upon approval CEO of the respective division issues the appointment letter for staff positions (other than CEO). Upon approval Vice-chairperson, BoD issues the appointment letter for CEO. After completion of service Vice Chairperson, BoD may approve the reappointment of administrative staff on recommendation of CEO and research staff on recommendation of Project Director (TIH).

5.4 Environmental Impact

The domain area of the TIH is Technologies for Underwater Exploration. Given this, environmental issues are of importance in the activities of the Hub. The Coordination wing shall setup bodies, from time to time, to ensure that all activities and products developed by the Hub are environment friendly, and that the required legal/environment clearances have been taken (wherever necessary).

Chapter 6

Conclusions

The development of CPS technologies in Underwater Exploration is a relatively new exercise undertaken in India. This TIH shall endeavour to ensure that the objectives of the NM-ICPS are successfully implemented in the next five years. The TIH will work in two primary research / application areas viz., (i) Underwater Systems Development and (ii) Underwater Vision, Monitoring, Surveillance, Intelligence and Tracking. The following list gives the nine different secondary application areas.

- Underwater Repairing and Maintenance
- Underwater Autonomous Vehicles
- Underwater Electronics & Powering
- Underwater Tourism
- Offshore Energy & Desalination of Sea Water
- Underwater Aquaculture
- Underwater Healthcare and Monitoring
- Underwater Vision & Communication
- Offshore Bio & Mineral-resources

The aims and targets of the Hub shall be followed diligently in the next five years. The strategy for the implementation of the deliverables has been stated in this document. Timely oversight shall be ensured so as the TIH objectives shall be achievable in the stipulated period.

TIH will collaborate with a number of industries to develop centre of excellence. A number of startup's companies and incubation centres will be benefitted by taking financial and other necessary assistance from the TIH.

Many start-up such as Yantrabot Technologies Pvt. Ltd., Invento Maker Spaces Pvt. Ltd., Marut Drontech have expressed their willingness for collaboration with TIH. CoreEL Technologies (I) Pvt. Ltd. has also expressed their willingness to develop the CoE, where several Divisions / Labs related to cyber physical systems can be developed (see Annexure - I).

Further the technology developed in the TIH will be very useful for industry partners like Guwahati Neurological Research Centre Ltd., Paramount Industry, Dibrugarh, Assam. The TIH work may directly be implemented in several public sectors like Assam Inland Water Transport, NIOT, CIFRI, MPEDA, Indian Navy, CSIR-CMERI, Durgapur, Hindustan Petroleum Corporation Limited (HPCL), Indian Oil Corporation Limited (IOCL), Oil and Natural Gas Corporation Limited (ONGC), Shipping Corporation of India Limited, Oil India Limited and Board of Research in Nuclear Sciences (BRNS).

Though due to COVID19 related pandemic situation recruitment of project staffs and other related activities have been affected severely, but the faculty members are trying their best to make some progress in research activities related to underwater exploration. Further, the formation of the section – 8 company for the TIH at IIT Guwahati has been completed. With the permission BoG IIT Guwahati a section – 8 company viz., IIT Guwahati Technology Innovation and Development Foundation (TIDF)) has already been created. The purchase, procurement and recruitment policies have already been formulated.

The Centre of Excellence (CoE) for social entrepreneurship developed by this hub will help in creating awareness and facilitating the use of CPS for achieving the National sustainable developmental goals.

We hope that the TIH will achieve all the stated targets of National Mission for Cyber Physical Systems with joint collaboration with Department of Science and Technology and IIT Guwahati.

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Annexure - I

CoreEL Technologies

CONSENT LETTER FROM INDUSTRY PARTNER

This is to state that CoreEL Technologies India Pvt Limited hereby consent to Partner with IIT Guwahati in the proposed NM-ICPS Technology Innovation Hub (TIH) **Technologies for Under water exploration** I am aware and agree to the activities mentioned in the proposal under Industry Partnership.

I hereby consent to support the TIH in terms of:

1. Contribution in Cash:............................... (Rs in Lakh)
2. Contribution in Kind

Branding

Tying up with global leaders thru our partnership and university program with, **SIEMEN**S, Stratasys-3 D printer, Xilinx-FPGA, VLSI AND EMBEDDED, Advance Communication-Mentor-5G, Ansys solutions.

Our expertise in Embedded Solutions, Defense Electronics labs, ARVR Lab and Iot Lab ,Robotics lab, Mechatronics

Helping in projects, industry collaboration, trainings and operations and placements, joint projects. .

Summary profile of the Industry is given below:

Name of Industry/Organization : CoreEL Technologies India Pvt LTD

Nature of Business : Electronic system level product development for Defence and aerospace

Number of Employees : 300

Annual Turnover : 110-120 CRORES

I hereby affirm that my Industry/Organization is committed to participate in the proposed TIH as indicated in the proposal including the financial liabilities as provided above.

