A Review on Latest Trends in Development of Remotely Operated Marine Robots.

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***Abstract*—Abstract— oceans, seas, and enormous water bodies have always been long unexplored areas, which in recent years have taken its place for exploration due to the evolution of sophisticated marine robots (ROUV – Remotely Operated Underwater vehicles and UUV – Unmanned Underwater Vehicle or Autonomous Underwater Vehicle/AUV- Autonomous Underwater Vehicle). This paper explores the growth of marine robots and analysis of key concepts of controllers, navigation algorithms, employed power systems, sensor networks and other key concepts of ROUVs and UUVs which had a significant growth in recent years as there have been big developments in AI, Big Data and Embedded Systems. Finally, a comparative analysis of some of the recent robots are also mentioned in this paper.**

***Index Terms*—component, formatting, style, styling, insert**

Keywords — marine robots, ROU, UUV, AI, Embedded systems.

I. Introduction

Marine technology has been developing from the ages for deep-water explorations and analysis of large water bodies. Aquatic conditions have never been easy for inquiry tasks, and a lot of research has been put in recent years, to explore the oceans and seas in harsh climatic conditions. ROUVs and UUVs have substantial applications in surveillance, ocean exploration, pollution monitoring, sea patrolling etc. The deep-water quest is one of the vital applications for which the research has picked up pace in recent years. Marine robots are the composition of many different aspects of navigation, processing systems, power systems and sensor systems that should work together to give the preferred output they are intended to provide. Large water bodies have turbulent waters, making it difficult for exploration, monitoring, and other related tasks of UUVs and ROUVs. A control system should adjust itself for such turbulence and complications to complete the trajectory designed for it. Power systems play one of the crucial roles because of the complicated situations present underwater; sensor systems are used with both trajectory planning and ocean monitoring, making them one of the vital onboard equipment. Much research has been employed in the design and construction of ROUVs and UAVs due to the complex environment they are placed in and the harsh environments of substantial water bodies such as oceans and seas. A lot of research has been employed with the help of an equipped gripper that can grasp an object and camera sensors along with it [1]. In these designs, additional equipment is required for trajectory maintenance and stability of the system because of the adverse conditions of the ocean, which were mentioned earlier. The dynamic equilibrium is achieved with the help of sensors that maintains the precise position of the entire UAVs and ROUVs and shall be achieved through INS (Inertial Navigation Systems), PIDs (Proportional Integral Derivative systems), ARC (Adaptive Robotic Control), Intelligent Automated Control or smart mechanical control [2][3].

II. Literature Review

Underwater vehicles have been here around since the 1990s and have been under constant development since then. The development of UUVs and ROUVs has become a challenge due to the unpredictable changes that induce turbulence throughout the ocean, making it difficult for UUV or ROUV to carry out the assigned work. A significant part of development came in recent years due to their growing importance in defense, commercial use, and growth of research. Figure1 shows the trend in UUVs and ROVs growth in market size [4]. Underwater

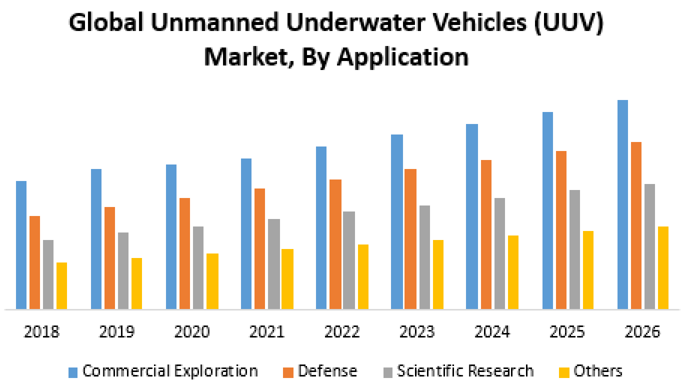

Fig. 1. trend in market size of UUVs and ROVs [4].

vehicle building started in 1953 when Dimitri Rebikoffin developed the 1st fully functional underwater vehicle. From the 1st UUV to the latest intelligent UUV, a lot of technological change and research is invested for such innovative robots. Figure 2 shows the significant types of underwater vehicles available today and a detailed analysis of factors required to create these projects in other sections. Recent advancements

