

PROFESSIONAL TRAINING REPORT - II

entitled

SoftRoboSampler: Integration of Soft Robotics and AI in Underwater Rover System to enhance exploration efficiency.

Submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering with specialization in Artificial Intelligence and Robotics

by
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**DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
SCHOOL OF COMPUTING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGYS
(DEEMED TO BE UNIVERSITY)**

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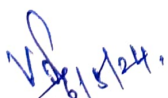
This is to certify that this Professional Training Report is the bonafide work of **Ms.Tabitha Juliana.S(41612036)** who carried out the project entitled **"SoftRoboSampler: Integration of Soft Robotics and AI in Underwater Rover System to enhance exploration efficiency"** under my supervision from January 2024 to April 2024.


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I, **Tabitha Juliana.S(41612036)** hereby declare that the Professional Training Report-II entitled '**SoftRoboSampler: Integration of Soft Robotics and AI in Underwater Rover System to enhance exploration efficiency**' done by me under the guidance of **Mrs. V. Subapriya, M. E, (Ph.D)**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering with specialization in Artificial Intelligence and Robotics.

DATE: 06-05-2024

PLACE: CHENNAI



SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

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ABSTRACT

The exploration and study of underwater environments present numerous challenges that traditional rigid robots struggle to overcome. Marine robotics, in particular, have been an essential advancement, owing to the increased demands of oceanographic engineering. This study investigates the convergence of advanced technologies to elevate the effectiveness of underwater exploration by integrating soft robotics, underwater wireless charging and biological sampling mechanisms using AI in underwater rover systems. Soft robotics revolutionize underwater exploration by offering enhanced maneuverability and adaptability, allowing rovers to navigate complex underwater terrains with finesse while minimizing environmental impact. Complementing this, underwater wireless charging systems address the challenge of power management, enabling extended missions without manual intervention. Biological sampling mechanisms integrated into the rover systems enable the collection of valuable specimens and environmental data, facilitating scientific research and biodiversity monitoring. Furthermore, incorporating AI-driven object recognition capabilities empowers rovers to autonomously identify and classify underwater objects and organisms in real time, streamlining data analysis and decision-making processes. By synergizing these technologies, underwater rovers can significantly enhance exploration efficiency, data collection capabilities, and scientific understanding of underwater ecosystems. This holistic approach not only advances marine science but also contributes to conservation efforts by providing valuable insights into fragile aquatic environments.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Underwater rovers, commonly referred to as underwater drones or remotely operated vehicles (ROVs), are unmanned submersible vehicles that are equipped with cameras, sensors, and, in some cases, robotic arms, allowing them to explore and interact with the underwater environment. These underwater rovers serve a vital purpose for exploring and studying the oceans, conducting scientific research, monitoring environmental health, monitoring infrastructure, assisting with search and rescue operations, helping resource exploration, and enhancing military capabilities. They play an important role in furthering our understanding of the underwater world and its importance in modern life. Our area of research under the topic of underwater rovers is to design and implement a model which utilizes soft robotic material as it is comparatively light weight, a system which can recharge itself by a wireless mode underwater and a biological sampling mechanism using the technology of AI. Soft robots are characterized by being made of stretchy and soft materials with almost infinite degrees of freedom and a high degree of flexibility. Compared to their rigid counterparts, soft robots have a superior ability to simulate the movement of living organisms and share a safe environment with humans, which serves the concept of Human-Robot Interaction (HRI). Underwater charging transforms underwater rovers' operational capability by enabling seamless battery recharge while submerged. This technology extends mission durations, permits autonomous operations, and allows for continuous data collecting, especially in distant or deep-sea locations where surface charging facilities are unfeasible. Underwater charging improves the efficiency, versatility, and sustainability of underwater rover operations in a variety of applications, including scientific investigation and environmental monitoring, as well as infrastructure inspection and exploration. Biological sampling with AI in underwater rovers has several applications in marine science and conservation. Researchers can use artificial intelligence (AI) to automate the process of identifying, sampling, and analyzing marine creatures and environments, increasing efficiency and accuracy. Applications include biodiversity surveys, species identification, ecosystem monitoring, and research into the effects of environmental change on marine life.

AI systems can analyze underwater imagery collected by rovers in real time, recognizing specific species or areas of interest and directing sampling appropriately. This technique allows researchers to collect enormous amounts of biological data more quickly, yielding vital insights into marine ecosystems and aiding conservation efforts.

There are approximately 40 research papers which we have referred with regards to our subject of interest in the years 2019-2024 from various sources such as IEEE, Springer, Sciencedirect. Most of our citations and references are from the papers by the name Underwater Soft Robot Modeling and Control With Differentiable Simulation, A Miniature Robotic Turtle With Target Tracking and Wireless Charging Systems Based on IPMCs, System for Wireless Charging of Battery-Powered Underwater Sensor Networks, Soft Robotic Grippers for Biological Sampling on Deep Reefs. Some Of our learning from these papers are that for soft robotics materials. Soft robotic materials for underwater rovers must balance flexibility, durability, and water resistance to navigate underwater environments effectively. Silicone elastomers, polyurethanes, and hydrogels are widely employed due to their flexibility and resilience, allowing soft robots to navigate complicated terrain and interact with sensitive marine habitats. Elastomeric polymers, such as EPDM rubber and thermoplastic polyurethane, provide additional benefits such as abrasion resistance and chemical stability. Fabric-based composites and bioinspired materials offer novel solutions for underwater robots by pulling inspiration from natural systems to improve adaptability and performance. The choice of soft robotic materials is determined by the application's specific requirements, with current research aiming at finding materials that can survive the rigours of underwater exploration while remaining flexible and useful. Following that wireless charging technologies for underwater rovers provide novel approaches to the problem of recharging batteries in submerged situations. Inductive coupling, ultrasonic power transfer, magnetic resonance coupling, hydrodynamic energy harvesting, and laser-based power transfer are some of the techniques proposed or investigated for this purpose. Each approach has advantages and disadvantages, including factors such as charging efficiency, distance, safety, and compatibility with underwater environments. Ongoing research intends to improve these wireless charging methods so that underwater rovers can operate reliably and efficiently for long-term missions and autonomous exploration in marine environments. Research findings from initiatives focusing on underwater rovers for biological sampling utilizing artificial intelligence demonstrate major advances in marine science and technology. These findings include improved species identification by automated picture recognition, increased sampling efficiency through self-directed decision-

making, real-time data analysis capabilities, and long-term ecosystem monitoring and assessment. Underwater rovers powered by artificial intelligence allow for distant sensing, mapping, and habitat classification, providing vital insights into marine biodiversity, habitat structure, and ecosystem health. Additionally, these programs help to validate and enhance AI technologies, robotics systems, and sensor platforms for underwater exploration and study, which has significance for marine conservation, resource management, and environmental monitoring.

Existing systems of underwater rovers with soft robotics have significant disadvantages, disregarding their potential benefits. These disadvantages include limited mechanical strength and durability, as soft materials may be more susceptible to damage or wear in hostile underwater settings. Furthermore, soft robotic systems may have lower precision and control than typical rigid robots, limiting their capacity to perform specific tasks or manipulate things precisely. Furthermore, combining soft materials with complicated mechanical and electronic components can increase system complexity and maintenance requirements, potentially causing dependability difficulties. The effectiveness and broad adoption of underwater rover systems with underwater charging are impeded by a number of issues. These disadvantages include difficulties with charging efficiency because of water's ability to conduct energy transfers more slowly, technical difficulties with corrosion resistance and waterproofing, and possible negative environmental effects such disruption of marine habitats and interference with marine life. Underwater charging technology is hindered in its accessibility and scalability by operational constraints, high prices, and reliability issues. Despite substantial developments, modern underwater rovers for biological sampling employing AI still have major limitations. These include restricted autonomy, dependency on human supervision, and limitations in sensor quality and reliability. Furthermore, understanding complicated biological data and translating discoveries into useful ecological insights remains difficult.

