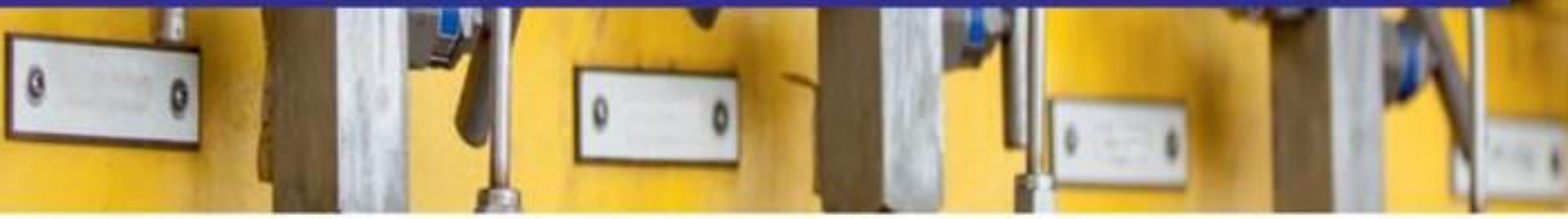


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Autonomous Underwater Drones – A Review on Submarine Surveillance and Exploration

K.Monika, B.Chandini, K.Vanajakshi, B.Ramana, J.S.V.Siva Kumar

B.Tech Scholar, Department of EEE, GMRIT-Deemed to be University, Vizianagaram, Andhra Pradesh, India

B.Tech Scholar, Department of EEE, GMRIT-Deemed to be University, Vizianagaram, Andhra Pradesh, India

B.Tech Scholar, Department of EEE, GMRIT-Deemed to be University, Vizianagaram, Andhra Pradesh, India

B.Tech Scholar, Department of EEE, GMRIT-Deemed to be University, Vizianagaram, Andhra Pradesh, India

Associate Professor, Department of EEE, GMRIT- Deemed to be University, Vizianagaram, Andhra Pradesh, India

ABSTRACT: Autonomous Underwater Drones (AUDs) are emerging as an important technology for exploring and monitoring underwater environments. These drones are designed to operate underwater with minimum human intervention, making it possible to collect information from areas that are difficult or unsafe for humans to access. They are equipped with sensors, cameras, navigation systems and communication technologies that help them move underwater, observe their surroundings and gather useful data.

This term paper focuses on the role of autonomous underwater drones in submarine surveillance and underwater exploration. It discusses their basic architecture, working principles, major components and navigation techniques. These drones can be used to observe underwater conditions, inspect underwater structures, map the ocean floor and support marine research. Their ability to perform missions for extended periods makes them useful tools for underwater monitoring and exploration.

The paper also highlights the major challenges faced by these systems, such as limited battery capacity, underwater communication difficulties, navigation errors and the effects of high water pressure. In addition, it explores how improvements in artificial intelligence, sensor technology and energy storage can make autonomous underwater drones more efficient and reliable in the future.

Overall, autonomous underwater drones have significant potential to improve underwater observation, data collection and exploration. With continuous technological development, they are expected to play an increasingly important role in marine research, underwater monitoring and submarine-related applications.

KEYWORDS: Autonomous underwater vehicle, underwater drone, submarine surveillance, underwater exploration, sonar, navigation, path planning, acoustic communication, sea drone, mine countermeasures.

I. INTRODUCTION

An autonomous underwater drone is an unmanned vehicle designed to travel and perform specific tasks underwater with little or no direct human control. As shown in the figure, these vehicles are generally designed with a compact, streamlined body to help them move through water efficiently. They contain different components, including sensors, cameras, navigation systems, batteries, control units and propulsion systems. All these components work together to help the vehicle move, collect information and observe its underwater surroundings.

Autonomous underwater drones are useful in several fields, particularly marine research, ocean-floor mapping, underwater inspection and submarine-related surveillance. They can collect valuable information from underwater locations that are difficult for humans to reach. Their ability to operate without continuous human control makes them suitable for long-duration observation and data collection. The main purpose of this term paper is to understand the technology behind autonomous underwater drones and explore their role in submarine surveillance and underwater exploration. It explains their construction, working principles, major components, applications and technical challenges. It also discusses how modern technologies such as artificial intelligence, advanced sensors and improved battery systems can make these vehicles more effective in the future.

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Fig. 1. Overview of Autonomous Underwater Drone(AUVs)

Overall, autonomous underwater drones represent an important step towards making underwater exploration easier, safer and more efficient. As technology continues to develop, these vehicles are expected to contribute significantly to ocean research, underwater monitoring and scientific exploration.

