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Submarine Vehicle Design: Technology Needs and Challenges

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Abstract—Submarine vehicle technology is yet to be developed much more to satisfy the needs of ocean engineering applications. Research and development on these areas has bright prospects in the future. The Autonomous Underwater Vehicle (AUV) has the several differing concept of complexity because of number of elements and relations, diversity of elements and relations and number and diversity of states. Also the AUV system is a structural and behavioral complex. In this paper an intelligent AUV system with the novel design approach is presented. It identifies the technology needs and challenges that are required for different AUV missions.

Keywords—submarine, sensors, communication modem, sonar imaging

I. INTRODUCTION

Underwater imaging is important for safe navigation, offshore installations, mine detections, marine communication, surveillance, oil and gas exploration. An underwater system transmits sound signals down range from a group or array of elements, which is a transient disturbance in a fluid medium that behaves as acoustic waves governed by the differential equations of fluid mechanics. The propagation of a signal in the sea is a complex phenomenon that depends on temperature, depth, position, salinity, and pressure. These factors give a time varying structure that is inhomogeneous both vertically and horizontally. The generated acoustic pulse in the water column expands spherically and insonify that region as depicted in Figure 1a. The ocean affects an acoustic signal in many complex ways (signal is delayed, distorted, and weakened by scattering and absorption, propagation does not occur in an exact straight line, but exhibits ducted characteristics over long distances). Also, the signal can be affected by multipath transmission, caused by reflection off the sea surface. Further, in a typical reception of a signal wavefront, noise and interference can degrade the performance of the system and limit the capability to detect signals. Also, the ambient noise may have unusual vertical or horizontal directivity.

II. SCIENTIFIC VIEW OF UNDERWATER VEHICLES

Underwater vehicles (UVs) have categorized as manned submarines and unmanned underwater vehicles (UUVs); the unmanned vehicles are either Remotely Operated Vehicles (ROVs) or Autonomous Underwater Vehicles (AUVs) [1]. The Figure 1b shows the overview of various UVs and the Figure 2 classifies UVs. The ROVs are remote controlled from an operator's desk on a ship, to which they are connected via an umbilical cable, that supplies control commands to the motors, transfers sensor data back to the operator, and supplies power as shown in Figure 3. It acts as an emergency cable to retrieve the vehicle in case of mechanical faults. Typically, the cable is very robust, a few hundred or thousand metres long, and can easily weigh several hundred kilograms. The vehicle must have strong propulsion to counter the weight and the hydrodynamic drag of the cable. AUVs are scientific robots that are equipped with on board computing for navigation and mission planning, carry their own power supply and a range of sensors (depth sensors, magnetometers, thermistors, conductivity probes, inertial navigation, compass, temperature, sonar and cameras). Once deployed, it carries out the mission autonomously without human interaction and returns to the surface for pickup after completion, as shown in Figure 4. They gain information from their sensors for navigation and mission tasks [2].

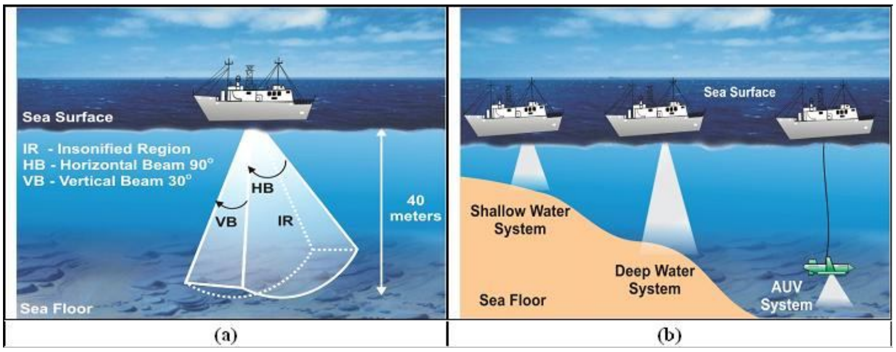

Figure1 a) Overview Insonification and b) Various underwater systems

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They can operate in water as deep as 6000 meters and with recent advances in battery technology, it can travel tens of kilometers [3]. The demand for advanced underwater robot technologies is growing and will eventually lead to fully autonomous, specialized, reliable underwater robotic vehicles [4]. Applications of AUVs are Seafloor Mapping, Geological Sampling, Long term monitoring (e.g. pollution, radiation leakage), Submarine off-board sensing, Water mine search and disposal, Ship hull inspections, Nuclear power plant inspections, Underwater cable inspection, Communications between UUVs and subsea sensors, Subsea navigation beacons, asset location, asset protection, Heterogeneous communications, Underwater navigation, sensing and Subsea networks etc [5]. The table 1 compares the concept of Deep Sea and the table 2 compares technical maturity and acceptance of UUV.

