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Autonomous Underwater Vehicles: Recent Developments and Future Prospects

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Abstract: Autonomous Underwater Vehicles (AUVs) have wide range of applications in fields like marine geoscience, military, commercial and policy sectors. Their need and applications increase day by day due to their ability operate autonomously of a host vessel which is well suited for exploration of extreme environment. Thus, research on AUVs have become popular in the present-day scenario. This paper is intended to summarise the developments in the field of AUVs in India and abroad and tends to focus on their future technical developments.
Keywords: Maya, Varun, PID, Sarafina, KAMBERA, Martin, GAVIA, HUGIN, WZODA, CR-01A, CR-02, ABE, Dorado, Thethys, Delphin2, Gambit, AEGIR, ABYSS, MUM

I. INTRODUCTION

An autonomous underwater vehicle (AUV) is an unmanned underwater self-propelled robot. They are a part of a larger class of unmanned underwater vehicles of which another part is Remotely Operated Vehicles (ROVs). The function of AUVs is to navigate through the water without the assistance of an operator performing surveys and collecting data which is achieved by pre-programming the AUVs at the surface. As against AUVs, ROVs remain tethered to the host vessel and controlled and powered by an operator through an umbilical.

AUVs are well suited to geoscience applications requiring constant altitude for their ability to maintain a linear trajectory through the water. Though a ROV can draw more power and communicate real-time data, its speed mobility and spatial range are limited compared to an AUV.

AUVs are playing some important roles in important cases since their inception. They have a wide range of application varying from commercial uses, research purposes, military applications, air crash investigations etc. They are used to make detailed maps and surveys of the sea floor (oil and gas industries) before building subsea infrastructure. This helps in installation of pipelines and subsea completions in a cost-effective manner with minimum disruption to the environment as compared to traditional bathymetric surveys which would be less effective or too costly.

With increasing advents of technological developments in AUVs, they are used to study lakes, oceans and ocean floors.

Some of the practical applications of AUVs are like the absorption and reflection of light and the presence of microscopic, Measurements of the concentration of various elements or compounds. They can also be configured as tow vehicles to deliver customized sensor packages to specific locations.

In the field of Defence, AUV has become an efficient tool. A group of AUVs are required to keep a specified formation for gathering intelligence, surveillance and reconnaissance. They have been successfully incorporated into operations like mine countermeasures, payload delivery, anti-submarine warfare, time-critical strike etc.

Due to extensive research in the field of AUVs and their application in different fields, there is a need for a deep review in this regard. The current research and development works going on and completed on AUVs and their future prospective are the focus of this paper.

II. RESEARCHES ON AUV

A. India

1) *Mechanical Engg, Dept., IIT, Kharagpur*: The AUV developed by IIT Kharagpur can be used to bring back deep sea images, record oceanographic data. In addition to these, it can also be used for collecting water samples and perform military surveillance like pinpointing sea mines planted by enemies. It’s manoeuvring range can be as good as 150m & has a life of minimum five hours under the sea [1].

