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A review on latest trends in development of remotely operated Marine Robots

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***Abstract*— oceans, seas, and great water bodies have always been a long unexplored piece of area, which in recent years has taken its place for exploration because of sophisticated marine robots (ROUV – remotely operated underwater vehicles and UUV – Unmanned underwater vehicle or Autonomous underwater vehicle/AUV- Autonomous under water vehicle) that are developed in recent years. This paper explores the recent trends in the growth of marine robots and analysis the key concepts of controllers, navigation algorithm, power systems employed, sensor network, and other key concepts of ROUVs and UUVs. Finally, a comparative analysis of some of the recent robots is mentioned in this paper.**

I. Keywords— marine robots, ROU, UUV.

II. Introduction

Marine technology has been developing from the ages for the deep-water explorations and other forms of analysis of great water bodies. Aquatic conditions have never been easy for the tasks of exploration and a lot of research has been put in, in recent years for exploring the oceans and seas in the harsh climatic conditions. ROUVs and UUVs have substantial applications in the places of surveillance, sea and ocean shore exploration, pollution monitoring, sea patrolling. Deep water exploration is one of the important applications for which the research has picked up the pace in recent years.

Marine robots are the composition of many different aspects of navigation, processing systems, power systems, sensor systems which should work together to give the preferred output in which they are intended to provide. Large water bodies have turbulent waters which make it difficult for exploration, monitoring and other related tasks of UUVs and ROUVs, a control system should be able adjust itself for such turbulences, complications to complete the trajectory designed for it. Power systems play one of the important roles because of the complicated situations that are present underwater, sensor systems are used with both trajectory planning and ocean monitoring which makes them one of the vital onboard equipment.

A lot of research has been employed in the design and construction of ROUVs and UAVs due to the complex environment they are placed in and harsh environments of huge water bodies such as oceans and seas. A lot of research has been employed with help of an equipped gripper that has a capability of grasping an object and the 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 stability is achieved with help of sensors which 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 robotic control or smart robotic control [2][3].

III. Literature review

Under water vehicles have been here around since the 90s and have been developed since then. The development of UUVs and ROUVs have become a challenge due to the unpredictable changes that induce turbulences that occur throughout the ocean which make it difficult for UUV or ROUV to carry out the work assigned.

A major part of development came in recent years due to their growing importance in sectors of defense, commercial use, and growth of research and development in recent years. fig1 shows the trend in UUVs and ROVs growth in market size [4].

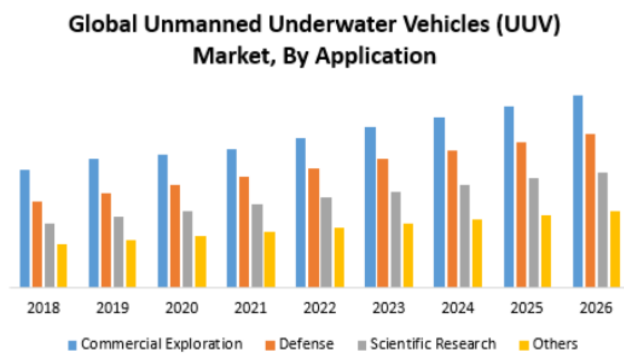

Fig 1: trend in market size of UUVs and ROVs.

Recent developments in UUVs and ROUVs is presented and reviewed. Underwater vehicle development started way back in 1953 when Dimitri Rebikoffin developed the 1st fully functional underwater vehicle. From the 1st UUV to latest smart UUVs that are developed a lot of technological change has happened and a lot of research is put in development of such robots. Fig 2 shows major types of underwater vehicles detailed analysis of factors required in development of these projects shall be explained in further sections.

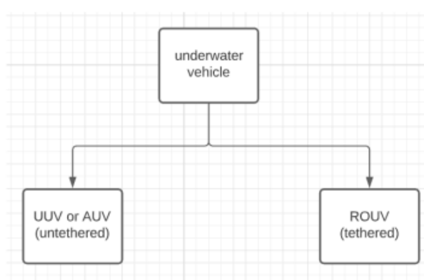

Fig 2: major types underwater vehicles

Recent advancements and improvements include 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 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 development of object avoidance system can be achieved with help of NN (Neural Network).