II. AUTONOMOUS UNDERWATER DRONE TECHNOLOGY

2.1 On-board Supervisory Control Computer: The onboard supervisory control computer is the main controlling unit of an autonomous underwater vehicle. It manages the operation of different subsystems and makes decisions based on the information received from sensors. It helps the vehicle follow its planned mission, maintain its direction and coordinate its movements without continuous human assistance.

2.2 Navigation Sensors: Navigation sensors help the underwater vehicle understand its position, direction and movement. Components such as the Inertial Measurement Unit (IMU), Doppler Velocity Log (DVL) and compass provide information about the vehicle's orientation, speed and movement. This information helps the vehicle navigate underwater and follow its planned path.

2.3 Mission Sensors: Mission sensors are used to observe the underwater environment and collect useful information. Sonar systems help detect underwater objects and measure distances, while cameras capture images and videos of the surrounding environment. These sensors support underwater exploration, environmental observation and general surveillance.

2.4 Propulsion and Control Surfaces: The propulsion and control system is responsible for moving the vehicle in the required direction. Thrusters provide the force needed for forward, backward and turning movements, while control surfaces such as fins help maintain direction and stability. This subsystem allows the vehicle to perform different underwater movements according to its mission.

2.5 Communication System: The communication system allows the underwater vehicle to exchange information with an external monitoring station or operator. Acoustic modems are commonly used for underwater communication because radio signals do not travel effectively through seawater. Radio-frequency or satellite communication may be used when the vehicle reaches the water surface. This system helps transmit collected information and receive mission-related instructions.

2.6 Power System: The power system supplies the electrical energy required to operate all the subsystems. Batteries or fuel cells can be used as energy sources, depending on the vehicle's design. The available power determines how long the vehicle can operate underwater and how much work it can perform during a mission.

2.7 Pressure Hull, Frame and Buoyancy System: The pressure hull protects sensitive electronic components from the high pressure of deep water. The frame provides mechanical support and holds the different components in their proper positions. The buoyancy system helps the vehicle maintain balance and control its depth while moving underwater. Together, these parts provide structural strength, protection and stability.

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2.8 Overall Working of the Architecture: All the subsystems work together to complete an underwater mission. The navigation sensors provide information about the vehicle's movement and position, while the mission sensors collect data from the surrounding environment. The onboard computer processes this information and coordinates the propulsion and control systems. The power system supplies the required energy, and the communication system supports information exchange with the external operator.

In this way, the combination of all these subsystems enables an autonomous underwater vehicle to perform underwater exploration and monitoring tasks with minimum human intervention.

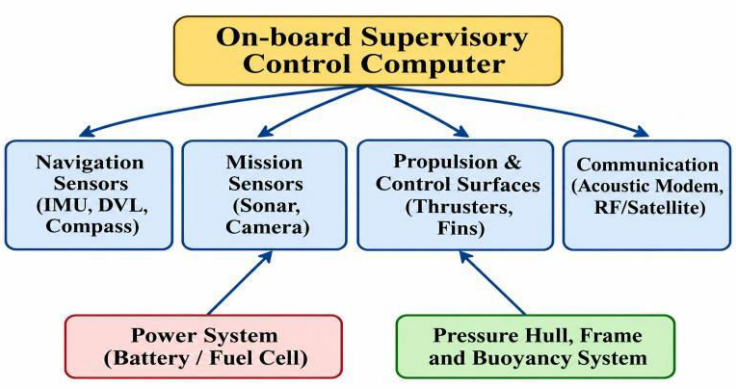


Fig. 2. General subsystem architecture of an autonomous underwater vehicle.

III. HISTORICAL DEVELOPMENT

Autonomous Underwater Vehicles (AUVs) were developed to make underwater exploration easier and safer. In earlier days, exploring deep-sea areas was difficult because humans could not easily reach such places. To overcome this problem, researchers started developing underwater vehicles that could move and collect information without needing continuous human control.

During the 1960s–1970s, the first experiments with autonomous underwater vehicles were carried out. These early vehicles had simple designs and could perform only basic tasks. During the 1980s–1990s, researchers started improving their design by adding better navigation, communication and sensor systems. Vehicles such as REMUS helped improve underwater research and exploration. In the 2000s, AUVs became more useful for ocean mapping, underwater exploration and environmental monitoring. During the 2010s, improvements in cameras, sonar systems, batteries and computer technology made these vehicles more advanced. They became capable of travelling longer distances and collecting more useful information from underwater areas. From the 2020s to the present, modern AUVs are being developed with advanced technologies such as artificial intelligence and machine learning. These technologies help the vehicles understand their surroundings and perform tasks more efficiently.



Fig. 3. Historical background and development of AUVs.