2) *National Institute of Oceanography (NIO), Goa*: The indigenously developed AUV called Maya (2006) has functional parts which are based on control system, mechanical design, navigation, on-board data collection etc [1]. The first prototype test was confined to freshwater environment. After the success in that, the design was modified to cope up with open oceanic environment.
3) *National Science and Technological Laboratory (NSTL)*: This laboratory has the credit for designing, fabricating, developing, installing, testing and trial of several micro AUVs which are able to meet various needs of defence and civil sectors such as underwater explorations, security patrols etc [1].
4) *Delhi Technical University (DTU)*: The first generation AUV was developed in 2007 and the work on the second generation is being carried out since 2009 on another project [1]. In 2011, they completed their work on 4th generation AUV named Varun [2]. It was developed by a team of undergraduate students for participating ONR's 14th International RoboSub Competition.
5) *National Institute of Technology (NIT), Rourkela*: This project provided by Defence Research Development Organisation (DRDO), Govt. of India, is being carried out in Center for Industrial Electronics and Robotics, NIT, Rourkela [1]. This project focuses on both theoretical and experimental parts. The first phase focuses on path following controller for a single AUV and an algorithm for cooperative control of a group of AUVs. This phase has been developed theoretically and in the second phase the experimental work is going on. The third phase of the project consists of experimental work ion cooperative control of multiple AUVs.
6) *CSIR-CMERI, Durgapur*: CSIR-CMERI has designed and developed a torpedo shaped AUV capable of operating up to 150m depth. The unit has 5 controllable degrees of freedom, which are controlled by 5 propellers placed in the various directions of AUV and equipped with Li-polymer batteries. For controlling the AUV through different paths during different missions, advanced controller has been used. They used navigational sensors to monitor the positional accuracy and velocity information of the AUV and payload sensors to map the seabed condition & underwater data collection [3].
7) *Dept. of Ocean Engg., IIT Madras*: The research work done by Singh, Bhattacharyya and Idichandy of IIT Madras focuses on the following [5]:
   a) CFD approach to modelling, hydrodynamic analysis, motion characteristics of an autonomous underwater glider.
   b) Another objective is to understand glider dynamics adapting CFD approach, test its trajectory in water and compare it with the numerically obtained trajectory.
   c) Identification of flow behaviour and drag & lift force distribution for different angle of attack and with changing Reynold's number.
8) *Dept. of Engg. Design, IIT Madras*: The experiments were carried by Santhakumar M. *et al.* [4]. Application of robust design techniques in the design of controllers for Autonomous Underwater Vehicles (AUVs) incorporated by them. The control techniques proposed here can be broadly classified into two major categories: Adaptive control & Robust control. Proper tuning of controllers is necessary in achieving the desired positional and tracking accuracy of AUVs in underwater missions. Adjusting of the feedback controller parameters for obtaining a specified closed-loop response is Turning. A new scheme of gain tuning using Taguchi method is introduced here for the Proportional-Integral-Derivative (PID) control of an under-actuated AUV with less controllable degrees of freedom than the total number of degrees of freedom. An optimal and robust set of PID controller gains have been obtained through the help of Design of Experiments (DOE) and robust design techniques, as applied in the Taguchi optimization method.

B. Australia

1) *Australian National University (ANU)*: The Sarafina project of ANU takes into consideration many small fully autonomous submerged vehicles which can carry only limited number of payloads due to their small size [1]. The technological objective include as follows. The school (group) of these AUVs allows fault tolerant and scalable coverage of ocean spaces. In the group, individual member adapts to the current physical position. Active and passive localization with each other or with other vehicles in environment is possible. These are mechanically robust and equipped with sufficient power supply for any level of autonomy. To cover a certain area by a group of submergible vehicles, the polygonal structure of vehicles is formed and is adjusted to get that polygonal structure. The controller for the group of submergible vehicles has been developed by using reinforcement learning technique.

Another project undertaken by ANU is KAMBERA project. It focuses on the following:

a) Localization of the vehicles which move in a desired path without the influence of an external force in a long-distance mission.
b) Surveying environmental effects of marine ecosystem sea floor exploration.

The controller is designed based on the concept of general curve evolution theory in a decentralized manner.

2) *University of Sydney*: The submersible Sirius AUV was built and is maintained by the Australian Center for Field Robotics based out of the school of Aerospace, Mechanical and Mechatronics Engg. at the University of Sydney [6]. It can undertake high resolution survey works. The Sirius AUV is equipped with the following:

a) a mechanically scanned low frequency terrain-aiding sonar;
b) a depth sensor;
c) Doppler Velocity Log (DPL) including a compass with integrated roll and pitch sensor.
d) Ultra-Short Baseline Acoustic Positioning System (USBL): forward looking obstacle avoiding sonar; v) a conductivity/ temperature sensor;
e) A high-resolution stereo camera pair and strobes.