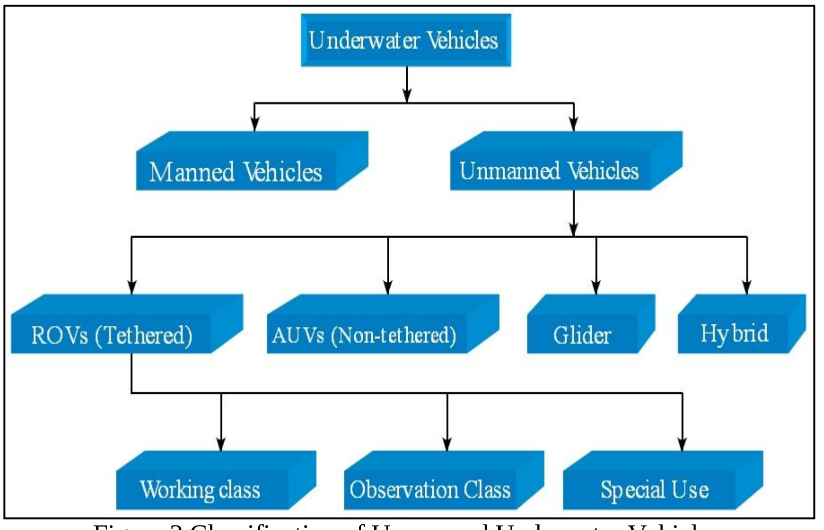

Figure 2 Classification of Unmanned Underwater Vehicles

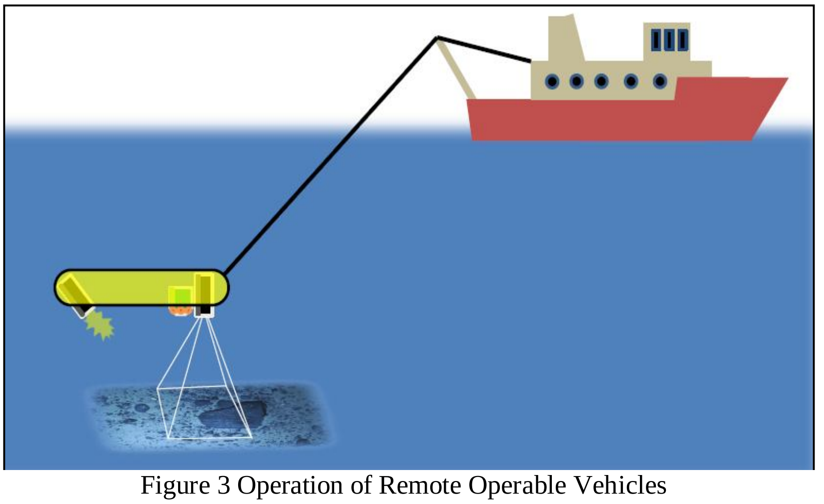

Figure 3 Operation of Remote Operable Vehicles

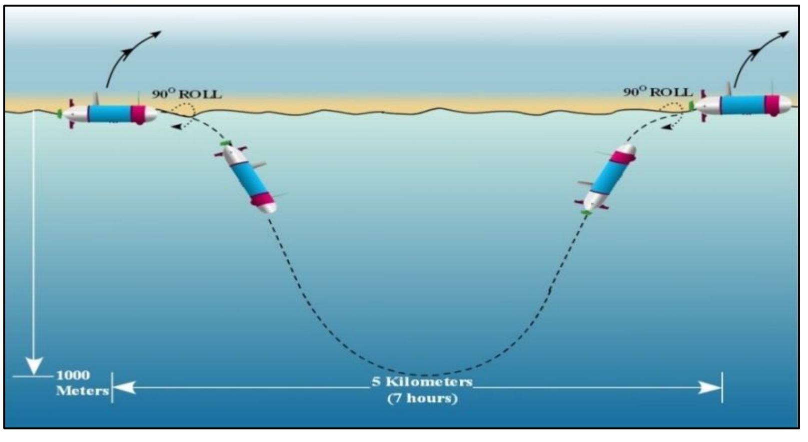

Figure 4 Operation of Autonomous Underwater Vehicles

Table 1 The concept of "Deep Sea"