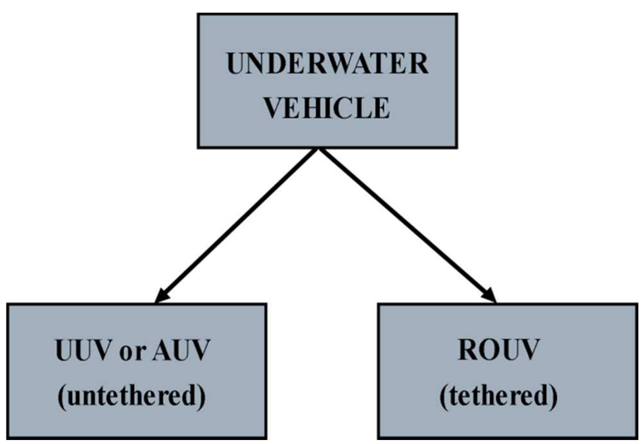

Fig. 2. major types underwater vehicles

and improvements include the creation of intelligent dynamic controller, high accurate sensor system, efficient power supply, dynamic propulsion system, sensing agents, and effective control of mechanical, software aspects of robotic systems that have been improving and developing in the field of ROUV and UUV. One such project is, object avoidance using RNN (Recurrent Neural Networks) along with CNN (Convolution Neural Networks) by Changjian Lin [5]. This project shows how the development in intelligent control systems, in this case, the result of an object avoidance system, can be achieved with the help of NN (Neural Network). Stabilization is also one of the main problems that are encountered in recent times wherein intelligent stabilization could be achieved through ANN (Artificial Neural Network); the paper analyzes how external disturbances could be an input to the neural net, and necessary adjustments could be made with the output of NN [6]. Internet of Underwater Things (IoUT) has become popular with the recent data explosion and need of data in recent years, which relies on Underwater Acoustic wireless Sensor Networks (UASN). An efficient path planning algorithm has been developed for data collection and energy usage reduction using clustering algorithms [7]. Another algorithm based on reinforcement learning which takes sensor data as input and outputs continuous surge force and yaw moment [8]. Propeller systems play a crucial role in trajectory and recent developments in propulsion system for UUVs which deal with fault diagnosis in propeller systems using deep learning have been developed [9]. These recent developments have been paving paths for advanced futuristic UUVs and ROUVs.

III. MAIN FEATURES OF UUVS AND ROUVS

A. *Design of the UUVs and ROUVs*

The design of the vehicle depends on many factors. The main problem regarding underwater vehicles is the shape of the vehicle, which decides how easily it can move through and in water and also determines the fluid resistance or "drag" acting on the vehicle. Greater the drag, greater the turbulence which would put pressure on the fuselage of the vehicle. The turbulence may also affect the data collection of the AUV, as it may cause tremors throughout the bot thereby interfering with the sensor readings. For camera-based applications this is a huge threat, so the design of the vehicle is generally fluid dynamic. Commonly used shapes are the torpedo or the curved rectangle shaped. Curved rectangle shaped objects reduce drag but not as much as torpedo shaped objects. The torpedo design which is frequently used in the designing of the UUVs and ROUVs will make the vehicle more fluid dynamic. To maneuver the vehicle in four degrees of freedom, many of the applications seen here may have extra motors or diving planes which use the dynamic lift concept to realize the degrees of freedom. For the sinking and rising of the vehicles, one methodology that can be used is to increase and decrease the density of the bot. For many applications, we see widespread use of the ballast tank method, which uses water to fill the ballast tanks and increase the mass of the vehicle which helps it sink into water. Another method is to use a vertical thruster for pushing the bot sink. The recent trends of the design have been referred here to compare and analyze the designs of the following vehicles which are used. The first reference is having a cuboidal design which takes an ROV from the BlueROV2 designed by the Blue Robotics company. The BluROV in design figure3 used the extra thrusters to maneuver the bot sideways, forwards and backwards for the sinking and rising motion. This design uses the ballast weights to ensure the weight of the bot is more than the buoyancy provided by the water. The weight plays a crucial role in the sinking of the vehicle as greater the weight, denser the vehicle becomes thereby increasing the buoyancy force acting upon the vehicle.