C. Canada

The AUVs of Canada varies from a simple and waterproof underwater vehicle known as Microseeker (produced by HUV, a small privately-owned underwater vehicle production company) to a long range (<400Km) AUV named as THESUS developed in International Submarine Engg. Research (ISER), Vancouver, Canada [1]. The length of the AUV is 35 feet and diameter is 50 inches which can work up to 1000m depth with a speed of 4.0kts. The payload is less than 100 Km. It can navigate under thick ice layer where remote control does not work such as Artic seabed. The other places where works on AUV are going on are the University of Newfoundland, NRC of Canada and University of Quebec.

D. Denmark

The basis for the design of the AUV 'Martin' carried out in the Dept. of Automation, Technical University of Denmark is the European MARIUS AUV (1992) [1]. It is an acoustical navigation AUV, instrumental for environmental study and studying the sea bottom. The objects are detected and identified by using sonar signals and the parts of the project include path planning, obstacle avoidance, image processing etc. The specifications of this AUV are Error detection: less than 3 undetected errors per billion detected error, latency: less than 0.5ms, differential termination: 62ohm multiple bit sampling, data rate: 100-500Kband, message size: max. 8 bytes, architecture: all messages are broadcasted.

E. Iceland

Hafmynd is a company which processes cylindrical AUVs known as GAVIA [1]. There are three types of GAVIA AUVs available:

1) Commercial applications: GAVIA offshore
2) Scientific applications: GAVIA scientific
3) Defence applications: GAVIA defence

This type of AUV can carry a number of high-quality long-range sensors to achieve good research works. It has a logistic footprint and operating depth of 1000m. GAVIA can be equipped with GPS (global positioning system) for the introduction of satellite communication, surface navigation and wireless LAN connection. The specifications of a GAVIA AUV are.

a) *Navigation:* As standard GPS and fluxgate compass, optional DVL aided INS, Optional DVL aided LBL.
b) *Communication; Wireless LAN*: IEEE 802.11g compliant, satellite communications: full global coverage via Iridium link, acoustic modem: for tracking and status updates.
c) *Measurements; Length:* from 1.8m for base vehicle, weight in air: from 49kg for base vehicle, diameter: 200mm, depth rating: 500m or 1000m.
d) *Battery Modules:* 1.2 kW Lithium ion rechargeable cells per module.
e) *Max Speed:* > 5.5 knots.
f) *Endurance:* depending on speed and exact configuration.
g) *Typical Scientific Configurations;* GAVIA base vehicle (500m or 1000m depth rating), DVL INS or LBL positioning, side scan sonar / camera, sound velocity meter, obstacle avoidance sonar.

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h) *Typical Options (Others Available):* CTD (Seabird SBE 49), ADCP, environmental characterization, optics (Wetlabs ECO Pucks), 02, swath bathymetry module, spare battery module(s) and custom payload modules for user supplied instrumentation etc.

F. Norway

Norwegian Underwater Institute (NUI), Bergan is responsible for the research and development of AUVs in Norway. Their famous underwater vehicle HUGIN AUV produced by Kongsberg Maritime Ltd. for performing high speed surveys with superb data quality and excellent navigation [1]. There are three types of HUGIN AUVs available according to the depth range: 1000m, 3000m and 4500m. The sensing concept allows alternate sensors for geological surveys search operations in addition to naval systems. The combined operations of HUGIN-1000 and HISAS-1030 are specially designed to find small modern minds efficiently searching large areas where GPS system does not work under water.

G. China

Shenyang Institute of Automation of Chinese Academy of Science, 702nd Research Institute of China Shipbuilding Industry Corporation (CSIC) and other establishments designed and fabricated AUVs equipped with Doppler Velocity Measurement, GPS, short baseline positioning, directional gyro, visual tracking and fluxgate compass, ultra-short baseline positioning etc. [1].