Ultimately, our research focuses on overcoming these shortcomings such as ensuring mechanical stability and durability so that there won't be a constraint in system complexity, operational constraints of underwater wireless charging and intricacy in understanding biological and ecological insights.

CHAPTER 2

LITERATURE REVIEW

2.1 SURVEY:

Soft Robots for Ocean Exploration and Offshore Operations: A Perspective

<https://www.liebertpub.com/doi/full/10.1089/soro.2020.0011>

The likelihood of a collision may be decreased by using soft materials to shield the central circuitry. Soft robots add to the difficulties involved in operating in the high seas and develop a new generation of robots that can keep an eye on even the most distant regions of our globe. Aquatic soft robot design safeguards the environment and promotes the expansion of offshore human activity in a sustainable manner. The creation of these systems will result in lower production costs and a long-term, widespread deployment of soft robots for ocean monitoring, improving environmental data's spatial resolution and enabling remote, autonomous asset management.

A Miniature Robotic Turtle With Target Tracking and Wireless Charging Systems Based on IPMCs

<https://ieeexplore.ieee.org/document/9205291>

The design was established to create a tiny robotic turtle that could track targets and be wirelessly charged. The robot moved forward and turned using its five IPMC-driven fins, and it employed two ultrasonic receivers as tracking eyes. The robotic turtle would be able to wirelessly recharge itself when its power source ran low. The work's outcomes offer useful strategies and examples for resolving the issue of micro undersea vehicles' brief operating times.

A Strategy for Sizing and Optimizing the Energy System on Long-Range AUVs

<https://ieeexplore.ieee.org/document/9393966>

A compact hybrid FC/battery system design approach has been developed for AUVs. Hybrid systems are compared with secondary and primary battery systems in terms of weight and volume using both user-designed and real power profiles. The primary factors affecting the ultimate weight and volume of the vessel's energy system are the fuel and oxygen storage options selected for the FC. The most restrictive factor in applications used underwater is volume. The optimized energy systems were evaluated for actual power profiles and are capable of continuously providing the AUV with the power it needs.

Evaluation of Sampling Methods for Robotic Sediment Sampling Systems

<https://ieeexplore.ieee.org/document/9835024>

The first outcomes from an earlier study are utilized in the model-based design optimization and testing of a bio-inspired soft underwater propeller. The efficacy of a precise theoretical instrument, the propelling mechanism of this novel propeller family, and ultimately, the creation of an enhanced

prototype. The elongated shape of the ideal soft module is one of its primary characteristics. This seems especially interesting for the creation of a multitasking module that can accomplish both vehicle mobility and manipulation. This supple, lengthy appendage with a coiled shape that would be ideal for a manipulation task can be produced by a straightforward bending actuation, such as implanted tendon cables or pneumatically driven chambers.

Persistent Sampling of Vertically Migrating Biological Layers by an Autonomous Underwater Vehicle Within the Beam of a Seabed-Mounted Echosounder

<https://ieeexplore.ieee.org/abstract/document/9093878>

The LRAUV tracked a Wave Glider that was station-keeping acoustically while gathering eDNA samples, staying within the echosounder's beam. This work showed a novel approach of persistently collecting eDNA samples and doing simultaneous acoustic observations to better understand the behaviors of animals that are vertically migrating. Correlation between eDNA signals and the acoustic traces of midwater creatures over diel migration cycles will be possible thanks to the samples' ongoing molecular examination. In this study, an image Dorado AUV and a Wave Glider were equipped with an echosounder.

Marine Robotics for Deep-Sea Specimen Collection: A Systematic Review of Underwater Grippers

<https://www.mdpi.com/1424-8220/22/2/648>

Manipulators intended for heavy industrial maritime operations are increasingly used for underwater telemanipulation for sample collecting. Furthermore, operating such manipulators to the required degree of dexterity is difficult and adds to the operator's effort. By examining the state-of-the-art underwater grippers for deft manipulation, we contrasted the novel solution encountered with the solutions in use. We examined popular design solutions and determined whether or not a certain technology is capable of handling the usual manipulating actions used in sampling methods. The gripper categories that are frequently used for marine sampling (which were frequently initially conceived as end-effectors of underwater industrial manipulators) as well as the research status prototypes of underwater grippers were both taken into consideration in this analysis, but we did not thoroughly explore the industrial solutions.

A Review of Physics Simulators for Robotic Applications

<https://ieeexplore.ieee.org/document/9386154>

Robotics research benefits greatly from simulators in many ways. Cost savings, improved time management, and an increased degree of safety in complicated contexts are some of the advantages. The types of simulators that are available to researchers in seven distinct, well-known robotics study topics are thoroughly summarized in this review paper. Competitions, simulator support for features required in each domain (sensors, actuators, environments), and the current SOTA are only a few of the topics covered in each part. This is the first review paper on robotic simulators that covers such a wide range of robotics research fields. It is a great place for novice researchers to start and a helpful resource for seasoned researchers.

Soft Robotic Grippers for Biological Sampling on Deep Reefs

<https://www.liebertpub.com/doi/full/10.1089/soro.2015.0019>

The goal of this endeavor is to develop haptically controlled soft robotic "arms" and "fingers" that can do tasks comparable to or even more efficiently than those performed by human SCUBA divers. We see the opportunity to do intricate scientific research and data collection using submersibles or remotely operated vehicles (ROVs). This might involve the careful gathering, handling, or on-site assessment of deep reef creatures. Additionally, we see this being linked with the capacity to apply RNA stabilizers, like RNAlater, to samples in order to help with transcriptome analysis and gene expression. As our understanding of the physiology and genomes of deep reefs advances, the marine biological and molecular biological communities stand to gain enormously from the ability to carry out these activities in situated deep sea organisms.

CHAPTER 3

REQUIREMENTS ANALYSIS

3.1 OBJECTIVE OF THE PROJECT

The objective of the project is to create a contemporary underwater rover with AI-driven biological sampling capabilities, progressive soft robotic materials, and underwater wireless charging technology. Fundamentally, the project aims to overcome the shortcomings of conventional underwater research techniques by developing an adaptable and self-sufficient platform that can traverse intricate underwater ecosystems with previously unheard-of efficiency and flexibility. The rover can interact gently with marine ecosystems, adapt to changing topography, and withstand hydrodynamic pressures more efficiently than rigid systems because of the integration of soft robotic materials. Furthermore, the rover's capacity to wirelessly charge underwater enables it to self-recharge while submerged, increasing its operational endurance for extended missions. Moreover, the rover can accurately and efficiently detect, track, and gather samples of marine species on its own by using AI algorithms for biological sampling and environmental monitoring. The rover's capacity to investigate marine biodiversity, habitat dynamics, and ecological interactions in real time is improved by this AI-driven method, which also provides important data for scientific research and conservation initiatives. The project's ultimate goals are to assist conservation and management initiatives that safeguard marine biodiversity and ecosystem health, as well as to increase scientific knowledge of marine ecosystems.