[10]. The design in fig5 uses big dynamos which use the water currents to turn the dynamos which in turn produces power. This design of the bot is almost torpedo shaped with diving planes consisting of dynamos. This design is inspired by the submarine and also shares the same concepts like having a streamlined body which reduces drag [11]. This design in fig 4 is inspired by the commercial aircraft method which has wings, or diving planes in this case, and a fin which helps it to move in all directions. This design uses the concept of dynamic lift where the vehicle's wings control the motion of fluid moving under or over the vehicle which helps it to move upwards or downwards [12].

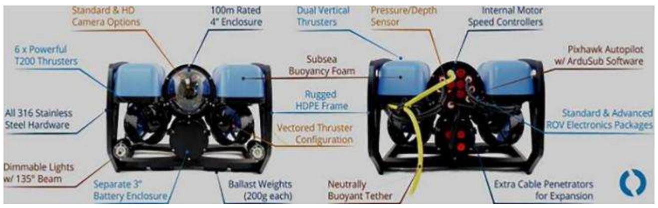

Fig. 3. The BluROV2 which is a design used in the development of a Small-sized Autonomous Underwater Vehicle Architecture for Regular Periodic Fish-cage Net Inspection.[13]

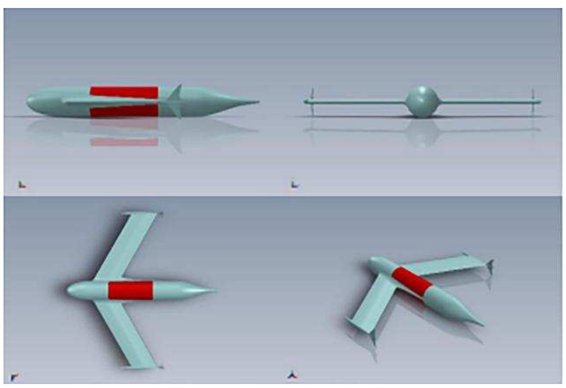

Fig. 4. SQUID TUG (Tailless Underwater Glider) view.[12]

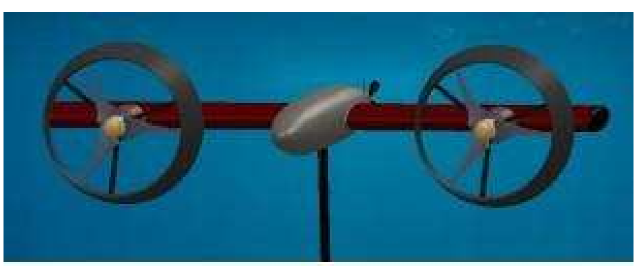

Fig. 5. Conceptual design of the autonomous underwater vehicle mounted ocean current turbine.[11]

B. Control systems

The control system for an AUV or ROV is fundamental as it is required to control the AUV or the ROV. Generally, the control system is responsible for the navigation and the movement of the vehicle. It is used to contact the base station in case of autonomous or remote vehicles. The control system can be of many types; the processor power and capabilities can be chosen according to the vehicle's primary purpose of functioning. For example, Many ROV and AUV applications depend on the OpenCV capabilities and use machine learning algorithms to analyze the area underwater. It is well known that this process requires a considerable amount of power required for processing. Therefore, those applications with higher-end control systems such as the NVIDIA TX2 are suitable for applications like the OpenCV application discussed before. To facilitate online deployment, the algorithm is deployed on a portable machine such as the NVIDIA TX2 or the Intel neural compute stick. The system can achieve 12 frames per second on Nvidia TX2[11]. In fig 6, the control system design is depicted.

Fig. 6. The above figure uses the control system architecture which is used to handle multiple processes which are used in the navigation, and movement of the bot. [12]

C. Sensor Networks

A sensor network plays a crucial role in the collection of data which the control system could use for navigation, trajectory, and planning where each sensor observes data in different locations and then sends the data to a storage unit for storage and analysis. Sensor networks control nodes that cooperatively sense and control the environment. They enable interaction between people or computers with the environment. Sensor networks are wired or wireless. Wired sensor networks utilize ethernet cables to connect sensors. Wireless sensor networks (WSNs) use Wi-Fi, Near Field Communications (NFC), etc., to connect sensors. Sensor networks are often installed under challenging environments to monitor infrastructure.