Parameter	Industry View	Scientific View
Definition	"Deep sea" means 1000 to 2000 m "Ultra-deep sea" means 2000 to 3000 m	Deep sea means up to 6000 m in order to cover the major area of interest. "Ultra-deep" is 11000 m
Motivations	Deep sea activities are driven by economical factors (oil price, political and strategically factors)	Study and comprehension of basic local (regional scale) and global phenomena (large/earth scale, such as global climate change, earthquakes, volcanoes, tsunami)
Fields of interest	Basically only oil Industry and cable communication Companies are involved in deep sea activities. Ocean mining and waste disposal activities are in initial phase.	Many disciplines interested in Deep Sea (Physical/Chemical Oceanography, Biology, Seismic, Geophysics, etc.) each with different approaches and requirements relevant to observation and acquisition methods.

Table 2 Technical Maturity and Acceptance of UUV

Vehicle	Technology Maturity	Industry Acceptance
ROV	High: Incremental improvement New class: Optionally tethered	High: Established
AUV	Medium: Continuing improvement of Sensors and Electronics means performance continues to improve	Medium: Gaining new user types, Customers become repeat buyers
USV	Low : Little track record for real use in operation and USV threatening small boats have put roadblocks on accumulating USV performance data that would turn prove reliability	Low: Case to be made in oil & gas, defense buyers are serious but slow to buy

III. AUTONOMOUS UNDERWATER VEHICLE TECHNOLOGY

AUV is a platform on which to mount sensors and processing systems that are of smarter, lower power, highly reliable, smaller in size, etc. It is driven through the water by a propulsion system, controlled and piloted by an onboard computer, and maneuverable in three dimensions. This level of control, under most environmental conditions, permits the vehicle to follow precise preprogrammed trajectories wherever and whenever required. AUV’s are also well suited to perform long linear transects, sea sawing through the water as they go, or traveling at a constant pressure. They provide a highly productive means of performing seafloor surveys using acoustic imaging systems [6]. Most vehicles can vary their velocity between 0.5 and 2.5 m/s. The battery runtime heavily depends on the use of propulsion. The two critical key factors are idle runtime and cruise speed runtime, which maximizes the range, but is not necessarily full speed. Idle runtime depends on the computing requirements with energy optimized embedded processors, idle runtimes of several weeks are possible. Greater depths of thousands of metres require special materials, such as titanium, to obtain sufficient structural integrity; designing seals and connectors becomes a lot more challenging. For reasons concerning engineering and cost it is usually better to design a cheaper shallow water vehicle and a more expensive deep sea version for special applications. The AUVs are constrained by underwater acoustic communication and navigation against a general behavioral background provided by programmed logics [7, 8]. The AUVs relied upon underwater acoustic signals for navigation and inter vehicle communication during their operations. They may react differently to a rising or falling seafloor based on the need to maintain a constant altitude above the bottom and not collide with the bottom, but in general they do use sensor data obtained during a mission to make them more successful and reliable [8,9].

The ability to imbed software into a vehicle system that can alter the vehicle's current mission, based on measurements from the sensor(s) it carries, and direct it toward a source or phenomena of interest will greatly reduce the time it takes to locate and study such phenomenon of interest [10]. The Figure 5 shows the elemental technologies for AUV and Figure 6 shows the Real time operational view of AUV