3.2 REQUIREMENTS

3.2.1 *HARDWARE REQUIREMENTS*

- Soft Robotic Actuators
- Charging Transmitter
- Electric coils(primary and secondary)
- Power Management System
- Battery or Energy Storage System
- AI Processing Unit(image recognition, pattern recognition, and decision-making)

- Sensors(cameras,IRsensor,depth sensors,temperature sensors,biological sensors, pressure sensor,temperature sensor,charging status sensor,water quality sensor, SONAR)
- Communication Systems
- Propulsion Mechanisms(flapping fins)
- Sampling Tools(pluckers,suction samplers)
- Navigation and Localization Systems(GPS Navigation system)
- Housing and Enclosures(waterproofing)

3.2.2 SOFTWARE REQUIREMENTS

- Control Software(MATLAB)
- AI Frameworks (OpenCV)
- Image Processing Software(MATLAB Image processing toolbox)
- Wireless Communication Protocols
- Simulation and Modelling Software(MATLAB,Arduino-TinkerCAD)
- Data Management and Analysis Tools(Tableau)
- Integrated development environments (IDEs) and software development kits (SDKs) (Arduino IDE)

CHAPTER 4

DESIGN DESCRIPTION OF PROPOSED PROJECT

4.1 PROPOSED METHODOLOGY

Our proposed methodology for the above-mentioned system for the usage of soft robotic materials is that it can benefit from the flexible, compliant, and mechanically robust nature of fabric-based materials. They may safely interact with sensitive marine ecosystems because of their innate flexibility, which enables them to conform to unusual shapes and deformations observed in underwater habitats. Fabric-based materials offer design and construction adaptability by being able to be tweaked and fitted to specific application requirements. Because of their low profile, lightweight, and seamless integration with sensors and electronics, they are a good fit for creating small, manoeuvrable underwater robotic systems. Fabric-based materials also provide little influence on marine species and habitats because they are environmentally safe and biocompatible. Fabric-based materials, with their unique blend of mechanical durability, environmental safety, adaptability, and personalization, offer a viable solution to the problems associated with underwater robots.

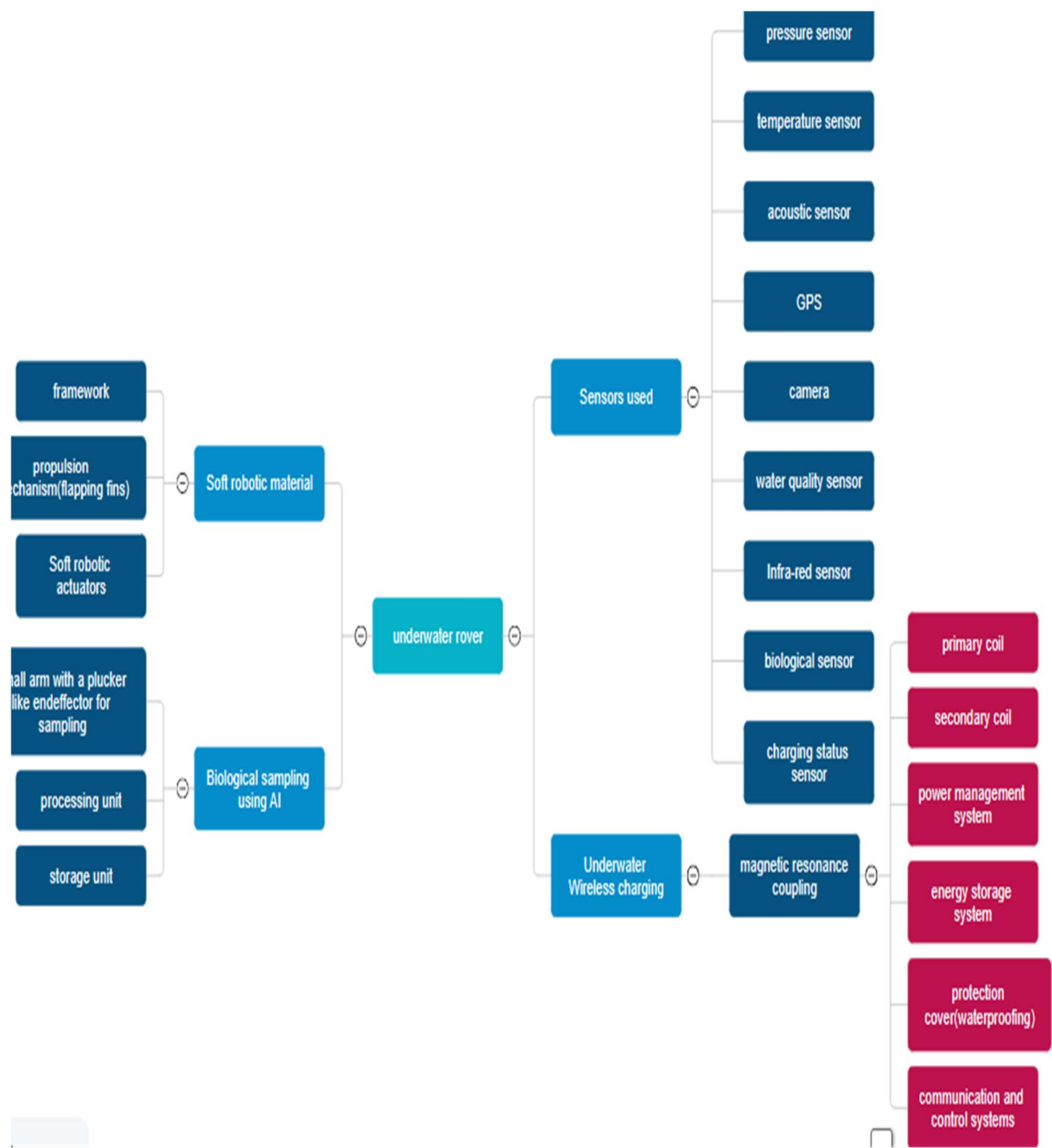
Following that for the underwater wireless charging mechanism, magnetic resonance coupling is more compatible to use. Underwater rovers can benefit from the efficient and dependable charging provided by magnetic resonance coupling, a wireless charging technique. Using the idea of magnetic resonance, power is wirelessly exchanged between a transmitter and a receiver coil in this manner. The transmitter coil creates an oscillating magnetic field at a certain frequency; it is usually placed on the seafloor or a stationary platform. The underwater rover's receiver coil resonates with this magnetic field, resulting in an electric current that charges the rover's batteries or power systems. Magnetic resonance coupling provides various benefits for underwater charging, including the capacity to transfer power over greater distances and through nonmetallic barriers like water. By minimizing the demand for exposed electrical contacts or physical connectors, this technique lowers maintenance costs and increases the operational longevity of underwater rovers for extended missions. To maximize the performance of magnetic resonance coupling for wireless charging of underwater rovers,

challenges like efficiency loss due to distance and alignment, as well as possible interference from nearby metallic objects or other electromagnetic sources, must be carefully addressed.

Underwater rovers equipped with robotic sampling devices are essential instruments for biological sampling in marine environments. In order to gather various biological specimens, such as water samples, sediment samples, benthic species, pelagic organisms, and microbial communities, these devices comprise a range of specialized tools and procedures. Every equipment, from sediment sampling tools like grabs and corers to water sampling systems with suction or filter mechanisms, is designed to meet certain sampling goals and requirements. Researchers can gather important information on marine biodiversity, habitat structure, ecological interactions, and environmental parameters in undersea habitats with the use of these sampling tools. Robotics sampling devices aid in the precise and effective gathering of biological samples, which advances scientific study, conservation activities, and ocean environmental monitoring.