An ROV camera allows users to see underwater by collecting high-definition images that aid scientific research and undertake various tasks, including inspection, retrieval, and observation, among other applications. It can also help in maneuverability in case of manual operation of the underwater vehicle. ROVs can deploy passive sound monitoring sensors to detect environmental noise and monitor vocalizing marine fauna or evaluate changes in the ecosystem that are apparent in the soundscape. Hardware such as the differential GPS, gyroscopes, and acceleration sensors, are used to combine information to refine the positional accuracy. At the front, there is a dome that contains the sensors kit. A computer manages the collected data. For visual assessment and object detection at a distance, a digital camera is used. On the bulkhead, a 106 candle and a flat LED have been mounted. In the case of turbid waters, where it isn't easy to see, lighting plays a crucial role in detecting objects [14]. The SICK LMS511 LIDAR is equipped with a rotating mirror mechanism, which deflects the emitted laser beam. LIDAR allows for time-of-flight calculation, where time-of-flight is a method for measuring the distance between a sensor and an object and gives a 2D slice of the environment. In the case of unsuitable weather conditions such as rain, the laser beam will most likely be reflected by a raindrop and therefore prevent it from measuring the object of interest with accuracy. A multi-echo LIDAR emits multiple echoes of the same pulse, which can then be monitored, improving the likelihood of striking the intended target. At a range of 0.8 to 80 m, the LIDAR has a 190° scanning angle and a resolution of 0.166°. The achieved LIDAR accuracies are on the order of 5 cm. [15].

D. Navigation systems of ROUV/UUV

Navigation in AUV is a challenging task for achieving high accuracy. There are numerous obstacles to underwater navigation. When a vehicle is submerged, radio frequencies, or electromagnetic frequencies, cannot penetrate the sea surface, making GPS information difficult to receive. Instead of using GPS modules, alternate methods include using the following sensors such as accelerometers and gyroscopes to visualize the vehicle's orientation. These sensor helps to give an approximate understanding of the position of the vehicle underwater. Auxiliary sensors or other navigation systems, such as a Doppler Velocity Log (DVL), compass, pressure sensor, global positioning system (GPS), acoustic positioning system (APS), or geophysical navigation system, are often combined with the INS to form an integrated navigation system for end-to-end AUV navigation [16]. The proposed navigation is depicted in fig7. This system helps get the following information from the bot and is run through the Kalman filter, giving an approximate position of the vehicle. [17] As shown in Fig.8, These systems have two local (body-fixed) borders and a global frame in north-east-down (NED) coordinates. To estimate the 6-DOF poses of the vehicle and the structure, monocular vision is combined with measurements from navigation sensors such as a Doppler Velocity Log (DVL) for linear velocity, an inertial measurement unit (IMU) for linear acceleration and angular momentum, and an attitude and heading reference system (AHRS) for roll and pitch angle.

Fig. 7. The kalam adaptive filter flowchart [16]

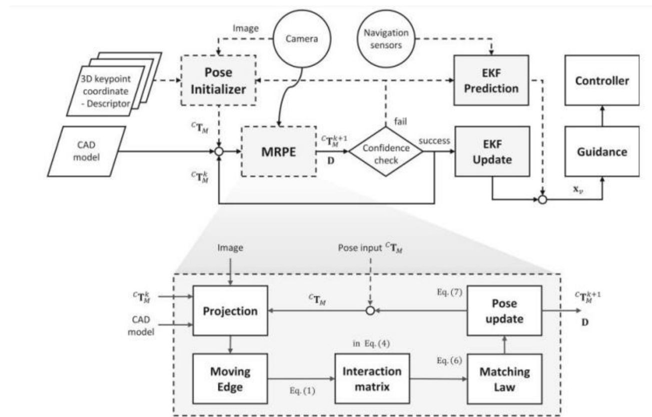

Fig. 8. Navigation systems in [17]