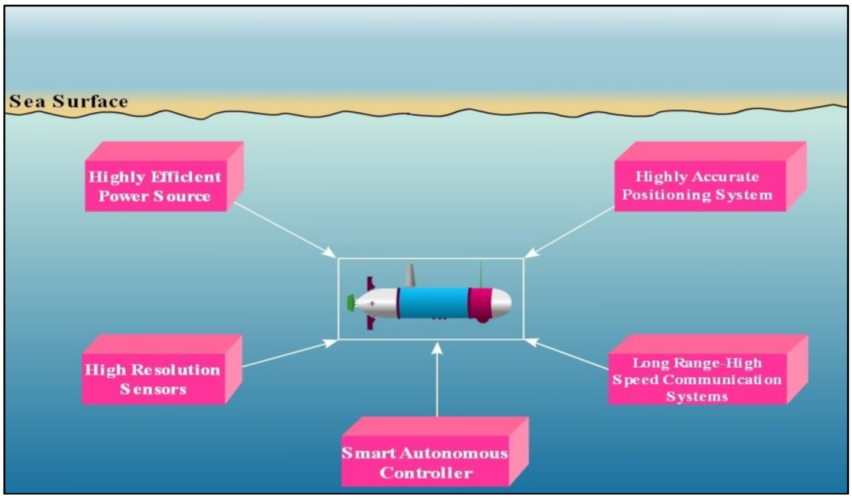

Figure 5 Elemental technologies for AUV

IV. CHALLENGES AND LIMITATIONS

The design of AUV must satisfy the technology needs in three major areas namely sensing, communications and vehicle autonomy. With the development of materials, computing and sensor technology, as well as theoretical advancements, research and development activities in the AUV community have increased. Further the evolution of nanotechnology has led to improvements and enabling them to go into the deepest depths. In order to survey the whole ocean efficiently, the development of intelligent underwater vehicles will be the necessary solution. The cost in time and money of assembling an AUV is high and beyond the reach of academic institutions. A variety of problems including ambient noise, multipath arrival, fading, shadow layers, masking and other effects can make AUV use difficult. A large gap exists between the projections of theory and the actual practice of design. Interactions and interdependencies between hardware and software component problems are poorly understood. Testing is difficult, tedious, infrequent and potentially hazardous. Potential loss is intolerable due to tremendous investment in time and resources, likelihood that any failure will become catastrophic and difficulty of recovery. The AUV has the several differing concept of complexity because of number of elements and relations, diversity of elements and relations and number and diversity of states. Also the AUV system is a structural and behavioral complex. A high number of element and relations leads to structural complexity. So with high number and diversity of states, the system gets difficult to predict. Further its complex due to interdisciplinarity that leads to higher diversity of elements and relations. Also the high degree in cross-linking is on par with a high number of relations. Then the flexibility in terms of increasing functionality increases the behavioral complexity

V. ENGINEERING DESIGN AND SOLUTIONS OF AUV

The primary difficulty is a challenging physical environment: an operating AUV is inaccessible, remote, and unattended. It is subjected to extremes of pressure, temperature, corrosion. Vehicle deployment, operation and recovery are time-consuming and expensive. Vehicle physical dynamic control is very challenging. Propulsion is costly, slow and limited. A typical vehicle only has a few hours endurance. A harsh working environment and susceptibility to physical failure are among the major reasons for this scarcity. AUV failure in the ocean is unacceptable for several reasons: any failure may become catastrophic, recovery may be difficult or pointless, and replacement costs in time and money are prohibitive. It is tremendously difficult to observe, communicate with and test underwater robots, because they operate in a remote and hazardous environment where physical dynamics and sensing modalities are counterintuitive. The solution is to develop, implement and verify an imaging and communication system which is fast, robust and accurate enough for modern AUV. Hence a need to develop a new model, algorithm and simulation of synthetic aperture sonar (SAS) system is required in order to investigate the feasibility of interferometric height estimation based on a typical processing chain. Also an efficient acoustic modem is required for the undersea communication. As the design grow in complexity and quantity of information represented, the ability to scale up and accommodate arbitrarily large numbers of information sources and interacting entities becomes a crucial requirement. Currently there are many bottlenecks preventing unlimited and seamless underwater communications. The AUV performance is coupled to sensor accuracy and interpretation. Sensors and Communications, Energy, Autonomy, Navigation is the major technologies that are needed for AUV systems.