The specification of this AUV are: length: 4.4m, width: 0.8m, height: 1.5m, weight: 2.2ton, speed: 4kt, side-traveling speed: 1kt, diving speed: 0.5kt, maximum operating depth: 1km, propulsion: electrically powered propellers, power: lead acid batteries.

WZODA AUV was jointly developed by Russia and several Chinese research and educational institutions. It can climb underwater slopes and has a depth of operation of 6000m. CR-01 AUV is also developed by the same developers as WZODA AUV, the joint Sino-Russo team. This is used for light and radio signal processing.

The specifications of this AUV includes as length: 4.374m, width: 0.8m, draft: 0.93m, weight: 1305.15kg, maximum depth: 6000m, maximum speed: 2kt, Endurance: 10hr, positioning accuracy: 10 to 15m. CR-01A AUV is the modified version of CR-01 AUV with detection ability to penetrate mud layer. CR-02 AUV is also the advanced version of CR-01 AUV with obstacle avoidance capabilities.

The specifications of CR02 AUV are: Length: 4.5m, diameter: 0.8m, weight: 1.5t, speed: 2.3kt, endurance: 25hr, depth: 6000m, power: silver-zinc battery, photographic capability: 3000 photos, recording capability: 4hr continuously, obstacle avoidance sonar range: 60m, obstacle avoidance sonar accuracy: 1%, survey sonar range: 12km, survey sonar accuracy: better than 20m, bottom penetration: 50m (soft mud).

Submerged Dragon-1 is the modification of CR-02 AUV which can retrieve the mother ship approaches directly which is less expansive in comparison to CR-02 AUV.

The specifications of Submerged Dragon 1 are as follows. Length: 4.6m, diameter: 0.8m, weight: 1.5t, max depth: 6000m, max speed: 2kt, endurance: 24hr, photographic capability: 3000 photos,

obstacle avoidance sonar range: 100m, side scan sonar range: 2 x 350m, bottom penetration: 50m (soft mud), sea state: ≤ 4. Arctic ARV is another Chinese AUV developed by SIoA. This is a fully automated and box shaped AUV which has better maneuvering capacity. The specifications include as: weight: 350kg, range: up to 3km, hovering depth: 100m.

H. USA

1) *DARPA*: Defense Advanced Research Project Agency (DARPA) and US Navy are responsible for research and development works on AUVs in USA [1]. First DARPA has started one project in Draper laboratory for a low drag of 10knot and 6.800kg weight UUV. This vehicle was limited for Martin Meritta crop used for different purposes. Next, DARPA developed the amphibious vehicle, Autonomous Amphibious Vehicle (AAV), which can travel in water and land. It can be used for different purposes. Then AUV is further developed to explore the cooperative motion of multiple vehicles with mother-daughter concept. In 1992, Florida Atlantic University developed AUV Voyager with the cooperation of Perry Technology. This AUV was the demonstration AUV based on power, sensor and autonomous vehicle technology. The operational depth is 152m. The mechanical modeling includes 1.5 HP, single screw, four 1hp side propulsion, one ducted main propulsion which can be lunched from semi-submersible catamaran. It has weight of 1226kg in air and dimension is 52.5cm in diameter and 480cm in length. This AUV is equipped with different sensors such as obstacle avoidance sensor, heading, auto-depth, altitude,

inclination depth and inclination rate sensors, side scan sonar and forward-looking sensors. It has an inter-storage hull of 19-inch circular internal diameter and accommodated with different sensors which are hull mounted.