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IV. SENSORS AND PERCEPTION

Sensors and perception systems are important parts of an Autonomous Underwater Vehicle (AUV). Since an AUV works underwater without continuous human control, it needs different sensors to understand what is happening around it. These sensors help the vehicle know its position, measure its depth, detect nearby objects, capture images and collect useful information. Each sensor has its own function, and all the sensors work together to help the vehicle perform its underwater activities smoothly.

Perception plays an important role in an Autonomous Underwater Vehicle (AUV) as it allows the vehicle to understand what is happening around it underwater. Different sensors collect information about its location, depth, direction and nearby objects. The collected information is processed by the control system to identify obstacles, observe underwater objects and prepare maps of the seabed. It also supports navigation, monitoring and data collection during underwater missions. Overall, perception makes underwater exploration and submarine surveillance easier, safer and more effective.

Sensor	Main purpose	Limitation
IMU	Measures acceleration and angular velocity	Position error can build up over time
DVL	Measures velocity relative to the seabed or surrounding water	Bottom-lock operation has a limited range
Pressure sensor	Estimates underwater depth	Does not provide horizontal position
Sonar	Detects obstacles and supports seabed mapping	Can be affected by noise and multipath reflections
Camera	Provides images for visual inspection	Performance decreases in dark or turbid water
Magnetometer	Provides a heading reference	Can be affected by magnetic disturbances
Acoustic modem	Supports underwater communication and, in some systems, positioning	Has limited bandwidth

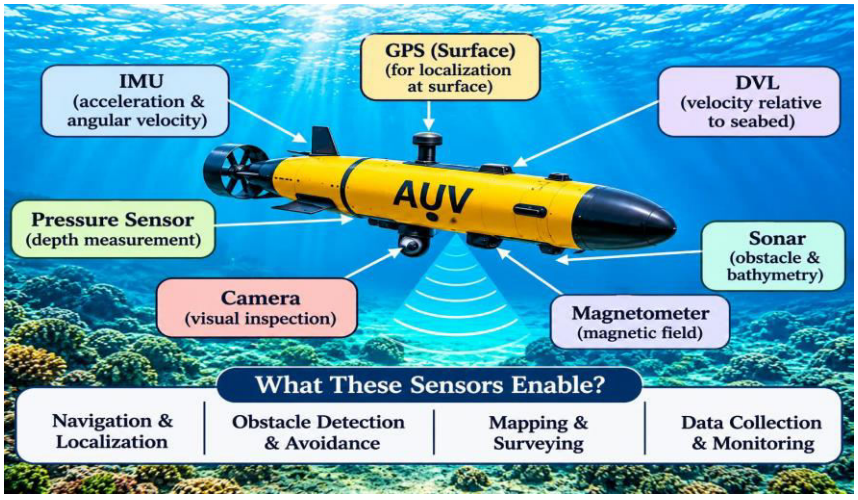


Fig. 4. Sensors and Perception

V. NAVIGATION AND LOCALIZATION

5.1 Dead Reckoning Navigation: It helps the AUV find its current position by using its previous position, speed and direction.

5.2 Signal-Based Navigation: It uses underwater sound signals to find the position of the AUV. It includes LBL, SBL and USBL methods.

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5.3 Map-Matching Navigation: It helps the AUV identify its location by comparing the surrounding seabed with stored underwater maps.

5.4 Integrated Navigation: It combines different navigation methods to get more accurate and reliable position information.

5.5 Cooperative Navigation: It allows multiple AUVs to communicate and share their position information while working together underwater.

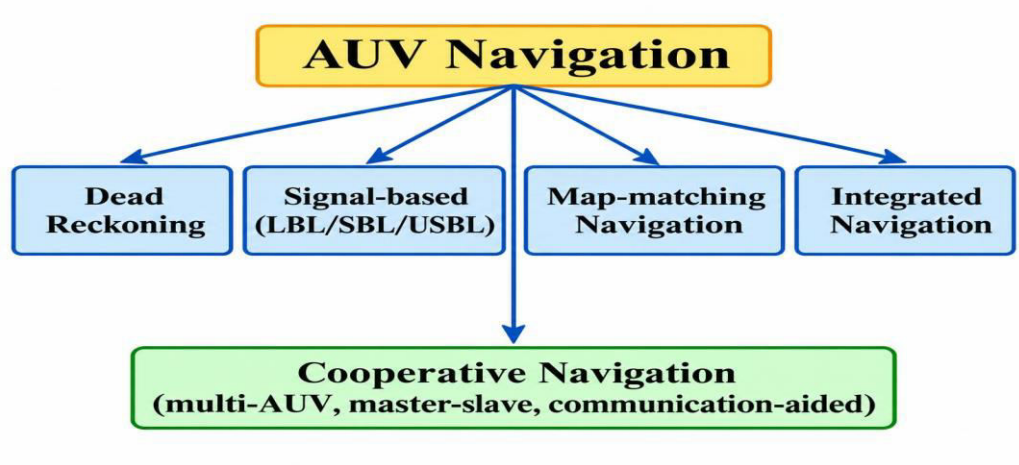


Fig. 5. Main categories of AUV navigation methods.