Stabilization is also one of the main problems that is encountered in recent times where in smart stabilization could be achieved through ANN (Artificial Neural Network), the paper analysis how external disturbances could be an input to neural net and necessary adjustments could be made with 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 the 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 uses sensor information as input and continuous surge force and yaw moment as output [8]. propeller systems play an important in the tasks of completing the trajectory recent developments in propulsion system for UUVs which deals with fault diagnosis in propeller systems using deep learning has been developed [9]. These recent developments have been paving paths for an advanced futuristic UUVs and ROUVs.

IV. Main features of UUVs and ROUVs:

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. For camera-based application this is a huge threat, so the design of the vehicle is done generally fluid dynamic.

Commonly used shapes are the torpedo or the curved rectangle shaped. Curved-rectangle shape objects also reduce drag but not as much as the 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 for this, many of the applications seen here may have extra motors or diving planes which use the dynamic lift concept to realize degrees of freedom. For the sinking and rising of the vehicles we need 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 the water. The other widespread method is to use a vertical thruster for making the bot sink into the water.

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 ROV from the BlueROV2 designed by the Blue Robotics company. The BluROV in design fig3 used the extra thrusters to maneuver the bot sideways and forwards and backwards for the sinking and rising motion this design uses the ballast weights to ensure the weight of the bot more than the buoyancy provided by the water. The weight plays a vital role in the sinking of the vehicle as the design has more area of contact with the water hence the buoyancy force increases [10].

The design in fig5 by uses big dynamos which are there for using the water currents to turn the dynamos which in turn produces power. This design of the bot is almost like a torpedo shaped with the diving planes which consists of the dynamos, this design is inspired by the design of a submarine and also shares the same concepts like 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 kind of design uses the concept of dynamic lift where the vehicles wings control the amount of fluid under the vehicle or over the vehicle which helps it to move upwards or downwards [12].

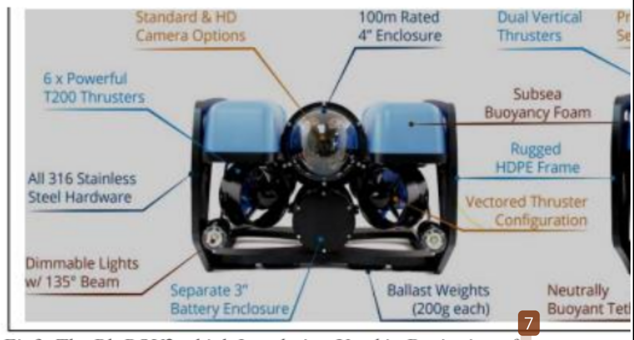

Fig3: The BluROV2 which Is a design Used in Designing of a Small-sized Autonomous UnderwaterVehicle Architecture for Regular Periodic Fish-cage Net Inspection.

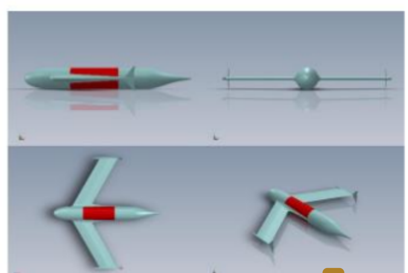

Fig 4: The Winged design used in the High Accuracy Attitude and Navigation System for an Autonomous Underwater Vehicle (AUV)

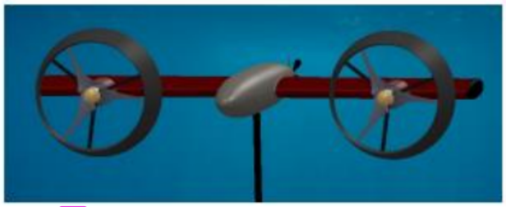

Fig 5: Conceptual design of the autonomous underwater vehicle mounted ocean current turbine.

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.

Control systems:

The control system for an AUV or an ROV is very important 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 be in contact with the base station in case of the autonomous or remote vehicles.