Data fusion and integration play crucial roles in enhancing the effectiveness and efficiency of biological sampling conducted by underwater rovers in marine environments. By combining data from multiple sensors and sources, such as cameras, sonars, environmental sensors, and sampling devices, data fusion enables a comprehensive understanding of the underwater environment and the biological communities within it. Integration of diverse data streams allows researchers to correlate environmental variables with biological observations, identify patterns and trends, and make informed decisions about sampling strategies and target locations. Additionally, data fusion techniques can improve the accuracy and reliability of species identification and quantification by integrating information from multiple sensor modalities, such as visual imagery, acoustic signals, and environmental parameters. By harnessing the power of data fusion and integration, underwater rovers can optimize their sampling efforts, maximize scientific yield, and contribute valuable insights into marine biodiversity, ecosystem dynamics, and environmental health.

4.1.1 Ideation Map/System Architecture



(FIG.1)ARCHITECTURE WORKFLOW

4.1.2 *Various Stages*

1. Conceptualization and Design:

- Begin by defining the purpose and objectives of your underwater rover. Consider aspects like environmental conditions, depth, and the specific tasks it needs to perform.
- Design the overall structure, including the soft robotic components. Soft robots are advantageous in underwater environments due to their flexibility and adaptability to complex terrain¹.
- Incorporate features such as a camera, sonar sensor, and other necessary equipment for data collection and exploration

2. Soft Material Selection:

- Suitable soft materials for the robot's body. These materials allow for deformability and better interaction with the underwater environment.
- Considering factors like buoyancy, durability, and resistance to water pressure and robustness to mechanical devices fabric-based materials are opted to be used.

3. Fabrication and Assembly:

- Assemble the soft robotic components, including actuators and sensors.
- Integrate rigid and soft elements strategically to create a hybrid design that balances stability and flexibility.
- Develop a robust frame to hold all the components securely.

4. Actuation and Locomotion:

- Soft robots use various actuation mechanisms, such as pneumatic or hydraulic systems. These allow for gentle movements and adaptability.
- Explore different locomotion patterns, such as crawling, swimming, or hovering. Each pattern serves specific purposes in underwater exploration.

5.Power Storage and Charging:

- Implement an efficient power storage system. Since our project involves wireless charging, design a mechanism to recharge the robot underwater.
- Investigate energy-efficient solutions to extend mission duration.

6.Sensing and Data Fusion:

- Equip the rover with sensors (e.g., sonar, IR) to collect environmental data.
- Integrate data fusion techniques to combine information from multiple sensors. This enhances perception and decision-making capabilities.

7.Biological Sampling:

- Develop mechanisms for non-invasive biological sampling. For instance, consider using soft grippers or suction devices.
- Ensure that the sampling process does not harm marine organisms.

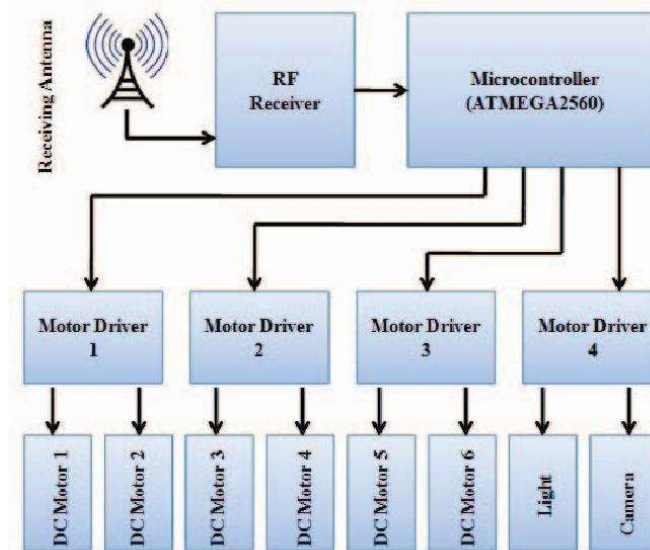
8.Wireless Communication:

- Establish reliable wireless communication between the rover and a base station (processing device) on the surface.
- Transmit captured images and other data wirelessly for analysis and real-time monitoring.

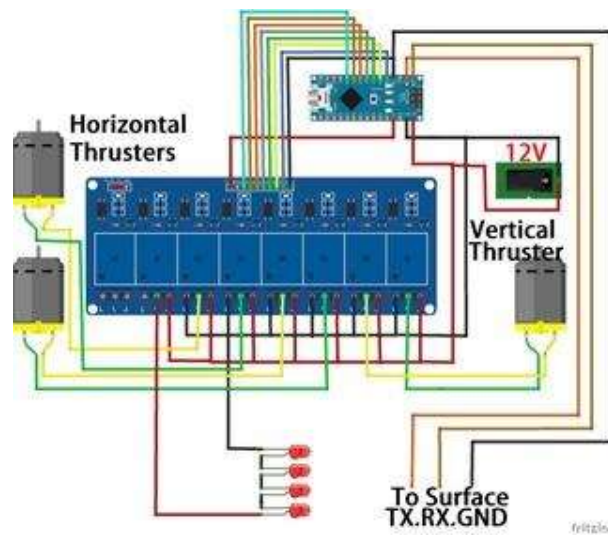
9.Control and Autonomy:

- Implement control algorithms to navigate the rover autonomously.
- Address challenges related to underwater communication delays and environmental uncertainties.

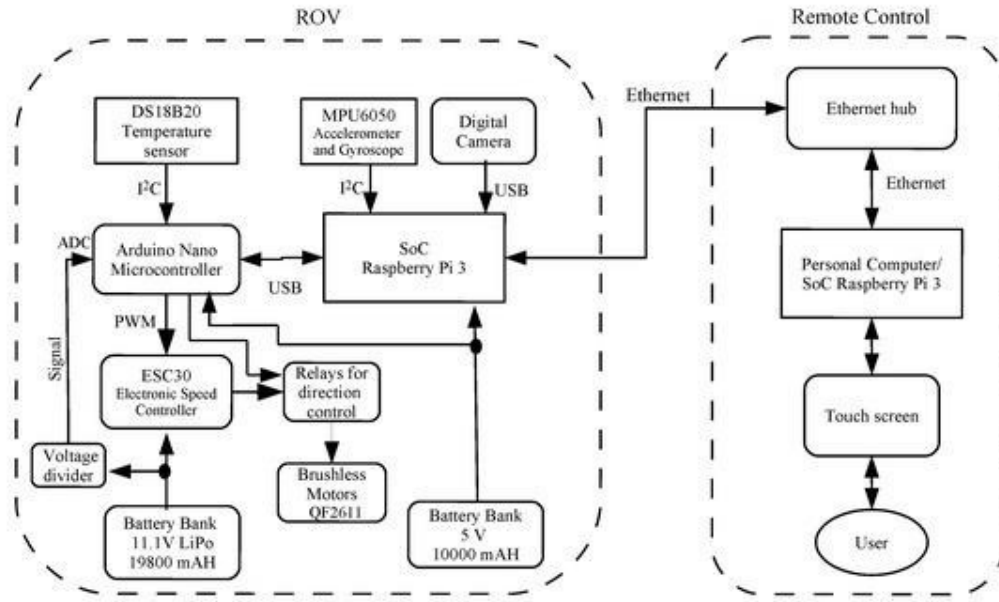
4.1.3 Internal or Component Design Structure



(FIG.2)COMMUNICATION SYSTEM



(FIG.3)CIRCUIT CONNECTION OF THRUSTERS



(FIG.4)SENSORS FLOWCHART

4.1.4 Working Principles:

1. Fabric-Based Flapping Fins: Flapping fins constructed from fabric-based materials utilize biomimetic principles to mimic the propulsion mechanisms of marine organisms such as fish or cetaceans. These fins are flexible, lightweight, and capable of generating thrust through rhythmic flapping motions. Fabric-based materials provide the necessary flexibility and durability for the fins to operate effectively in underwater environments.
2. Underwater Wireless Charging by Magnetic Resonance Coupling: Underwater wireless charging systems based on magnetic resonance coupling enable the autonomous recharging of the rover's batteries while submerged. A charging station deployed in the underwater environment generates an oscillating magnetic field, which induces an electric current in a receiver coil integrated into the rover. This wireless power transfer mechanism allows the rover to recharge its batteries without the need for physical connectors or exposed electrical contacts, ensuring continuous power supply for extended missions.