VI. PATH PLANNING AND CONTROL

A. Path Planning

Path planning helps an AUV decide which route to follow to reach its destination safely. It allows the vehicle to move through underwater areas while avoiding obstacles such as rocks and other objects. It uses sensors and underwater maps to find a suitable path. It also helps save time and battery power during the journey.

Main functions:

1. Finding a suitable route.
2. Avoiding underwater obstacles.
3. Reaching the target location.
4. Saving time and energy.
5. Ensuring safe movement underwater.

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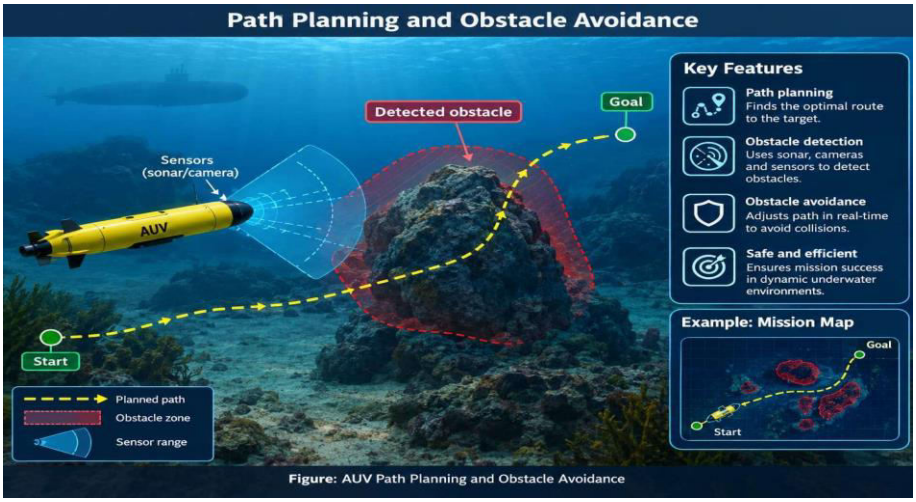


Fig. 6. Path planning and obstacle avoidance for an AUV.

B. Vehicle Dynamics and Control

Vehicle dynamics and control explain how an AUV moves and responds underwater. It helps the vehicle move in the required direction, maintain its depth and stay stable during its journey. The AUV uses motors, propellers and sensors to control its movement and adjust its position whenever needed.

Main functions:

1. Controlling the movement and speed of the AUV.
2. Maintaining the required depth underwater.
3. Changing direction when needed.
4. Keeping the vehicle balanced and stable.
5. Adjusting its movement according to underwater conditions.

VII. UNDERWATER COMMUNICATION

Underwater communication helps an AUV send and receive information while travelling underwater. It allows the vehicle to share information with ships, control stations and other underwater vehicles.Since Wi-Fi does not work properly underwater, AUVs mainly use sound waves to communicate. Light signals can also be used for short distances. When the AUV comes to the surface, it can use Wi-Fi or other wireless methods to transfer data.

Main methods:

Acoustic Communication: Uses sound waves to send information underwater.
Optical Communication: Uses light signals to transfer data over short distances.
Radio Communication: Mainly used when the AUV comes near or above the water surface.

Main functions:

1. Sharing location and sensor information.
2. Sending data to control stations.
3. Communicating with other AUVs.
4. Receiving instructions.
5. Transferring collected data.

VIII. UNDERWATER SURVEILLANCE APPLICATIONS

AUVs are used to observe and monitor underwater areas. They help explore the seabed, find dangerous objects and keep track of activities happening underwater. They can also work together and share information to cover larger areas.

1. Seabed Exploration and Mapping: AUVs help explore the ocean floor and collect information about underwater areas and structures.

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2. Threat Identification (Mines/UXO): They help find underwater mines and other dangerous objects that may cause damage to ships and submarines.
3. Intrusion Detection: AUVs help identify unwanted objects or activities entering protected underwater areas.
4. Cooperative AUV Surveillance: Multiple AUVs can work together, share information and monitor different underwater areas.

Challenges
• Navigation errors during long-distance movement.
• Limited communication underwater.
• Poor visibility in deep water.

Benefits
• Makes underwater monitoring safer.
• Covers larger underwater areas.
• Helps detect threats more easily.