The control system can be of many types, the processor power and capabilities can be chosen according to the vehicles main purpose of the functioning. For example: Many ROV and AUV application depend on the OpenCV capabilities and use machine learning algorithms to analyze the area underwater. It is well known that this process requires a huge demand of processing for power. Therefore, those applications having the higher end control systems such as the NVIDIA TX2 is suitable for applications such as the OpenCV application Discussed before. The algorithm is deployed on a portable system such as the NVIDIA TX2 or the intel neural compute stick will enable online deployment and the system can achieve 12 fps on Nvidia tx2[11]. **Pixhawk** PX4 with Raspberry Pi3 (Raspbian equipped) for "companion" computer [12].

The loaded Pixhawk firmware is "Ardusub" version 3.4 (Ardupilot adjusted for ROV). The "surface computer" is either a Linux (Debian or a Windows 10 workstation. **Raspberry** system it contains the Glider Integrated Control System (GICS), the INS (Inertial Navigation System) platform in the above applications of the AUV they have used the following navigation systems which are suitable with a raspberry pi system. And also, the other AUV uses NVIDIA TX2, and Pixhawk PX4 which are used as said before for the applications which uses more processing power [13]. In fig 6, the control system design is depicted.

Sensor Networks

A sensor network plays an important role in collection of data which could be used for navigation, trajectory and planning where each sensor monitors data in a different location and sends that data to a central location for storage, viewing, and analysis. Sensor network nodes cooperatively sense and control the environment. They enable interaction between people or computers and the surrounding environment. Sensor networks can be wired or wireless. Wired sensor networks use ethernet cables to connect sensors. Wireless sensor networks (WSNs) use technologies such as Wi-Fi or near field communication (NFC) etc. to connect sensors. Sensor networks often have to be installed in challenging environments to be able to monitor structures and infrastructure.

The ROV camera allows users see underwater to perform the specific purpose of collecting HD imagery that facilitates scientific research and also undertake a variety of tasks including inspection, retrieval and observation among other applications. It can also help in maneuverability in case of manual operation of the underwater vehicle. Passive sound monitoring sensors can be deployed by ROVs to monitor environmental noise and detect vocalizing marine fauna or evaluate ecosystem changes evident in the soundscape. Some hardware such as Differential GPS, gyroscopes and acceleration sensors, are used to fuse the information to improve the position accuracy.

At the front, there is a dome with a "nostril" that houses the sensor kit: The data collected is managed by a computer. There is a digital camera (GoPro class) for visual inspection and recognition of objects at depths. On the bulkhead, a 10^6 candle and a flat LED has been mounted. In case of turbid waters where it is difficult to see lighting plays a crucial role in detecting objects **[14].**

The SICK LMS511 LIDAR (Light Detection and Ranging) sensor installed on the Rmax helicopter (RW-UAV) is equipped with a rotating mirror mechanism, which deflects the laser beam emitted. LIDAR allows for time-of-flight measurements not just of a point, but of a 2D slice of the environment. In case of bad weather conditions (rain or snow) a laser pulse can be reflected by a raindrop or a snowflake preventing from measuring the object of interest. In a multi-echo LIDAR, several echoes of one single pulse emitted can be measured thus increasing the probability of hitting the desired target. The LIDAR offers a 190° scanning angle with resolution down to 0.166° at a range from 0.8 to 80 m. The accuracies achieved are in the order of 5 cm. [15]

Fig 8: the proposed navigation systems in [17]

Navigation systems of ROUV/UUV:

Navigation in AUV is a very difficult task to achieve with high accuracy. There are a lot of barriers to achieve navigation under water like it is impossible to receive GPS information when the vehicle is underwater as radio frequencies or electromagnetic frequencies cannot penetrate the water surface. Instead of using GPS modules other methods include to use the sensors such as accelerometers, and gyroscope to visualize the orientation of the vehicle. This helps to give an approximate understanding of the position of the vehicle underwater.