E. Power Systems

AUVs and UUVs are powered primarily by gas and chemical batteries and lithium-ion as secondary batteries, which are insufficient to power the vehicle. In order to increase the run time of vehicles, endurance needs to be increased. Fuel Cell Energy Power System (FCEPS) has been found as a viable option for achieving this endurance. Considering the present-day literature, it is found that the technology being used in AUVs and UUVs are rechargeable batteries. [18]

F. Comparative analysis of latest UUVs and ROUVs projects

S.No.	Title	Specific Application	Algorithm for navigation	Controller used	Sensor network	Power Systems
1.	Coral Identification and Counsting with an Autonomous Underwater Vehicle. [10]	Analyze the coral reef visual data and automating the task of estimating the population of a coral reef. The modified network identifies and localizes different coral species in an image.[10]	Navigation through a camera and manual operation. [10]	NVIDIA TX2(controller) (Portable system). [10]	The data collection for the following is done with stereo cameras powered by OpenCV and a complex neural network that determines the coral reef species by localizing it, and it is further tracked. [10]	Cable power supply. [10]
2.	High Accuracy Altitude and Navigation System for an Autonomous Underwater Vehicle (AUV) [12]	To design an underwater glider that is an AUV, by changing its buoyancy which moves up and down in the ocean. An underwater glider uses hydrodynamic wings to convert the vertical motion to horizontal, moving forward with meager power consumption. [12]	Figure 9 shows the navigation algorithm that's been used for the AUV. [12]	The ancillary systems, based on the new Raspberry system it contains the INS (Inertial Navigation System) platform, Glider Integrated Control System (GICS), and the radio communication systems (Global Positioning System-GPS, Iridium TX, and HF emergency beacon). The GICS is in charge of all navigation, guiding, and vehicle control tasks. For glider management, a centralised control system called "Glider Integrated Control System (GICS)" was created. The GICS keeps track of the payload's buoyancy and attitude control, as well as the data package it provides and any communications with the "outside world." [12]	Gyros, accelerometers, servo motors, for trajectory and position optimization Fig shows the sensor network interaction. [12]	Onboard battery systems. [12]
3.	Designing a Small-sized Autonomous Underwater Vehicle Architecture for Regular Periodic Fish-cage Net Inspection [13]	Small-sized, low-cost autonomous devices can offer a lower-cost alternative to the solution, providing more frequent inspection and efficient, timely alarming capabilities. [13]	The navigation technique is based on a photogrammetry-based optical recognition/validation system that is applied to a known-characteristics reference target attached to the net. To make measurements from photographs, Photogrammetry techniques are used to reconstruct the motion pathways of designated reference points on any moving object. [13]	The equipment Configuration follows Pixhawk PX4 with Raspberry Pi3 (Raspbian equipped) for "companion" computer. The communication with the Blue ROV is established via an Ethernet cable under IP protocol. [13]	3-DOF Gyroscope, 3-DOF Accelerometer, 3-DOF Magnetometer, Internal barometer, Blue Robotics Bar 30 Pressure/Depth, Temperature Sensor Current and Voltage Sensing Have been used for tasks for trajectory planning, pose estimation, environment sensing, etc. [13]	Power cable to power the on-board equipment and data link through the same cable. [13]