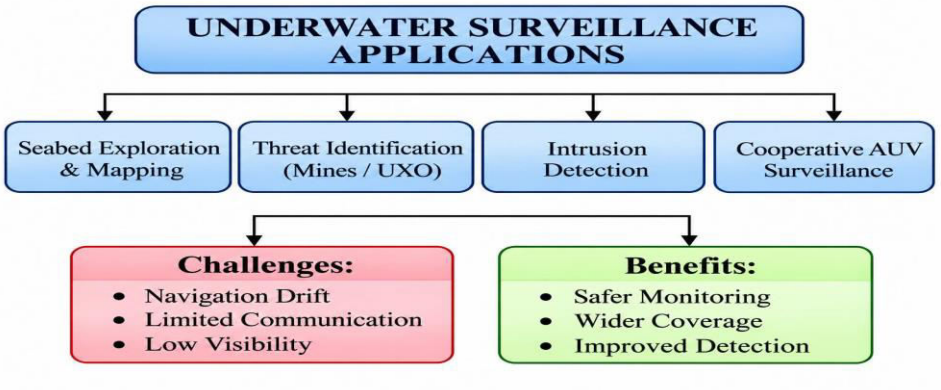


Fig. 7. Functional overview of Underwater Surveillance Application Using AUVs

IX. SEA DRONES IN MODERN NAVAL OPERATIONS

The integrated system of naval unmanned vehicles brings together different underwater and surface vehicles to work as a team during naval operations. It includes UUVs, USVs, gateway buoys, support ships and communication systems. These vehicles help naval forces observe underwater activities, detect mines, monitor submarines and explore the ocean without putting human lives at risk. The support ship acts as the main control centre and keeps track of the activities of underwater vehicles. Satellite and radio links are used for communication above the water, while acoustic signals are used to exchange information underwater. Gateway buoys help transfer information between underwater vehicles and surface ships.
UUVs: Move underwater to observe the surroundings, collect information and detect objects.
Gateway Buoys: Help transfer information between underwater vehicles and support ships.
Support Ships: Monitor the activities of unmanned vehicles and provide the required support.
Acoustic Links: Allow underwater vehicles to communicate with each other using sound waves.
Midget Submarines: Help in underwater exploration and special naval operations.
Divers: Carry out underwater inspections and support different missions.
Mine Detection: Helps locate underwater mines and keeps naval operations safer.

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Fig. 8. Integrated system of naval unmanned vehicles.

X. PERFORMANCE OF UNDERWATER DRONES

Underwater drones, also known as UUVs, are useful in modern naval operations. They can travel underwater and perform different tasks without requiring a person to control them directly all the time. They help naval forces explore the ocean, detect underwater objects and monitor activities safely.

The performance of underwater drones depends on several factors:

1. Speed: It determines how fast the drone can move underwater and complete its work.
2. Depth Capability: It shows how deep the drone can travel and work underwater.
3. Battery Life: A good battery allows the drone to work for a longer time without charging.
4. Communication: Underwater drones use sound signals to share information with other vehicles and ships.
5. Navigation: Sensors help the drone find its direction and move to the required location.
6. Payload Capacity: It determines how much equipment, such as cameras and sensors, the drone can carry.
7. Obstacle Detection: It helps the drone identify underwater objects, rocks and mines.
8. Stability: It helps the drone maintain its balance and move smoothly underwater.