2) *WHOI*: Woods Hole Oceanographic Institution (WHOI) designed and built an Autonomous Benthic Explore, known as ABE AUV, which can cover a large area underwater and was thus employed by scientists for frequent need for monitoring a large area underwater for a long period of time which helped in overcoming the large expensive jobs of monitoring the sea floor by surface ship. Its weight is about 1200lbs and length is about 2m. This AUV can take photograph and collect data samples during maneuvering under water. After performing its task, ABE goes to sleep for conserving energy and operating for a long period with a certain amount of power supply once a month. These can perform task under a depth of 5000m with a variety of sensors and tools.
3) *MBARI*: Monterey Bay Aquarium Research Institute (MBARI) developed AUVs in order to take the high personnel costs out of scientific sampling of the ocean [7]. MBARI engineers created a modular vehicle that can be quickly reconfigured to host several payloads without modifying basic components such as the propulsion, navigation, power, control, and emergency location systems. They can measure physical characteristics of the water, such as temperature, salinity, and dissolved oxygen. Detection of chlorophyll in microscopic marine algae, measurement of concentrations of small particles in the water, mapping the seafloor and collecting images of the seafloor and the midwater are some of the works performed by them. MBARI developed two types of AUVs viz. MBARI *Dorado* AUVs and MBARI *Thethys* AUVs. The Dorado-class AUVs are 53.3 centimeters (21 inches) in diameter and can be as short as 2.4 meters (8 feet) or as long as 6.4 meters (21 feet), depending on the mission. The first Dorado was operated in 2001. Upper-water-column vehicle, seafloor mapping AUV and imaging AUV are the systems currently operational at MBARI. The Tethys AUV is a long-range AUV, designed to operate over longer ranges. Tethys is 30.5 cm (12 inches) in diameter, 230cm (7.5 feet) long, and weighs 120 kg, can support an 8 W sensor payload for distances in excess of 1000 km at 1 m/s. Operating at a speed of 0.5 m/s with minimal sensors allows ranges of several thousand kilometers. The vehicle is simple enough for operations by individual PI laboratories. Tethys provides capabilities falling between existing propeller driven vehicles and buoyancy-driven vehicles (gliders).

I. UK

1) *University of Southampton*: A team has developed a man portable AUV, named Delphin2, for exploration of lakes and coastal waters [8]. It possesses low speed manoeuvring capability and flight style operation. It can be operated by a team of two owing to its low mass and short length (2m.). A forward facing and downward facing video camera alongside a scanning sonar, thermal and altimeter sensors provide environmental monitoring capability. The primary aim for its development was to provide a test bed platform for research into the manoeuvring performances of AUVs. Initial trials were performed in assessing the population of zebra mussels in Long Erne, Northern Ireland. It is now frequently deployed on local lakes where it performs various manoeuvres and has therefore become a useful tool for scientific applications.
2) *Marine and Acoustics Centre*: The Marine and Acoustics Centre (MAC) at QinetiQ Bincleaves developed AUV Gambit focusing on surveillance and reconnaissance [9]. The focus of the program was to impart abilities to the AUV like detecting and locating targets, coping with obstacles and environment, communicating findings and providing suitable connectivity with other military assets. The following technologies were integrated onto the vehicle platform to achieve the above mention goals:

a) Wideband high frequency Synthetic aperture sonar (SAS) offering near photographic imagery of the seabed at long ranges;
b) Non-acoustic sensors in the form of a 9- axis magnetic gradiometer for buried mine detection;
c) Advanced navigation combining high-grade INS and MCM sensor data for improvement of accuracy and robustness of the overall navigation solution;
d) On-board computer aided detection and classification algorithms to provide a high probability of detection and low false alarm rates;
e) 3-dimensional forward-looking sonar;
f) High data rate acoustic communications optimised for operation in shallow water;
g) Sensor optimisation by vehicle autonomy, collision avoidance, communications scheduling and run-time mission re-plannin
h) Inclusion of the threat information into the wider battlespace picture by network enabled capability.

