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Underwater Vehicle for Surveillance with Navigation and Swarm Network Communication

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Abstract

Autonomous Underwater Vehicles (AUVs) have gained more popularity in recent years for military as well as civilian applications. One potential application of AUVs is for the purpose of undersea surveillance. As research into underwater surveillance using AUVs progresses, issues arise as to how an AUV acquires acts on, and shares information about the underwater battle space. These issues naturally touch on aspects of vehicle autonomy and underwater communications, and need to be resolved through a spiral development process that includes experiments at sea. This paper presents an implementation of swarm network communication for AUVs which is used to transfer the data, to communicate with one another to perform tasks as an intelligent group including surveillance. When a task identified from a seafloor, a single AUV could follow that task and report the whereabouts. Other vehicles in the swarm could track additional individuals, produce detailed maps of the area, detect AUV updates to a distant command post. As individual AUV leave the swarm to fulfill their assigned tasks, the swarm could autonomously reorient itself. This reduces the inspection duration and inspection cost for underwater vehicle. This paper has described the on-board signal processing including a navigation and network communication which were successfully implemented. The vehicle is designed and simulation is studied in computer analysis as per the required parameters and condition. The Simulation of swarm network communication and navigation multi-path trajectory is performed.

Keywords: Communication, Intelligent, Navigation, Swarm Network, Underwater Vehicle

1. Introduction

Autonomous Underwater Glider (AUG) are the main autonomous underwater platforms available currently, which play important role in the marine environmental monitoring. The relationships between those three types of vehicles were shown in Figure 1.

Autonomous Underwater Vehicles (AUV) speed and position control systems are subjected to an increased focus with respect to performance and safety due to their increased number of commercial and military application as well as research challenges in past decades

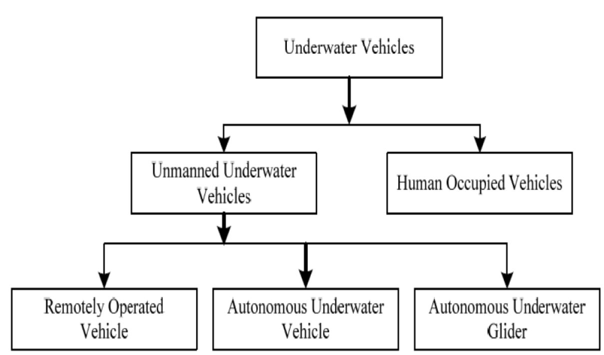

Figure 1. Underwater vehicle relationships.

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including underwater resources exploration[1], oceanographic mapping, undersea wreckage salvage, cable laying, geographical survey, coastal and offshore structure inspection, harbor security inspection, mining and mining countermeasures. It is obvious that all kinds of ocean activities will be greatly enhanced by the development of an intelligent underwater network system, which imposes stricter requirements on the control system of underwater vehicles. The control needs to be intelligent enough to gather information from the environment and to develop its own control strategies without human intervention. However, underwater vehicle dynamics is strongly coupled and highly nonlinear due to added hydrodynamic mass, lift and drag forces acting on the vehicle. And engineering problems associated with the high density, non-uniform and unstructured seawater environment, and the nonlinear response of vehicles make a high degree of autonomy difficult to achieve. Hence six degree of freedom vehicle modeling and simulation are quite important and useful in the development of undersea vehicle control systems. Used in a highly hazardous and unknown environment, the autonomy of AUV is the key to work assignments. As one of the most important subsystems of underwater vehicles, network communication system is a framework that manages both the sensorial and actuator systems for multi number AUVs, thus enabling the robot to undertake a user-specified mission.