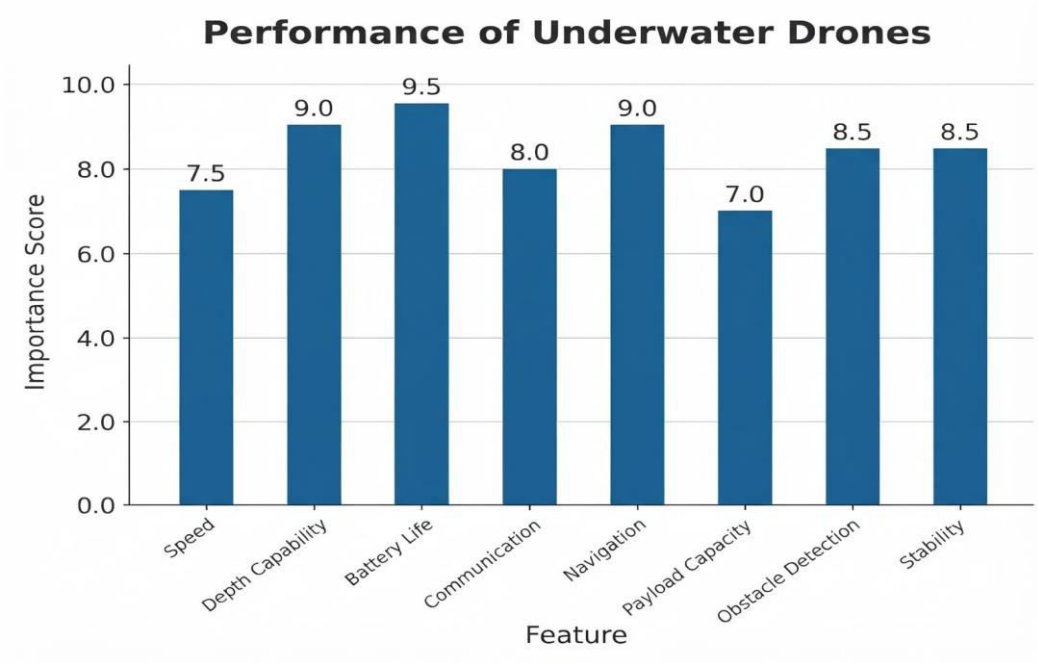


Fig. 9. Perfomance of Underwater Drone

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XI. ADVANTAGES OF UNDERWATER DRONES

Underwater drones are very useful in modern naval operations. They make it easier to explore underwater areas and perform tasks that may be difficult or dangerous for humans.

1. Safety: They can perform dangerous underwater tasks without putting human lives at risk.
2. Mine Detection: They help find underwater mines and alert naval forces about possible dangers.
3. Ocean Exploration: They can travel deep into the ocean and explore places that humans cannot easily reach.
4. Surveillance: They help monitor underwater activities and keep track of submarines.
5. Cost Saving: They can reduce the need for divers and make some underwater operations less expensive.
6. Long-Distance Operation: They can cover large underwater areas and collect useful information.
7. Easy Monitoring: Cameras and sensors help capture underwater pictures, videos and other details.
8. Accurate Detection: They help identify underwater objects and obstacles with the help of advanced sensors.
9. Environmental Protection: They can be used to study marine life and monitor water conditions.
10. Naval Security: They support the navy in underwater inspection, monitoring and security activities.



Fig.10. Advantages of underwater drones autonomous underwater drones.

XII. CHALLENGES AND LIMITATIONS

Autonomous Underwater Vehicles (AUVs) are very useful for exploring the ocean, collecting information and performing underwater operations. However, they also face some challenges that can affect their performance.

1. Limited Battery Life: AUVs depend on batteries to operate underwater. If the battery runs out, the vehicle cannot continue its mission for a long time.
2. Communication Problems: Communicating underwater is difficult because normal mobile and radio signals cannot travel properly through water.
3. Navigation Difficulties: AUVs cannot use GPS underwater, so finding their exact location and moving in the correct direction can be challenging.
4. High Cost: Building and maintaining AUVs is expensive because they need advanced technology, sensors and special equipment.
5. Harsh Underwater Conditions: Deep-sea pressure, cold temperatures and strong water currents can affect the vehicle and its working ability.
6. Sensor Limitations: Sometimes, underwater cameras and sensors cannot collect clear information because of muddy water, low visibility and underwater disturbances.
7. Maintenance Problems: If an AUV gets damaged underwater, repairing or bringing it back to the surface can be difficult.
8. Limited Carrying Capacity: AUVs have limited space to carry cameras, batteries and other equipment needed for different missions.

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XIII. FUTURE SCOPE

AUVs have a lot of potential in the future, especially in underwater exploration and marine research. As technology develops, they will become smarter, faster and easier to operate. They will help us explore deeper parts of the ocean, collect useful information and perform underwater tasks more efficiently.

1. Artificial Intelligence: In the future, AUVs will become smarter and make their own decisions while exploring underwater.
2. Improved Battery Life: Better batteries will help AUVs work underwater for longer periods without needing frequent recharging.
3. Better Communication: New communication technologies will make it easier for AUVs to send and receive information underwater.
4. Advanced Navigation: Improved navigation systems will help AUVs find their location and move safely underwater.
5. Deep-Sea Exploration: AUVs will help us explore deeper parts of the ocean and discover places that humans cannot easily reach.
6. Environmental Protection: They will help identify water pollution, study marine life and protect ocean environments.
7. Military Applications: AUVs may be used for underwater security, surveillance and detecting underwater mines.
8. Swarm Technology: In the future, many AUVs may work together like a team to complete underwater missions faster.
9. Improved Sensors: Better cameras and sensors will help collect clear and accurate information from underwater environments.
10. Reduced Cost: With new technology, the cost of building and maintaining AUVs may become lower, making them more affordable.

XIV. RESULTS AND DISCUSSIONS

The analysis shows that Autonomous Underwater Vehicles (AUVs) are becoming very useful in underwater operations. The graphs help us understand the different challenges faced by these vehicles, such as poor visibility, limited communication, battery problems, and navigation difficulties. Among these, poor visibility is one of the major problems because it makes it difficult to observe and identify objects underwater.