Head of Industry/Organization
Seal

Date: 07.06.2020

Place: Bangalore

CoreEL Technologies (I) Pvt. Ltd
#21, 7th Main, I Block, Koramangala, Bangalore – 56
Tel: 91-80-4197 0400/2522 6775, Fax: 080- 30723638 Website: www.coreel.com

4 Laboratories to be set up at COE

S No	LAB
1	Design and Validation lab
2	Digital Manufacturing
3	Simulation , TEST AND OPTIMIZATION LAB
	Test Hardware Lab
4	Autonomous and Electric mobility
5	Additive Manufacturing and CAM
6	ROBOTICS Software & Hardware LAB
7	IIOT/CLOUD LAB
8	Lifecycle Collaboration LAB
9	AR VR LAB
10	CNC CONTROLLER LAB
11	INTELLIGENT SERVO LAB
	ADVANCE SWITCHGEAR LAB
12	MECHATRONICS BASED IOT LAB

8 Program Budget

Table 1 Capital Support Required for Siemens Centre of Excellence

	Scope	Total Project Cost	Academic Grant	Contribution by IIT
		₹ 1,67,80,06,789	₹ 1,48,99,67,148	₹ 18,80,39,641
1	Design and Validation lab			
2	Digital Manufacturing			
3	Simulation , TEST AND OPTIMIZATION LAB			
	Test Hardware Lab			
4	Autonomous and Electric mobility			
5	Additive Manufacturing and CAM			
6	ROBOTICS Software & Hardware LAB			
7	IOT/CLOUD LAB			
8	Lifecycle Collaboration LAB			
9	AR VR LAB			
10	CNC CONTROLLER LAB			
11	INTELLIGENT SERVO LAB			
	ADVANCE SWITCHGEAR LAB			
12	MECHATRONICS BASED IOT LAB			
13	Project Management Project Management during site readiness, installation and commissioning Train the trainers			

- Applicable Taxes (GST) would be charged at actuals at the time of invoicing.
- Any other Taxes , Duties will be extra.
- Any change in Taxes will be borne by IITG .
- All Exception Certificate need to be provided along with the Purchase Order

Annexure – II

NMICPS-TIH IIT Guwahati Supported Prototype of Remotely Operated Food and Medicine Delivery Robot in COVID-19 Isolation Wards

Following two prototypes of the COvid Patient Assistant Robot (COPARBOT), a Remotely Operated Food Delivery robot have been developed by IIT Guwahati in collaboration with Yantrabot Technologies Pvt. Ltd. a startup company in consultation with Guwahati Medical College and Hospital. The first version working prototype (V1) was tested and demonstrated on 8th April 2020 and the 2nd version (V2) of working prototype with camera vision facility has been developed and successfully demonstrated on 2nd May 2020. As the concept validation and prototyping phase has been completed, we are now capable of developing such robots in more numbers. These robots can be customized as per the requirements of the customer.

Features of prototypes:

Fig. 1: COPARBOT1.0

- Remotely controllable via android mobile app.
- Remote operation range: 1000 Sq. meter area *.
- Wide angle camera vision enables easy access to multiple rooms.
- Compact & robust design to enable safe movement in Covid-19 isolation wards.
- Payload: Food for 8 person (8 plates & 8 water bottles).
- Maximum payload: 9 Kg.
- Water resistant body for Easy Cleaning and Disinfection.
- Give way /call attention horn.
- Electronic Bumper for obstacle avoidance and safe parking
- Two hand sanitizer holders.
- 6 hrs. Operation on one full charge.
- Charging supply line voltage: 250 V, 50 Hz AC.


Fig. 2: COPARBOT2.0

* Remote control range subjected to minor variation depending on position of Wi-Fi router and room wall thickness. Present version has been tested up to 60 meter x 60 meter area. Best position for the router placement is the center of the working area.

The Robot Package Includes:

1 x Food Delivery Robot.
1 x Wi-Fi Router.
1 x IEC Type Power Cord.
1 x Android App. for robot navigation. (Picture 3.)
1 x Instruction manual.

Modification can be made for waste collection

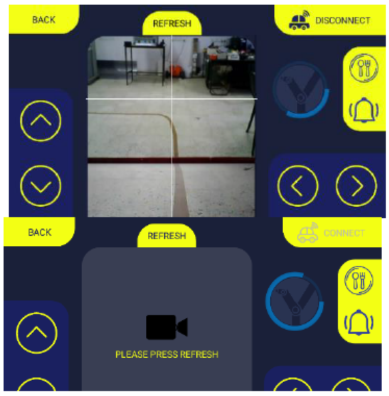

Fig. 3: Screen shots of Android mobile App.