In fact many of the tasks being assigned to today's AUVs required only a list of preprogrammed instructions to accomplish a task. For this reason, there has not been a significant level of development, recently, that is focused on AUV autonomy. The problem of autonomy still remains unsolved. There have been some successes with other autonomous systems, but those advances have not been brought into the AUV community. There are very few programs funded to address these issues and the problem remains. As AUV operations increase, it will become apparent that more investigation is needed. This will again emphasize the need for more development along the lines of making AUV systems more intelligent and better able to adapt to the environment within which they exist. In the past few years, there has been increased recognition of the potential of multiple cooperating AUVs. Currently some work is underway to investigate cooperating AUVs tasked to meet some of the needs of mine clearance. Many more investigations are required as it is a significant problem and far from being solved. Initial efforts to develop AUV technology was more concerned about the basic technologies required to allow reliable vehicle operation. As that reliability was achieved, sensors were added to the vehicle system to acquire data from the ocean environment. Most of these efforts to date have been to integrate existing sensors and sensor processing to the sometimes unique constraints of the AUV. This paradigm has proven to work reasonably well. Recently it has been recognized that we must develop entirely new sensors based on the constraints imposed by an AUV. This would change the paradigm of sensor integration. It would encourage the development of sensors specifically for AUVs; smarter, lower power, highly reliable, smaller in size, etc. It is also becoming clear that AUVs can be used in groups to act cooperatively to acquired needed data. By maintaining a common spatial and temporal reference, data acquired by multiple AUVs can be aggregated and processed to obtain synoptic, high resolution data describing a process of interest. Much work continues on the development of higher and higher resolution imaging systems, both optical and acoustic. With the new processors it has been possible to obtain very high resolution images over longer and longer ranges. The roadblock to much of this work is the ability to analyze the acquired data autonomously such that the AUV can utilize this data for guidance and control decisions. This perception ability is still beyond the current capabilities of AUVs.

VI. ELECTRICAL NEEDS

The AUV is needs complex electrical, electronics and computing backbone and sensors to perform the mission tasks. Completely isolated power supply systems were used to separate the drive motors and the electronic systems in order to avoid damaging feedbacks. Furthermore, each subsystem has its own power supply regulators and has also been protected by using fuses to avoid any unexpected failure or current draw while maintaining a steady voltage. In an open water environment the interest is primarily on the global position, which is then compared with a map. In this case the AUV is acting in a pool with straight walls; it has to know the relative position to the wall. This helps to prevent collisions with the wall, and enables tasks like wall following and the driving of search patterns. The position can be integrated by using the heading and the measured speed. This method is called dead-reckoning and is used whenever an absolute position measurement is not possible. Electric power storage is an important technology for all equipment of the underwater vehicle because environmental pressure is high, the temperature is 5 degrees Celsius or less, and conditions are unsuitable for many chemical reactions in the deep sea. Battery capacity is mainly dependent on its mass; this means that the cruising range is proportional to the mass of the battery. The underwater power source is an important element to operate AUV for a long time. Because there is no energy supply places in underwater. The power source has heaviest weight with the components of the vehicle. When the power source becomes big in proportion to the scale up of the body, maneuverability and energy efficiency worsen. Therefore it is important that the power source is small and light weight. Low vibration and low noise environment is important not to interfere acoustic equipments such as observation devices or communications devices.

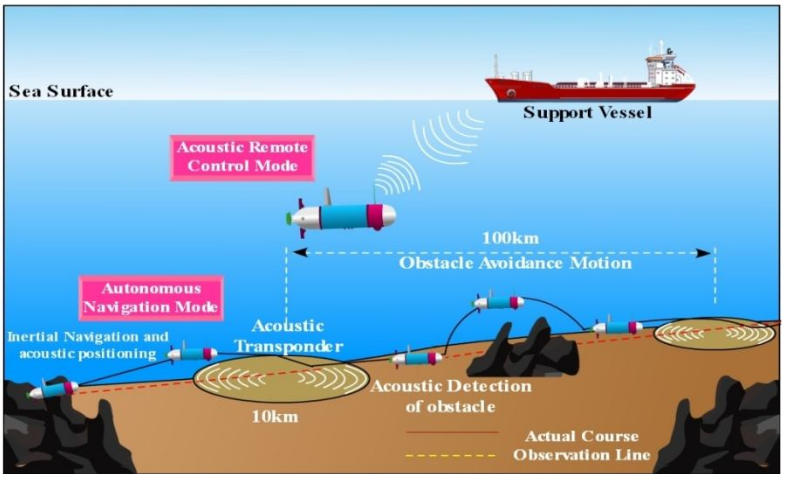

Figure 6 Real time operational view of AUV

CONCLUSION

The use of autonomous systems is a revolutionary concept and over the years it has become reasonably clear that there will be no single AUV concept that meets all user needs. Certainly the timing of AUV technology is good. It has been able to leverage its development by utilizing many technologies. There are still many important research investigations to be undertaken. Autonomy is probably the most important issue to be addressed but others, such as those described above, certainly must be addressed. It is clear that the limit to the capability of any AUV is the amount of energy it has onboard. Most important, the AUV community must educate the user community of the future about AUV systems capabilities and operational reliability.

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