J. Germany

GEOMAR The Helmholtz entre for Ocean Research Kiel developed two AUVs viz. AUV AEGIR and AUV ABYSS. The AUV AEGIR [10] is designed for water depths up to maximum 200m. and its dimensions are specified with the aim to increase portability and to make it robust for use in the North and Baltic Sea. It is equipped with a camera (main sensor) directed to the seabed and a flashlight consisting of two LEDs. The machine vision camera is installed in a pressure body having its own computer and connection to the main computer. There is also an acoustic Doppler speed meter, a combined pressure and sound velocity sensor and a total of four propellers.

The AUV ABYSS [11] is designed for deep sea manoeuvres at depths between 2000-6000m. It operates with lithium-ion batteries and can dive up to 22 hours. It is equipped with sensors like Conductivity, Temperature and Depth Probe (CTD), particle sensor, multi-beam echosounder, sidescan sonar, sub-bottom profile sonar and electronic still camera. It can map the ocean floor using various sonar systems and collect data of the water column by different sensors.

Furthermore, a team of engineers from ThyssenKrupp, Berlin Technical University, University of Rostock, ATLAS ELEKTRONIK and EvoLogics is promoting a new German technology called Large Modifiable Underwater Mothership (MUM) [12] as the next generation in AUVs. It is a modular, unmanned underwater vehicle which can be for a variety of missions with cost-efficiency. It is being designed aiming activities ranging from payload transportation and operations to research missions and stationery deep sea tasks, making it potentially useful for various stages of deep-sea mining from scientific monitoring to extractive activities. It is targeted to be a heavy duty, floating, wireless AUV capable of diving to depths up to 5000m., equipped with an emission-free, air independent fuel cell propulsion system that can continuously operate for several weeks.

III. CHRONOLOGICAL DEVELOPMENT IN AUV TECHNOLOGY

The development of AUV is not a present endeavor. Its inception dates to the 1970s. A brief account is presented here starting from the level of simulation study to commercialization and technologically from modelling a single AUV to the cooperative control of multiple AUVs.

A. Prior to 1970

1) *Initialization of Development of AUV:* The first AUVs were developed as early as in the year of 1960s which were used for data gathering and transferring.

B. 1970- 1980

1) *Exploration of AUV Potentials:* The first true AUVs named 'Torpedoes' were developed in the 1970s by USA which were used for test purposes. During this period many successful and failure experiments were carried out and in addition to these, this decade also formed the basis for most of the theoretical and experimental works on AUVs.

C. 1980- 1990

1) *Experimentation with Prototype:* This period was the golden era in the history of chronological development of AUV because of the fact that most of the theoretical developments were implemented in the practical fields (testbeds were fabricated for this purpose). During this period DARPA lab developed most of the prototypes in USA.

D. 1990- 2000

1) *Goal Fulfilling Technology Development:* This decade saw the development of the first generation of developed AUVs which were able to perform the task accomplished with the goal of the experiments. A number of organizations were able to develop the AUVs according to their objectives and also this decade forced the underwater- oceanic vehicles towards commercialization.

E. 2000- 2010

1) *Commercialization of AUVs and Development of Cooperative Motion Control Technology:* This is the decade of movement of research and technology on AUV from the academic level to the industrial level. In this period many companies were able to develop the AUVs according to the market demand and this was the proper utilization of AUV technology in the practical field. Theoretical development of cooperative motion control of multiple AUVs was also done in this decade.

F. 2010- Onwards

1) *Implementation of Cooperative Motion Technology in Commercial Manner:* Though in the previous decade cooperative motion technology was developed theoretically they were implemented and developed practically in this decade. The AUVs are to be manufactured commercially and would be good from economic point of view.

IV. FUTURE PROSPECTIVE OF AUV RESEARCHES

Though many problems on AUV research have been solved in the last few decades, still a lot of unsolved problems lies in the field of AUV research. Nowadays the major problem regarding AUVs is the problem of autonomy which can be solved by using intelligence system up to certain extent.