In a paper for end-to-end AUVs navigation [16], 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 usually combined with the INS to form an integrated navigation system and the proposed navigation is depicted in fig7. This system helps in getting the following information from the bot and is run through the Kalman filter which helps it to give an approximate position of the vehicle. [17] These systems consist of a global frame in north-east-down (NED) coordinates and two local (body fixed) frames, as shown in Fig.8 .The 6-DOF poses of the vehicle and the structure are estimated by fusing monocular vision and the measurements from navigation sensors, such as a Doppler velocity log (DVL) for linear velocity, an inertial measurement unit (IMU) for linear acceleration and angular velocity, and an attitude and heading reference system (AHRS) for roll and pitch angle

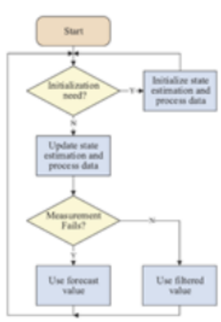

Fig 7 The kalam adaptive filter flowchart

V. Comparative analysis of latest UUVs and ROUVs projects:

S. No	Title	Specific application	Algorithm for navigation
1.	**Coral Identification and Counting 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. (Using a KCF tracker fromOpencv2 the bounding boxes are tracked)	Navigation through a camera and manual operation
2.	**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 the solution, providing also more frequent inspection and efficient timely alarming capabilities.	The navigation scheme is based on an optical recognition/validation the system combined with photogrammetry fundamentals applied to a reference target of known characteristics attached to the net. Using Photogrammetry techniques to make measurements

			from photographs, the motion pathways of designated reference points on any moving the object is recovered	Software used: [illegible] operations [illegible] ROS [illegible] arduino utilizing The Graphical [illegible] the software	environment sensing, etc.	
3.	**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 moves up and down in the ocean like afloat, an underwater glider uses hydrodynamic wings to convert the vertical motion to horizontal, moving forward with very low power consumption.	Fig shows the navigation algorithm that's been used for the AUV	The ancillary systems, based on the new Raspberry system it contains the Glider Integrated Control System (GICS), the INS (Inertial Navigation System) platform, and the radio communication systems (Global Positioning System-GPS, Iridium TX, and HF emergency beacon). The GICS oversees all the functions of navigation, guidance, and vehicle control A centralized control system called "Glider Integrated Control System (GICS)" was developed for glider management. The GICS monitors the buoyancy and attitude control, handles the payload by taking care of the entire data package that it provides and of all communications with the "outside world"	Gyros accelerometers servo motors For trajectory and position optimization Fig shows the sensor network interaction	**On board battery systems**

4.	**Three dimensional trajectory tracking of a hybrid autonomous Underwater vehicle in the presence of underwater current [18]**	The conventional AUV has a torpedo shape that is driven by at least one propeller to go forward, and control surfaces to change direction and altitude; The linearization algorithm was developed for the H-AUV's propulsive mode only is extended to include the gliding dynamics of the vehicle. It autonomously switches the vehicle's operation mode.	The algorithm for the trajectory has been shown in the fig1.
5.	**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 which uses raw data from sensors to obtain position estimation directly.	Algorithm is based on LSTM (long short-term memory) a class of NNs used predict time series data has been employed to calculate next position of the system
6.	**Acoustic Search and Detection of Oil Plumes Using an Autonomous Underwater Vehicle [19]**	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	Sonar Imaging Sensor uses a non-contact method for oil detection by utilizing a forward scanning sonar on the AUV.