4.	End-to-end Navigation for Autonomous Underwater Vehicle with Hybrid Recurrent Neural Networks [16].	This paper presents a novel end-to-end navigation algorithm based on deep neural networks that directly uses raw data from sensors to obtain position estimation. [16]	The algorithm is based on LSTM (long short-term memory), a class of NNs used to predict time series data that has been employed to calculate the next position of the system. [16]	\ To achieve autonomy and data acquisition MOOS-IVP is the software used. [16]	The IMU device significantly increases the cost of GPS. The Kalman filter is adopted to address this issue by building a robust pure- software filter to solve this problem. Attitude and Heading Reference System (AHRS) the wide array of sensor systems is to have the necessary parameters for training and testing purposes. [16]	-
5.	Three-dimensional trajectory tracking of a hybrid autonomous underwater vehicle in the presence of underwater current [19]	The conventional AUV has a torpedo shape driven by at least one propeller to go forward and control surfaces to change direction and altitude; The linearization algorithm was developed for the HAUV's propulsive mode only is extended to include the gliding dynamics of the vehicle. It autonomously switches the vehicle's operation mode. [19]	The traditional AUV features a torpedo form that is propelled forward by at least one propeller, as well as control surfaces that allow it to alter direction and altitude. The linearization algorithm was developed for the H-AUV's propulsive mode only that is extended to include the gliding dynamics of the vehicle. It autonomously switches the vehicle's operation mode. The algorithm for the trajectory is shown in figure 10. [19]	In the presence of an unknown underwater current, a linear controller to instruct the vehicle to trace a 3D trajectory is examined, and the results are recorded. Courses with linear control have shown to have good effects. [19]	-	-
6.	Acoustic Search and Detection of Oil fumes Using an autonomous Underwater Vehicle [20].	Based on an acoustic detection and in-situ analysis program that allows an AUV to perform automatic detection and autonomous tracking of an oil plume. [20]	Sonar Imaging Sensor uses a non-contact method for oil detection by utilizing a forward scanning sonar on the AUV. [20]	Software Used: BV5000 3D scanning sonar uses ProScan, and the M450 2D sonar uses Pro Viewer. [20]	BV5000 3D scanning uses a high-frequency sonar, and the M450 2D sonar uses low-frequency sonar. The sensors are used for the detection of micro-droplets that form the oil plume. [20]	Batteries are placed in the AUV. [20]
7.	Basic Design for the development of Autonomous Underwater Vehicle [21].	An AUV must be autonomous for searching and decision making based on real-time data or current condition. It must make intelligent decisions based on the immediate surrounding environment or situation. It should be able to detect any abnormal condition. [21]	An AUV must be autonomous for searching and decision making based on real-time data or current condition. It must make intelligent decisions based on the immediate surrounding environment or situation. It should be able to detect any abnormal condition. [21]	Computer microcontroller can be used. [21]	Computer Microcontroller, SONAR System, Vision system, Depth System, Infrared distance sensor, Magnetic Compass, Accelerometer, Camera. [21]	The battery is the primary power source, notably supplied by the onboard Lithium-ion batteries. [21]

8.	Autonomous Underwater Vehicles: Instrumentation and Measurements [22].	An AUV is a submerged system that contains the power source and onboard computer. AUVs can follow a preset trajectory. [22]	AUV navigation and localization techniques can be divided into acoustic transponders and modems, Inertial/dead reckoning, and Geophysical methods. [22]	Microcontroller is used. [22]	Geophysical Sensors, Inertial Sensors, Beacon, Imaging Type Sensor, Rating Type sensor. [22]	Batteries developed, magnesium seawater battery, a pressure tolerant Li-ion battery and an aluminum-hydrogen peroxide semi fuel cell, e.g., alkaline cell or fuel cell. [22]
9.	Autonomous underwater vehicle challenge: design and construction of a medium-sized, AI-enabled low-cost prototype [23].	Development of a low-cost AUV(Synoris). It is developed for low power applications which involve surveillance, tasks involving ML features, etc. [23]	The navigation system is based on (GCS) guidance and navigation system, which is enabled with GPS and other navigational devices for maneuvering. [23]	The central controller/processor consists of a Raspberry Pi Model4 running Ubuntu 20.04.1 LTS, the main kernel for housing MSS, MDS, and parts of GCS and INS. MCC is the vehicle's center of command. It is also responsible for deep-learning techniques used for mission planning, navigation, situational awareness, etc. [23]	Inertial measurement unit, accelerometers, magnetometers, gyroscopes, altitude indicators, depth sensors have been included for various tasks of navigation and exploration. [23]	Two lithium-ion batteries (14.8V,18Ah) with high capacity is the energy source for the prototype vehicle. Additionally, two extra battery tubes containing a total of four batteries could provide enough energy for four days of operation.[23]
10.	Visual tracking of deep-water animals using machine learning-controlled robotic underwater vehicles. [24].	Multi-class object detection algorithms have been employed to observe deep waters and detect undiscovered aquatic life. These systems demonstrate how tracking through detection algorithms can have on exploring new environments and discovering undiscovered life in the ocean. [24]	The 3d positions of the detected objects are developed, and the corresponding supervisor controller adopts itself (moving, aligning, etc.) and, if at all, to decrease the distance or increase the stretch. Search continues till the object is found. [24]	Hardware control: Supervisor controller [25][26][27]: Two states search mode and detection mode are employed for the whole task PID used to manure according to the requirement. Software: Software of the system extensively uses LCM (lightweight communications and marshaling) to communicate between various modules. [24]	Sensing is done through various stereo cameras to localize the object, and then the supervisor controller takes care of the rest of the maneuvering. [24]	Power for the on-board systems is done through the cable attached to the base station. [24]
11.	Collaborative Control of Unmanned Underwater Vehicles [28].	Complex underwater understanding and development of a collaborative control for UUV. [28]	Understanding collaborative behavior in three main aspects I. collaboration with the leader II. Collaboration without a leader III. collaboration with multiple leaders These three aspects are analyzed and made explicit through task-oriented cooperative control of UUV to achieve rendezvous of UUV. [28]	-	-	-