Energy is the most common problem in AUVs. The batteries contain Silver-Zinc composition or Lead-Acid composition. But now commercial NiMH battery is available which can provide energy better than the previous ones. Another good way of solving this problem is using of solar cells as supplementary energy sources. This can reduce the endurance of the energy cells.

Another problem faced by AUVs is navigation in a desired path. This problem can be solved by using the acoustic transponder navigation systems. Although this is cost effective, it can solve the navigation problem up to certain extent with taking advantages of Global Positioning Systems (GPS). In certain cases, the problem arises due to the use of some common types of sensors for a group of AUVs. In this case the sensors are not fixed for any kind of AUVs. So, the range problem arises for making decision in case of emergency. These problems are now solved by using embedded sensors, which are high range sensors and are designed for AUVs.

AUV communication is a difficult task as the signal travel within water. Due to chances of multiple propagation, small available bandwidth, uncertainty of time variation in channel of propagation, strong attenuation of signal in travelling medium and due to various other reasons keeping communication underwater is not easy. Generally, laser communication is possible for short range and RF communication for long range. But due to their predefined problems in the present-day acoustic signals are used instead of electromagnetic waves. But one demerit of acoustic communication is the transmission of low data rate comparing to terrestrial communication. A wireless network is necessary for each AUV to keep the information of its neighbouring AUVs.

V. FUTURE PROSPECTIVE OF COOPERATIVE CONTROL OF AUVS

A. Real World Implementation

Real life application of formation control of AUVs vary from pipeline survey, ocean floor exploration, military inspections etc. It is very difficult to implement these complex operations by multi vehicle systems in real life. The ability of formation pattern to face the dynamically changing environment is a challenging task. The multi-vehicle systems face some unavoidable and difficult circumstances in the form of static or dynamic obstacle avoidance, switching of the formation structure according to situations, keeping formation among all vehicles in group in case of communication failure or missing of any vehicle, repairing of formation structure etc. These tasks are also solved by the multi-robot system wherever necessary. But in real word, yet there are so many challenging tasks are being bounded within theoretical limitations. Some of them include formation control of AUVs, spacecraft formation etc. Some of the experimental results verifying the theoretical formation control laws show the usefulness of the formation control.

B. Hybrid and Bio Mimic Controller

Due to various complexities, undefined uncertainties and various other sub problems traditional controllers might not have the efficiency to solve all these formation control problems. Hence it is necessary to implement different advanced controller which possess higher level of computing and coordination protocols such as adaptive controller, robust controller etc. To solve the uncertainty problems, the controllers like Fuzzy or Neural Network, for optimization problems some evolutionary computing like Genetic Algorithm (GA), Bactria Foraging Optimization (BFO), PSO, and Ant/Bee Colony Optimization etc. can be used. In case of necessity, hybrid controllers which are the combination of more than one type of controllers should be used. The hybrid controllers, working both under discrete and continuous integrated domain and possessing higher computing capability, should be used for solving formation control problems. The biological agents present in nature also form an important inspiration for designing formation control. By studying their nature and behavior controllers can be developed to control the agents in such a manner that the team of agents should behave exactly similar to that of the biological agents. This property as known as Bio mimics. Hybrid control strategy technology may be used to solve different tasks simultaneously

VI. CONCLUSIONS

In the last few decades AUVs have emerged rapidly as a vital tool for various sectors like oil, defense, research and exploration purposes. The ability of these vehicles to fly at relatively low altitude over the seabed enables them to collect spatial data at far higher resolution than surface vessels. Continued development of new vehicles and sensors will increase the range of their application while advances in artificial intelligence will increase reliability and flexibility. They are capable of making decisions that allow them to avoid sea floor and under ice collision and with increased intelligence they can adapt their surveys according to the changes in the environment they are monitoring. It is also clear that with the incoming days AUVs will continue to play an increasingly important role in the exploration and monitoring if the oceans