7.	**Basic Design for the development of Autonomous Underwater Vehicle [20]**	AUV must be autonomous for search operation, decision making based on the real-time data or current condition (object detection), intelligent decisions for the immediate surrounding environment or condition to perform the task or mission and Detect any abnormal condition.	Doppler velocity Log (DVL) provides the solution to meet the navigation requirements. Pairing the DVL with a high-quality compass can provide the location and speed of the AUV. Navigation system can be grouped as Inertial navigation system, acoustic navigation system and Geophysical navigation system.	Computer microcontroller can be used	Computer Microcontroller, SONAR System, Vision system, Depth System, Infrared distance sensor, Magnetic Compass, Accelerometer, Camera	Battery is the primary power source, notably supplied by on board Lithium-ion batteries.
8.	**Autonomous Underwater Vehicles: Instrumentation and Measurements [21]**	An AUV is a submerged system that contains its own power and is controlled by an onboard computer. Although these vehicles could be called remotely operated vehicles (ROV), unmanned underwater vehicles (UUV), submersible devices, or remote-controlled submarines, AUVs are able to follow a preset trajectory.	AUV navigation and localization techniques can be divided according to three categories: Acoustic transponders and modems, Inertial/dead reckoning, and Geophysical techniques.	Microcontroller is used	Sensors: Inertial Sensors, Beacon, Imaging Type Sensor, Rating Type sensor	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,
9.	**Autonomous underwater vehicle challenge: design and construction of a medium-sized, AI-enabled low-cost prototype [22]**	Development of a low cost AUV(Synoris).It is developed for low power applications which involves surveillance, tasks involving ML features etc.	The navigation system is based on (GCS) guidance and navigation system which is enabled with GPS and other navigational devices for maneuvering.	Main controller/processor consists of Raspberry Pi Model4 running Ubuntu 20.04.1 LTS, which is the main kernel for housing MSS, MDS, and parts of GCS and INS. As its name implies, MCC is the vehicle's center of command. It is also responsible for deep-learning techniques that are used for mission planning,	Inertial measurement unit, Accelerometers, magnetometers, gyro scopes, altitude indicator, depth sensor have been included for various tasks of navigation and exploration	Two lithium-ion batteries (14.8V,18 Ah) with high capacity were chosen as the energy source for the prototype vehicle. Additionally, two extra made battery tubes containing a total of four batteries

10.	**Visual tracking of deep-water animals using machine learning-controlled robotic underwater vehicles. [23]**	Multi class object detection algorithms have been employed for the observation of deep waters and detection of undiscovered aquatic life. These systems demonstrate the how tracking through detection algorithms can have on exploration in unexplored environments and discovery of undiscovered life in ocean.	The 3d positions of the detected objects are developed and correspondingly supervisor controller adopts itself (moving, aligning, etc.) and if at all to decrease the distance or to increase the distance. Search continues till the object is found
11.	**Collaborative Control of Unmanned Underwater Vehicles [27]**	Complex underwater understanding and development of collaborative control for UUV	Understanding collaborative behavior in three main aspects I. Collaboration with leader II. Collaboration without leader III. Collaboration with multiple leaders These three aspects are analyzed and made clear through task oriented cooperative control of UUV to achieve

			rendezvous UUV.			
12.	**Design and Testing of a Spherical Autonomous Underwater Vehicle for Shipwreck Interior Exploration [28]**	The nature of shipwreck interiors, the exploration of which the vehicle was originally designed, imposes special 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.	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	Controller is computer software (SIMULINK) has been used for task completion through Raspberry pi 3B+, actual controller is yet to be developed.	Multiple cameras are used and deployed around the robot, used for analyzing its surroundings.	14.8v lithium-ion batteries have been used for powering up the 4 motors and other hardware

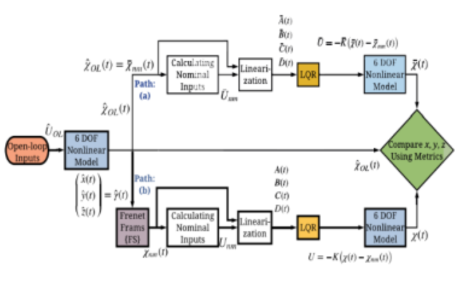

Fig1: shows algorithm used in []

VI. Conclusion:

Autonomous underwater vehicle development is a critical field of study for scientific research in numerous industrial applications such as defense, ocean exploration, ocean mining etc. The contributions of this paper are a general and updated review of the latest in the systems embedded in AUVs as well as ROVs. It provides detailed future uses and development, a summary of the main navigation, mapping and sampling technologies and their applications. This paper also takes into consideration of the structural representation of the vehicle as the shape largely determines the movement, stability, fluid resistance etc. The control system This paper also gives a comprehensive analysis between various UUVs and ROUVs.

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