12.	Design and Testing of a Spherical Autonomous Underwater Vehicle for Shipwreck Interior Exploration [29]	The nature of shipwreck interiors, the exploration of which the vehicle was initially designed, imposes unique risks that constrain system requirements while promoting other attributes uncommon in typical open-water UUV designs. So, design (Wreck Interior Exploration Vehicle (WIEVLE)) suitable for such applications is developed here. [29]	The algorithm developed for mere exploration is through a tethered cable, and simple maneuvers have been realized through the proposed propeller system of spherical design of UUV. [29]	The controller is computer software (SIMULINK) used for task completion through Raspberry pi 3B+; the controller is yet to be developed. [29]	Multiple cameras are used and deployed around the robot for analyzing its surroundings. [29]	14.8v lithium-ion batteries have been used for powering up the four motors and other hardware. [29]

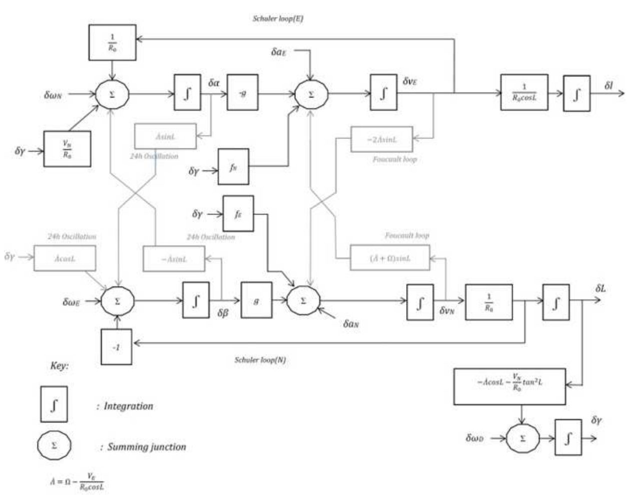

Fig. 9. Algorithm for object detection/tracking/data used in [12]

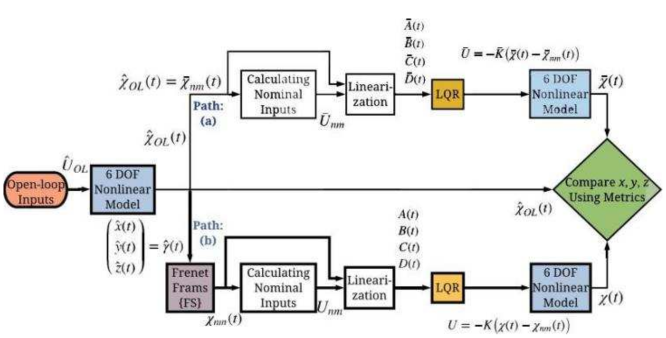

Fig. 10. shows algorithm used in [18]

CONCLUSION

The creation of autonomous underwater vehicles is a vital subject of study for scientific research in a variety of industrial applications, including military, ocean future usage and development, and a description of the primary navigation, mapping, and sampling technologies and their applications. This research also analyses the structural representation of the vehicle because the shape greatly influences mobility, stability, fluid resistance, and so on. The command-and-control system This report also provides a thorough comparison of several UUVs and ROUVs.

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