3. Biological Sampling with Data Fusion and Integration: The underwater rover is equipped with specialized biological sampling devices, such as water samplers, sediment corers, and benthic grabbers, constructed from fabric-based materials. These sampling devices are integrated with sensors and actuators to enable precise and controlled sampling operations. Data fusion and integration techniques combine information from multiple sensors and sources to generate a unified dataset, providing comprehensive insights into the underwater environment and the biological communities within it.

4. Flapping Fin Propulsion: The flapping fins generate thrust through rhythmic flapping motions, propelling the rover through the water with efficiency and agility. By mimicking the propulsion mechanisms of marine organisms, the rover can navigate through complex underwater environments, manoeuvre around obstacles, and reach target locations for biological sampling tasks.

5. Adaptive Control Algorithms: Adaptive control algorithms govern the operation of the flapping fins, adjusting the flapping frequency, amplitude, and phase to optimize propulsion efficiency and manoeuvrability based on sensor feedback and environmental conditions. These algorithms enable the rover to adapt its propulsion strategy in real-time to changes in water currents, obstacles, and desired navigation trajectories.

6. Real-Time Data Fusion and Integration: Sensor data from the rover's onboard sensors, including environmental sensors, imaging systems, and biological sampling devices, is processed in real-time using data fusion and integration techniques. This allows for the generation of actionable information for researchers and operators, including maps of marine biodiversity, habitat characteristics, and environmental parameters, facilitating informed decision-making and adaptive sampling strategies.

4.2 FEATURES:

1. Autonomous Navigation: The underwater rover is capable of autonomous navigation through complex underwater environments using soft robotics principles. Its flexible and compliant actuators allow it to manoeuvre through tight spaces, navigate around obstacles, and interact safely with marine organisms and structures.

2. Underwater Wireless Charging: The rover features underwater wireless charging capabilities, allowing it to recharge its batteries autonomously while submerged. This feature extends the operational endurance of the rover, enabling prolonged missions without the need for manual intervention or retrieval for recharging.

3. Biological Sampling: Equipped with specialized biological sampling devices, the rover can collect various types of biological specimens from marine environments. These sampling devices are designed to perform precise and controlled sampling operations, enabling researchers to gather valuable data for scientific research and environmental monitoring.

4. Data Fusion and Integration: The rover integrates data fusion and integration techniques to combine information from multiple sensors and sources, including cameras, sonars, environmental sensors, and biological sampling devices. This allows for a comprehensive analysis of the underwater environment, including marine biodiversity, habitat characteristics, and environmental parameters.

5. Remote Operation and Control: The rover can be remotely operated and controlled by researchers or operators from a surface vessel or a shore-based facility. This remote operation capability allows for real-time monitoring and control of the rover's movements, sampling activities, and sensor data acquisition.

6. Environmental Sensing: The rover is equipped with environmental sensors to monitor water quality parameters, such as temperature, salinity, pH, and dissolved oxygen levels. This environmental sensing capability provides valuable data for assessing the health and condition of marine ecosystems.

7. Adaptive Sampling Strategies: The rover employs adaptive sampling strategies based on data fusion and integration algorithms to optimize sampling efforts and target locations of interest. These strategies enable researchers to efficiently collect biological samples and prioritize areas for further investigation.

8. Modularity and Scalability: The project is designed with modularity and scalability in mind, allowing for easy integration of additional sensors, sampling devices, or functionalities as needed. This modular approach enables flexibility in adapting the rover to different research objectives and environmental conditions.

4.2.1 Novelty of the proposal

The design and development of an underwater rover equipped with soft robotic materials, wireless charging beneath the surface, and AI-powered biological sample capabilities is a unique and inventive initiative for multiple reasons.

- **Integration of Soft Robotics:** This innovative method to underwater robotics is introduced by incorporating soft robotic materials into the underwater rover's architecture. Compared to standard rigid systems, soft robotics have more flexibility, can adapt to more complicated situations, and can interact with fragile marine ecosystems more effectively. With the help of this innovative method, the underwater rover can now more accurately and efficiently travel difficult terrain, engage with marine life, and carry out sensitive sample duties.
- **Underwater Wireless Charging:** Employing this technology to charge autonomous underwater vehicles (AUVs) and underwater rovers is a creative way to address the problem. Wireless charging reduces maintenance costs and allows the rover's batteries to be seamlessly recharged while underwater by doing away with the need for exposed electrical contacts or physical connectors. This invention increases the underwater rover's operational endurance, allowing for longer trips without requiring manual assistance or recovery for recharging.
- **AI-Driven Biological sample:** This innovative method of undersea study and exploration makes use of artificial intelligence (AI) algorithms for biological samples. With previously unheard-of efficiency and accuracy, the underwater rover can gather vital data for scientific research, biodiversity studies, and environmental monitoring by

autonomously detecting, tracking, and collecting samples of marine species. The rover's capacity to investigate marine ecosystems is improved by this AI-driven method, which also advances our knowledge of the dynamics of underwater habitats and biodiversity.

- **Interdisciplinary Integration:** Robotics, materials science, wireless communication, artificial intelligence, and marine biology are all integrated together in this project. The development of a comprehensive approach to tackle the difficulties associated with underwater exploration and research is made possible by the integration of knowledge from several disciplines. This multidisciplinary approach encourages the creation of new technologies and methods for researching and protecting maritime habitats, as well as innovation and cooperation across a range of disciplines.