In this paper we discusses the development of a acoustic communication channel model in short range and its properties for the evaluation and design of medium access control and routing protocols, to support network available Autonomous Underwater Vehicles (AUV)[2]. The growth of underwater survey has required data communication between various miscellaneous underwater and surface based communication network. In the future, AUV's will be expected to be deployed in a swarm fashion operating as an ad-hoc sensor network. In this case, the swarm network itself will be developed with corresponding network that is each being identical, as shown in Figure 1, with the swarm network then interfacing with other fixed underwater communication network. The focus of this paper is on the reliable data communication between AUVs that is essential to exploit the collective behavior of a swarm network communication. A simple arrangement, as shown in Figure 2, will be used to investigate swarm based operations of AUVs. The vehicles within the swarm will move together, in a self organizing, sensor network with all vehicles hovering at the same depth.

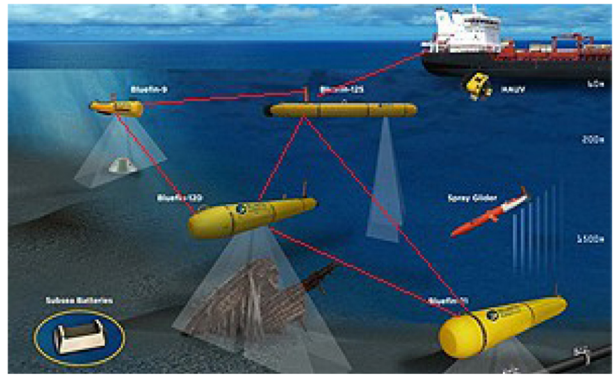

Figure 2. Swarm based arrangement.

The coverage area will depend on application. For example, the exploration of oil and gas deposits underwater using hydrocarbon sensing would initially require a broad structure scanning a large ocean footprint before narrowing the range between vehicles as the sensing begins to target an area. Thus vehicles may need to work as closely as 10 m with inter-network communication distance extending out to 500 m. These operating distances are substantially shorter than the more traditional operations of submarines and underwater sensor to surface nodes that have generally operated at greater than 1km. Thus, the modeling and equipment development for the communication needs of these operations has focused on longer range data transmission and channel modeling[3]. To exploit the full benefits of short range communication systems it is necessary to study the properties of short range communication channels. Most AUV development work has concentrated on the vehicles themselves and their operations as a single unit without giving much attention to the development of the swarm architecture which requires wireless communication networking infrastructure. To develop swarm architectures it is necessary to research effective communication and networking techniques in an underwater environment. Swarm operation has many benefits over single vehicle use. The ability to scan or 'sense' a wider area and to work collaboratively has the potential to vastly improve the efficiency and effectiveness of mission operations. Collaboration within the swarm structure will facilitate improved operations by building on the ability to operate as a team which will result in emergent behaviors that are not exhibited by individual vehicles. A swarm working collaboratively can also help to solve the problem of high propagation delay and lack of bandwidth available in underwater communication environments. Swarm arrangement will facilitate improved communication performance by utilizing the inherent spatial diversity that exists in a large structure. For example, information can be transmitted more reliably within swarm architecture by using multi-hop networking techniques. In such cases, loss of an individual AUV, which can be expected at times in the unforgiving ocean environment, will have less detrimental effect compared to a structure where multiple vehicles operate on their own.