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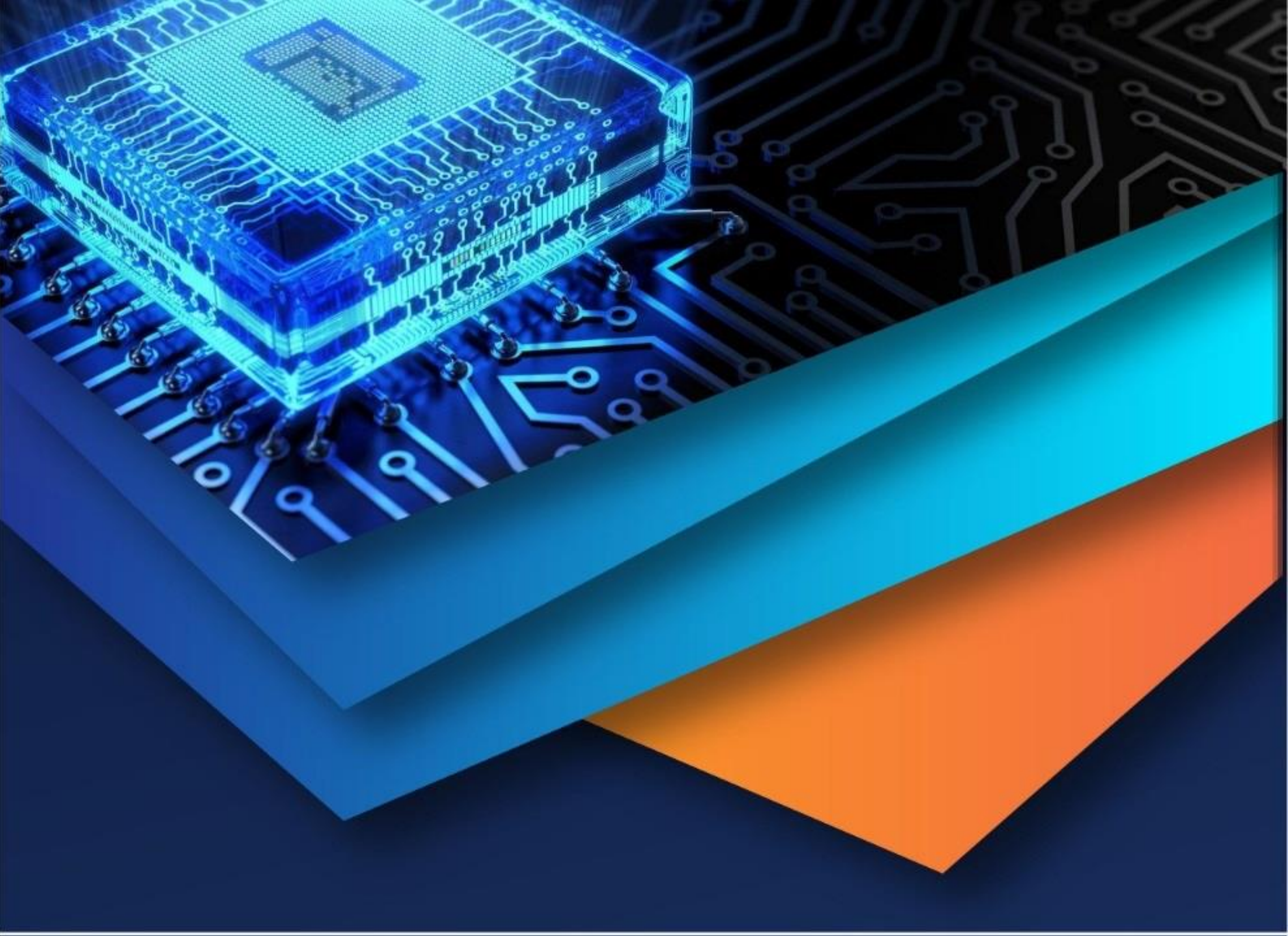

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