CHAPTER 5

CONCLUSION

This exploration and study of underwater environments concludes challenges that traditional rigid robots encounter. They are overcome through features such as Underwater Wireless Charging which is an increasingly utilized attribute. This feature extends the operational endurance of the rover, enabling prolonged missions without the need for manual intervention or retrieval for recharging. The fabrication of soft robotics significantly influences the robot functionality. Compared to standard rigid systems, soft robotics have more flexibility, can adapt to more complicated situations, and can interact with fragile marine ecosystems more effectively. With the help of this innovative method, the underwater rover can now move more accurately and efficiently travel difficult terrain, engage with marine life, and carry out sensitive sample duties. The AI Driven biological sample applied here aids subtly by collecting vital data for further study and research. The rover's capacity to investigate marine ecosystems is improved by this AI-driven method, which also advances our knowledge of the dynamics of underwater habitats and biodiversity. The autonomous navigation system implemented elevates the efficiency distinctively. The underwater rover is capable of autonomous navigation through complex underwater environments using soft robotics principles. Its flexible and compliant actuators allow it to manoeuvre through tight spaces, navigate around obstacles, and interact safely with marine organisms and structures. Environmental sensing feature allows this robot to perceive through the environment gathering the data for later analysis. The adaptive sampling strategies employed in the functionality of the robot works based on data fusion and integration algorithms to optimize sampling efforts and target locations of interest. These strategies enable researchers to efficiently collect biological samples and prioritize areas for further investigation. Data fusion and algorithms implemented in this robot combine information from multiple sensors and sources, including cameras, sonars, environmental sensors, and biological sampling devices. This allows for a comprehensive analysis of the underwater environment, including marine biodiversity, habitat characteristics, and environmental parameters. The remote operation and control employed in the robot can be remotely operated and controlled by researchers or operators from a surface vessel or a shore-based facility. This remote operation capability allows for real-time monitoring and control of the rover's movements, sampling activities, and sensor data acquisition. The final evaluation involves the integration of the components such as Robotics, materials science, wireless communication, artificial intelligence, and marine biology. The development of a comprehensive approach to tackle the difficulties associated with underwater exploration and research is made possible by the integration of knowledge from several disciplines. This multidisciplinary approach encourages the creation of new technologies and methods for researching and protecting maritime habitats, as well as innovation and cooperation across a range of disciplines. The project is designed with modularity and scalability in mind, allowing for easy integration of additional sensors, sampling devices, or functionalities as needed. This modular approach enables flexibility in adapting the rover to different research objectives and environmental conditions.

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Appendix

A. Source Code

ARDUINO CODE FOR UNDERWATER ROVER MOTION(ENDEFFECTOR USED FOR BIOLOGICAL SAMPLING):

```
#include <Servo.h>

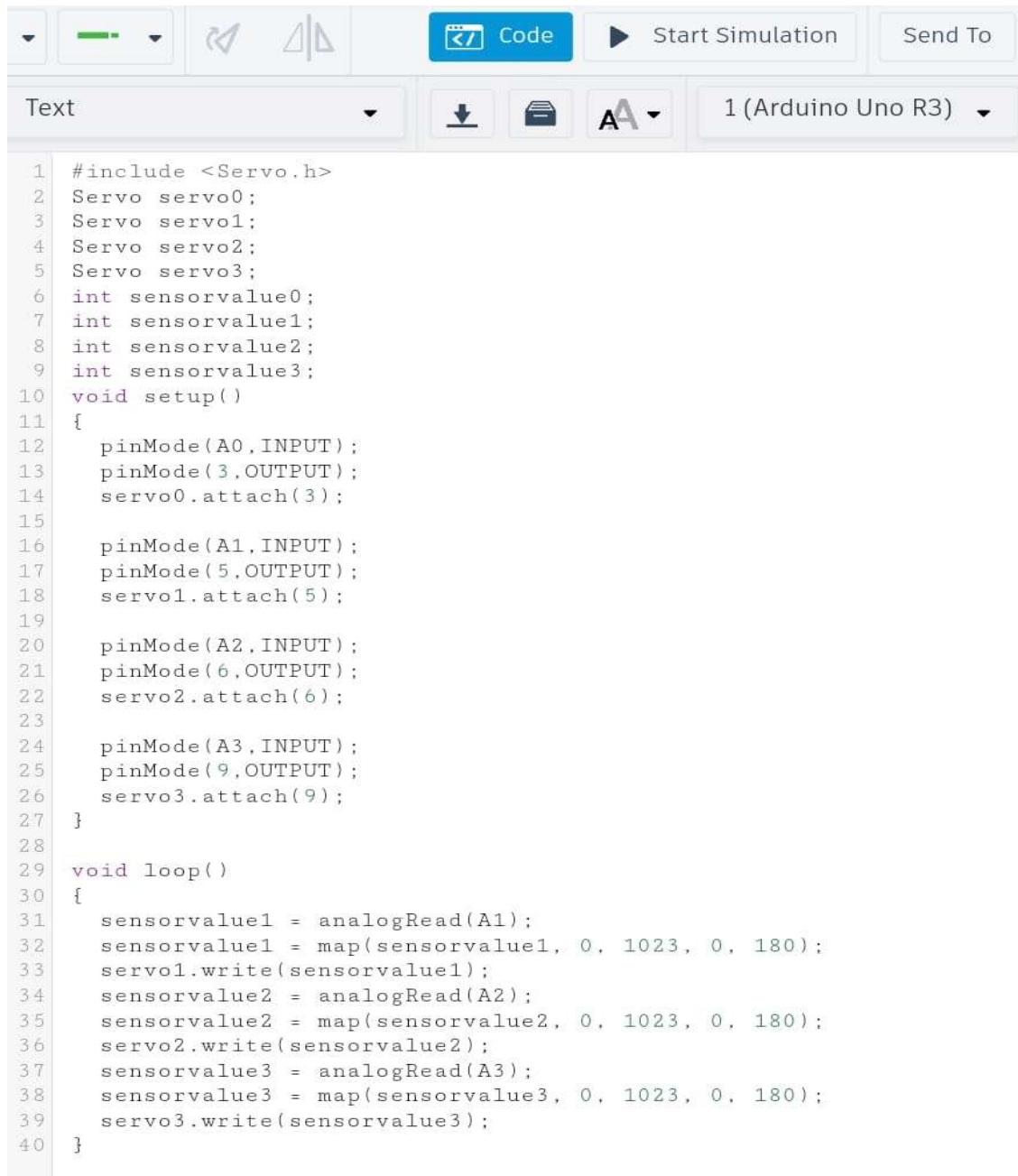
Servo servo0;
Servo servo1;
Servo servo2;
Servo servo3;
int sensorvalue0;
int sensorvalue1;
int sensorvalue2;
int sensorvalue3;
void setup()
{
  pinMode(A0,INPUT);
  pinMode(3,OUTPUT);
  servo0.attach(3);

  pinMode(A1,INPUT);
  pinMode(5,OUTPUT);
  servo1.attach(5);

  pinMode(A2,INPUT);
  pinMode(6,OUTPUT);
  servo2.attach(6);

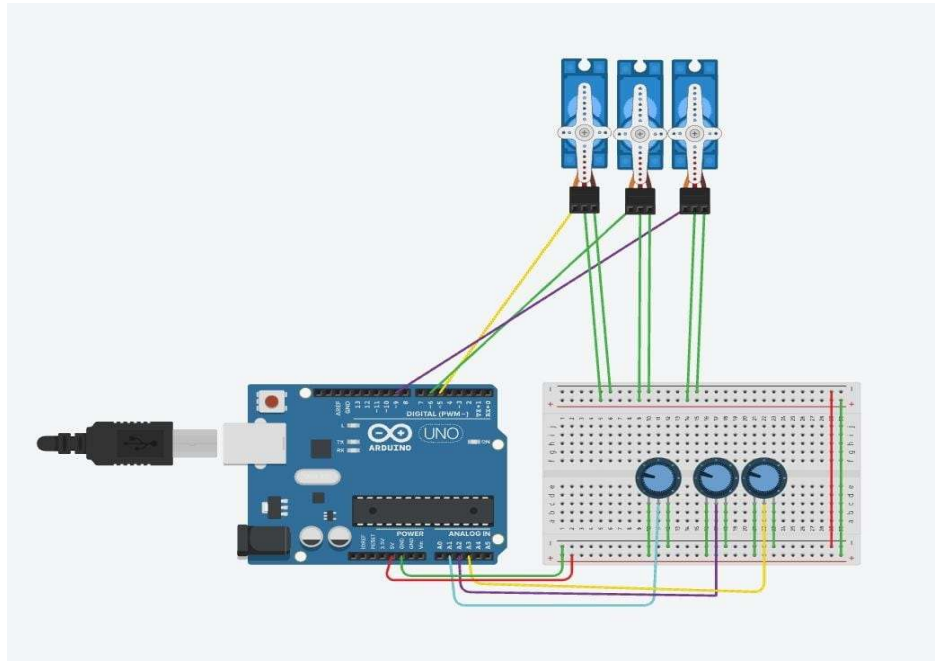
  pinMode(A3,INPUT);
  pinMode(9,OUTPUT);
  servo3.attach(9);
}
void loop()
{
  sensorvalue1 = analogRead(A1);
  sensorvalue1 = map(sensorvalue1, 0, 1023, 0, 180);
  servo1.write(sensorvalue1);
  sensorvalue2 = analogRead(A2);
  sensorvalue2 = map(sensorvalue2, 0, 1023, 0, 180);
  servo2.write(sensorvalue2);
  sensorvalue3 = analogRead(A3);
  sensorvalue3 = map(sensorvalue3, 0, 1023, 0, 180);
  servo3.write(sensorvalue3);
}
```