AUVs are mainly used for underwater surveillance, object detection, exploration, and collecting important information. They can travel through deep underwater areas and explore places where humans cannot easily reach. They are also helpful in monitoring marine environments and identifying objects that may be important for naval operations.

The performance of AUVs can be improved with the help of advanced sensors, artificial intelligence, and better navigation systems. These technologies help the vehicles understand their surroundings, detect objects, and avoid obstacles while moving underwater. They also make the operation of AUVs easier and more accurate.

Battery life and power management are also important for the proper working of AUVs. Limited battery power can affect how long the vehicle can operate underwater. Using improved batteries and efficient power systems can help AUVs travel longer distances and complete their tasks without frequent interruptions.

Overall, AUVs provide a useful solution for underwater surveillance and exploration. Even though they face some challenges, continuous improvements in technology can make them more reliable and efficient. In the future, these vehicles can play an important role in naval operations, submarine surveillance, and deep-sea exploration while reducing human effort and risk.

AUVs also make underwater work safer and easier because they can explore places where it is difficult for humans to go. They can collect useful information and complete different tasks without needing a person to control them all the time. With better technology and improved systems, these vehicles can become more useful in future naval operations and underwater exploration.

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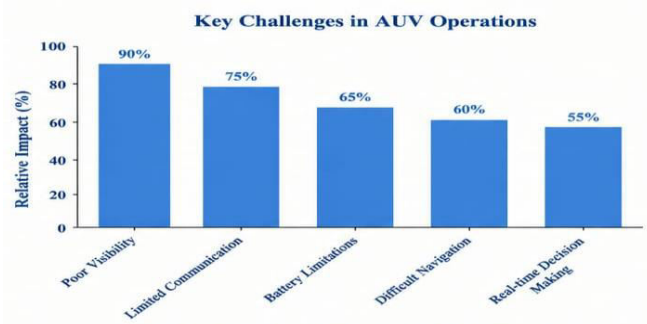


Fig. 4. Analysis of key challenges in AUV operations

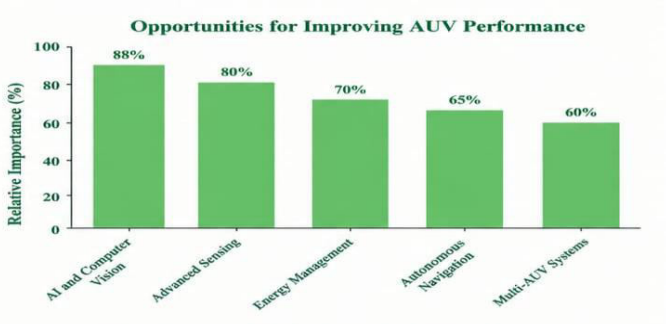


Fig. 5. Opportunities for improving AUV performance

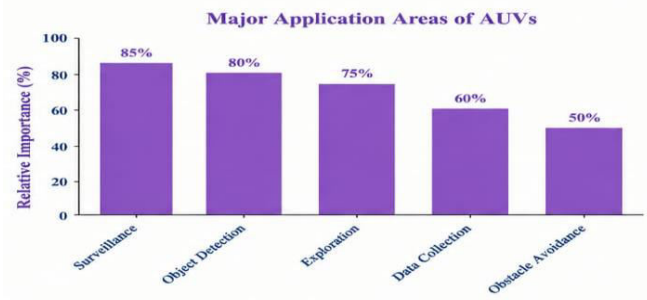


Fig. 6. Major application areas of AUVs

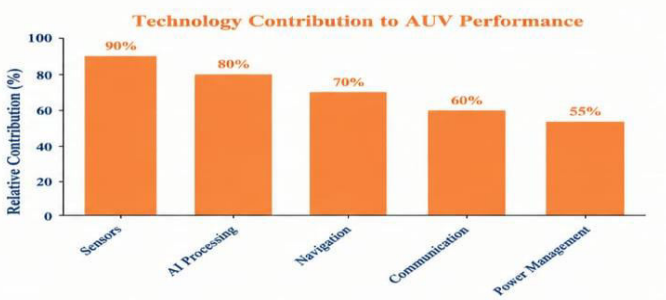


Fig. 7. Contribution of key technologies to AUV performance

Fig. 11. Analysis of AUVs

XV. CONCLUSION

Autonomous Underwater Vehicles (AUVs) are making underwater activities easier and safer. They help in exploring deep-sea areas, finding underwater objects, collecting information, and monitoring activities beneath the water. One of their main advantages is that they can reach places where humans cannot easily go and perform different tasks without putting human lives at risk.

Even though AUVs have some challenges, such as poor visibility, limited communication, battery problems, and navigation difficulties, these can be improved with better technology. The use of advanced sensors, artificial intelligence, cameras, and improved navigation systems can help them work more accurately and smoothly.

AUVs are useful in many areas, especially submarine surveillance, naval operations, marine research, and underwater exploration. They help in observing underwater activities and collecting important information. This makes them a valuable technology for both defence and scientific purposes.

In the future, AUVs may become smarter and more advanced, allowing them to complete difficult underwater missions with less human support. Improvements in battery life, communication, and control systems will make them more efficient and reliable.

Overall, AUVs have a promising future in underwater technology. With continuous improvements, they can make underwater operations easier, safer, and more effective. They will be an important part of future naval systems and deep-sea exploration.

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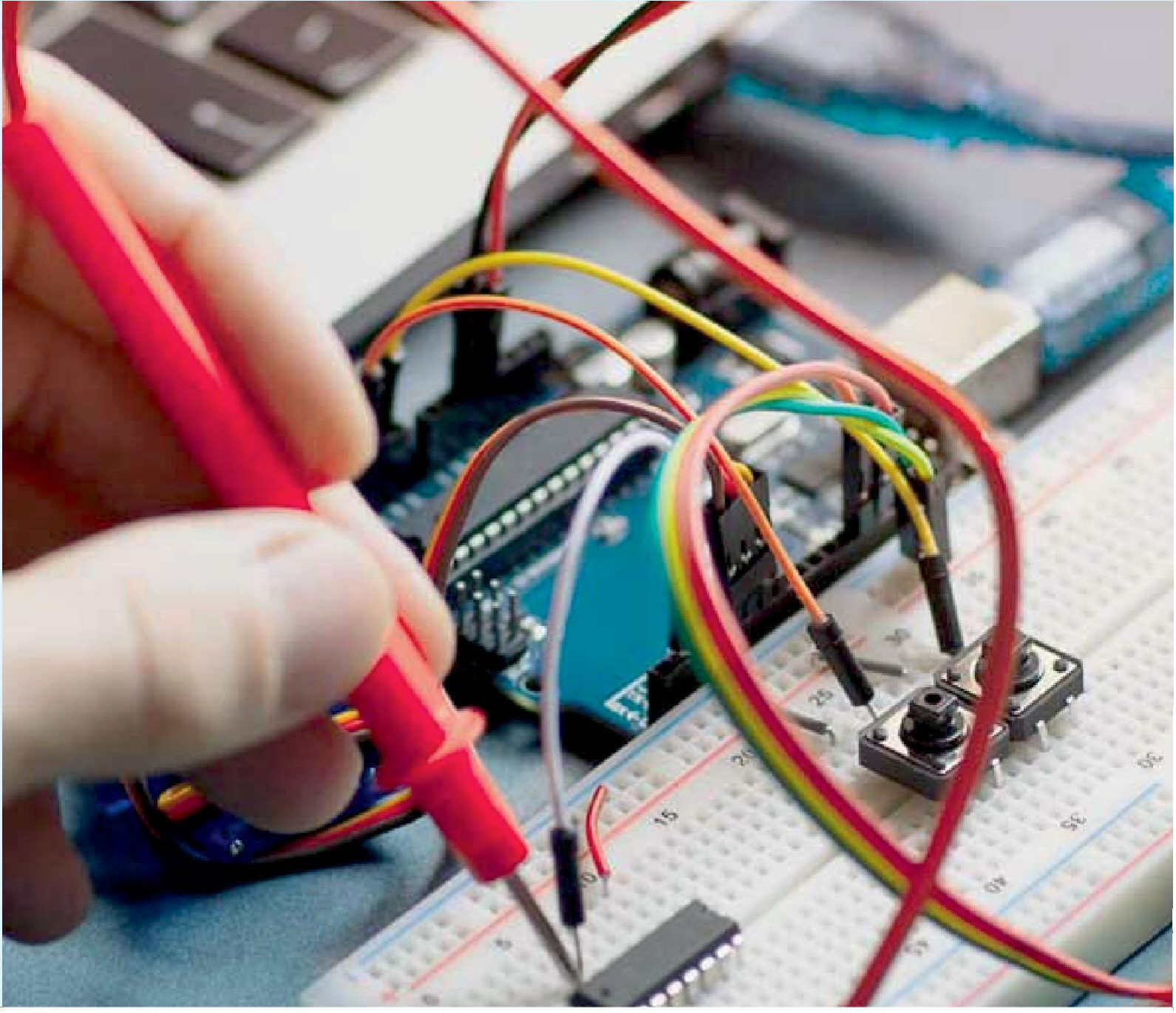
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