B. Output

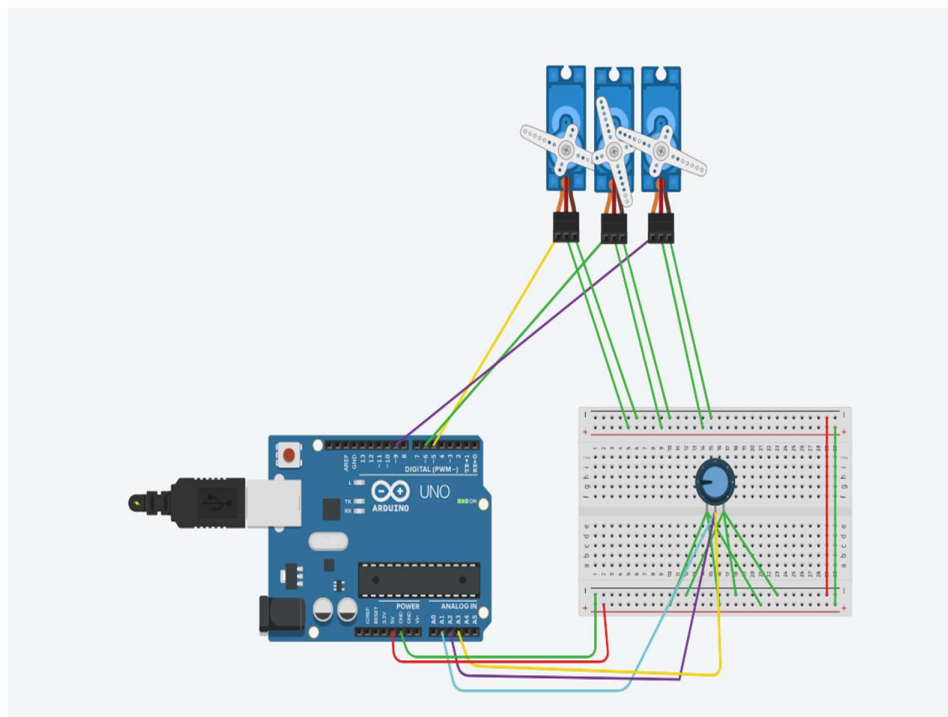


```
1  #include <Servo.h>
2  Servo servo0;
3  Servo servo1;
4  Servo servo2;
5  Servo servo3;
6  int sensorvalue0;
7  int sensorvalue1;
8  int sensorvalue2;
9  int sensorvalue3;
10 void setup()
11 {
12     pinMode(A0, INPUT);
13     pinMode(3, OUTPUT);
14     servo0.attach(3);
15
16     pinMode(A1, INPUT);
17     pinMode(5, OUTPUT);
18     servo1.attach(5);
19
20     pinMode(A2, INPUT);
21     pinMode(6, OUTPUT);
22     servo2.attach(6);
23
24     pinMode(A3, INPUT);
25     pinMode(9, OUTPUT);
26     servo3.attach(9);
27 }
28
29 void loop()
30 {
31     sensorvalue1 = analogRead(A1);
32     sensorvalue1 = map(sensorvalue1, 0, 1023, 0, 180);
33     servo1.write(sensorvalue1);
34     sensorvalue2 = analogRead(A2);
35     sensorvalue2 = map(sensorvalue2, 0, 1023, 0, 180);
36     servo2.write(sensorvalue2);
37     sensorvalue3 = analogRead(A3);
38     sensorvalue3 = map(sensorvalue3, 0, 1023, 0, 180);
39     servo3.write(sensorvalue3);
40 }
```

(FIG.5)PROGRAM CODE



(FIG.6)SIMULATION CIRCUIT



(FIG.7)SIMULATION CIRCUIT OUTPUT

C. Research Paper

SoftRoboSampler: Integration of Soft Robotics and AI in Underwater Rover System to enhance exploration efficiency.

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Abstract—This study explores the integration of soft robotics, underwater wireless charging, biological sampling mechanisms, and AI in underwater rover systems to enhance underwater exploration. Soft robotics offers improved manoeuvrability and adaptability, allowing rovers to navigate complex terrains with finesse. Underwater wireless charging addresses power management challenges, enabling extended missions without manual intervention. Biological sampling mechanisms collect valuable specimens and environmental data for research and monitoring. AI-driven object recognition enhances autonomy by identifying underwater objects and organisms in real time, streamlining data analysis. By synergizing these technologies, underwater rovers enhance exploration efficiency, data collection, and scientific understanding of ecosystems, contributing to conservation efforts.

Keywords—underwater rover, soft robotics, underwater wireless charging, magnetic resonance coupling, biological, AI, marine.

I.INTRODUCTION

The exploration and study of seas, as well as scientific research, environmental monitoring, infrastructure inspection, search and rescue, resource exploration, and military activities, are made possible by underwater rovers, sometimes referred to as underwater drones or remotely controlled vehicles (ROVs)[24]. Through the integration of soft robotics, underwater wireless charging, and AI-powered biological sampling in underwater rover systems, our research seeks to improve underwater exploration. Soft robotics minimizes environmental effect when navigating intricate underwater terrains by providing improved dexterity and flexibility[1]. Power management issues are resolved with underwater wireless charging devices, allowing for longer missions without human involvement. Mechanisms for biological sampling gather important specimens and

environmental information for study and observation[16].By enabling rovers to independently recognize and categorize underwater objects and animals in real time, AI-driven object identification capabilities simplify data analysis. Underwater rovers can greatly improve scientific understanding of underwater ecosystems, data collection capabilities, and exploration efficiency by combining various technologies[13]. We address limitations in the form of guaranteeing mechanical stability and durability, resolving underwater wireless charging operational constraints, and improving comprehension of biological and ecological insights.

II.Proposed Methodology

Our proposed methodology utilizes fabric-based materials for soft robotics, benefiting from their flexibility, compliance, and mechanical robustness. Fabric-based materials safely interact with marine ecosystems due to their flexibility, conforming to underwater habitats' irregular shapes. They offer adaptability in design and construction, seamlessly integrating with sensors and electronics to create small, manoeuvrable underwater robotic systems. Moreover, fabric-based materials are environmentally safe and biocompatible, minimizing their impact on marine species and habitats.

For underwater wireless charging, magnetic resonance coupling is preferred for its efficiency and reliability. This technique wirelessly transfers power between a transmitter and a receiver coil using magnetic resonance. The transmitter coil, usually on the seafloor, generates an oscillating magnetic field that resonates with the receiver coil on the rover, charging its batteries or power systems. Magnetic resonance coupling overcomes distance and non-metallic barriers, reducing maintenance costs and extending rover missions. Challenges like

efficiency loss and interference from nearby objects must be addressed for optimal performance.

Underwater rovers equipped with robotic sampling devices are crucial for biological sampling in marine environments. These devices gather various biological specimens using specialized tools, aiding in scientific research, conservation, and environmental monitoring. Robotics sampling devices enable precise and effective collection of samples, advancing our understanding of marine biodiversity and habitat structure.

Data fusion and integration enhance the efficiency of biological sampling by combining data from multiple sensors and sources. This allows for a comprehensive understanding of the underwater environment and biological communities. Integration of diverse data streams improves species identification and quantification, optimizing sampling efforts and providing valuable insights into marine ecosystems.

Overall, our methodology leverages fabric-based materials, magnetic resonance coupling for charging, robotic sampling devices, and data fusion to advance underwater exploration and biological sampling while minimizing environmental impact.

III. Literature Survey

Underwater rover systems that integrate biological sampling with artificial intelligence (AI), underwater wireless charging, and soft robotics—all of which have the potential to significantly improve ocean exploration and offshore operations[19]. Soft robotics, with its flexible materials, reduces collision risks and allows for manoeuvrability in high seas, extending robotic monitoring to remote oceanic areas[1]. Underwater wireless charging, on the other hand, allows these systems to sustain operations by self-recharging when power levels are low[15]. Biological sampling mechanisms that are outfitted with AI also simplify data collection and analysis, providing insights into marine ecosystems[16].

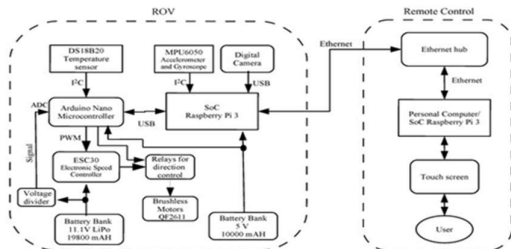
These technologies promise to lower manufacturing costs, increase deployment scalability, and improve the environment[9]. Underwater rover systems are poised to revolutionize ocean exploration and contribute to sustainable offshore development through interdisciplinary collaborations and technological innovation[29]. Examples of this progress include projects like tiny robotic turtles with target tracking and wireless charging and strategies for designing

compact hybrid energy systems, which improve operational efficiency and reliability[13]. Moreover, developments in soft robotic grippers for delicate sampling on deep reefs show the potential for intricate scientific experiments and in situ measurements, which enhance our understanding of marine biodiversity and molecular biology[2].

IV. Materials and Methods

The undersea rover's materials are categorized generically. Actuators that are specifically made using soft robotic components are known as soft robotic actuators[4]. A gadget called a charging transmitter is used to enable wireless charging, which lessens the main disadvantage of an underwater rover's extended use[3]. The underwater rover's charging method uses primary and secondary electric coils to enable wireless battery recharging while it is submerged[28]. The Power Management system creates an energy domain that is optimized to effortlessly and efficiently control the robot's energy[27]. In order to power its numerous onboard components and systems during its operations in underwater environments, the underwater rover is outfitted with a sturdy battery or energy storage device. This rover has an artificial intelligence system[23]. For autonomous navigation and mission execution underwater, this rover has an AI processing unit specifically designed for functions like image recognition, pattern identification, and decision-making[6]. Modern communication devices have been installed on the rover to enable dependable data transfer and remote control in submerged settings, where radio waves and other conventional wireless connection techniques are useless[20]. Flapping fins provide several benefits for underwater mobility by mimicking the propulsion mechanisms found in aquatic species such as fish and marine mammals[5]. The purpose of the specialized sampling equipment is to gather environmental samples and a variety of biological specimens from underwater habitats[17]. Suction samplers and pluckers are two frequently used sampling instruments[29]. The rover makes use of sophisticated localization and navigation algorithms designed to function in underwater conditions, where conventional GPS navigation systems are not as reliable[25]. The underwater rover's housing and enclosures are painstakingly developed and designed to provide waterproofing and shield

internal components from the corrosive effects of seawater[34]. The housing and enclosures of the rover are effectively waterproof thanks to a number of important factors and characteristics. The underwater rover's sensory equipment aids in its ability to perceive its surroundings[26]. For visual examination, navigation, and data collecting in underwater habitats, cameras are a sensory essential. They give operators the ability to remotely monitor the rover's surroundings, recognize impediments, and take in marine life thanks to real-time video feeds and photos[32]. By detecting the infrared radiation that objects generate, infrared sensors allow the rover to sense changes in temperature and identify items in its immediate area based on their heat signatures. The distance between the rover and the seabed or water's surface is measured by depth sensors, such as pressure transducers or sonar altimeters[7]. They offer crucial depth data for safe operation depth maintenance, navigation, and preventing collisions with the seafloor or surface. Temperature sensors track changes in the water's temperature in the submerged environment[24]. They offer useful information for determining thermoclines, evaluating thermal gradients, and researching temperature-dependent phenomena like ocean circulation[30]. Biological sensors identify and measure biological elements in water samples, such as the amount of dissolved organic matter, microbial activity, and chlorophyll. In order to calculate water column pressure and identify the rover's depth, pressure sensors detect water pressure at different depths[31]. In order to provide real-time feedback on battery charge levels, charging speeds, and charging status indications, charging status sensors keep an eye on the rover's battery charging operation[21]. In order to evaluate the state of aquatic ecosystems, water quality sensors detect a number of factors, including pH, dissolved oxygen, conductivity, turbidity, and nutrient levels[18]. In order to measure distances, detect objects, and produce comprehensive maps of underwater topography, SONAR systems send out acoustic pulses and then analyze the returned signals[12].



A flexible instrument for environmental monitoring and scientific research in marine areas is the underwater rover[8]. Its autonomous navigation, based on the concepts of soft robotics, allows it to securely interact with structures and marine life while navigating over intricate underwater terrain[22]. Most notably, it can be wirelessly charged, which increases its operational durability for extended missions without requiring manual assistance[11]. The rover's data fusion capabilities, which combine information from many sensors, enable it to collect a variety of specimens for research purposes. It is equipped with specialist biological sample instruments[33]. Real-time monitoring and control are possible through remote operation from surface ships or land-based facilities. The rover also uses adaptive sampling tactics and keeps an eye on environmental parameters to optimize its sampling efforts depending on data collected[14]. Its flexible and modular architecture makes it simple to add more sensors or features and adjust to various environmental factors and study goals.

V. Conclusion

Our underwater exploration project integrates several key features to overcome challenges faced by traditional rigid robots. Underwater Wireless Charging extends rover missions without manual intervention, while soft robotics enhance adaptability and interaction with marine ecosystems. AI-driven biological sampling collects vital data, improving our understanding of underwater habitats. Autonomous navigation enables efficient manoeuvring through complex environments, aided by environmental sensing for data collection. Adaptive sampling strategies optimize sample collection based on allowing for comprehensive analysis of the underwater environment. Remote operation facilitates real-time monitoring and control from surface vessels. Our multidisciplinary approach integrates robotics,

materials science, wireless communication, AI, and marine biology, fostering innovation and collaboration across disciplines. Modular design enables easy integration of additional functionalities, ensuring adaptability to various research objectives and environmental conditions.

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