In general, the performance of an acoustic communication system underwater is characterized by various losses that are both range and frequency dependent, background noise that is frequency dependent and bandwidth and transmitter power that are both range dependent. The constraints imposed on the performance of a communication system when using an acoustic channel are the high latency due to the slow speed of the acoustic signal propagation, and the signal fading properties due to absorption and multipath. Specific constraints on the performance due to the mobility of AUV swarms is the Doppler effect resulting from any relative motion between a transmitter and a receiver, including any natural motion present in the oceans from waves, currents and tides. Noise in the ocean is frequency dependent. There are three major contributors to noise underwater: ambient noise which represents the noise in the far field; self noise of the vehicle and intermittent noise sources including noises from biological sources such as snapping shrimp, ice cracking and rain. Ambient noise is therefore the component of noise taken into account in acoustic communication performance calculations. It is characterized as a Gaussian distribution but it is not white as it does not display a constant power spectral density. For the frequencies of interest for underwater acoustic data communication, from 10 to 100 kHz, the ambient noise value decreases with increasing frequency. Therefore, using higher signal frequencies, which show potential for use in shorter range communication, will be less vulnerable to the impact of ambient noise. Short range underwater communication systems have two key advantages over longer range operations; a lower end-to-end delay and a lower signal attenuation. End-to-end propagation at 500 m for example is approximately 0.3 sec which is considerable lower than the 2 sec at 3 km but still critical as a design parameter for shorter range underwater medium access control protocols[4]. The lower signal attenuation means potentially lower transmitter power requirements which will result in reduced energy consumption which is critical for AUVs that rely on battery power. Battery recharge or replacement during a mission is difficult and costly. The dynamics associated with attenuation also changes at short range where the spreading component dominates over the absorption component, which means less dependency on temperature, salinity and depth (pressure). This also signifies less emphasis on frequency as the frequency dependent part of attenuation is in the absorption component and thus will allow the use of higher signal frequencies and higher bandwidths at short ranges. This potential needs to be exploited to significantly improve the performance of an underwater swarm network communication system. A significant challenge for data transmission underwater is multipath fading. The effect of multipath fading depends on channel geometry and the presence of various objects in the propagation channel. Multipath occur due to reflections, refractions and acoustic ducting (deep water channels), which create a number of additional propagation paths, and depending on their relative strengths and delay values can impact on the error rates at the receiver. The bit error is generated as a result of inter symbol interference (ISI) caused by these multipath signals. For very short range single transmitter-receiver systems, there could be some minimization of multipath signals. For swarm operations, however, there is potentially a different mix of multipath signals that need to be taken into account, in particular, those generated due to the other vehicles in the swarm.

2. Mechanical System

For the convenience of maintenance and also under the security consideration, we separate the battery system from other electronics systems. Main frame is made of aluminum; fixing parts for camera and range sonar are made of PVC. To increase the hydrodynamic mobility in the underwater horizontal plane, the open frame of vehicle is wrapped in a two-piece of FRP (Fiber-Reinforced Plastic) shell. Throughout its underwater missions, AUV is always keeping zero pitch angle using two vertical thrusters. With this kind of stability in its pitch dynamics, the vehicle's horizontal 3DOF motion[5] is steered by two horizontal thrusters. From control point of view, this is a typical under actuated system. And how to design path tracking or following scheme for this kind of under actuated system has become one of most intense research area in the nonlinear control community.

3. Power System

For underwater vision, there is one color camera mounted at the vehicle nose. Three directional sonars (forward, backward and downward) are mounted on the vehicle. The sonars are designed for obstacle detection and also for assisting vehicle's underwater localization. For AUV, we design a relatively simple but low grade of inertial navigation system which consists of AHRS, 1-axis Gyro, 1-axis accelerometer, one depth sensor. This is a small size underwater thruster with 90W of average power consumption. For power system, the calculated total power consumption of vehicle system is about 450W. And correspondingly, we design the 1.2kW Lithium Ion battery system, which can support more than two hours of the vehicle's underwater continuous operation.

4. Embedded System

There are some of the AUV developed with embedded system for the network communication and collection data on sensor circuit transfer from AUV to server system. In this paper we develop embedded system for multiple AUVs to interact with each other using swarm method. The Arduino Boards come with AVR controllers is chosen as core modules, each of vision, navigation, and control shown Figure 3. AVR provides 4 RS232 channels plus 4 USB channels ARM 64bit Processor. And using these USB channels, we can easily extend the necessary serial channels (RS232/422/485) using proper USB to serial converters. PCM3718HG analogue and digital I/O board is used for various peripheral interface. In addition, two peripheral boards, including DC/DC converter system, 2GB RAM magnetic switch circuit, leakage detection circuit, are also designed.

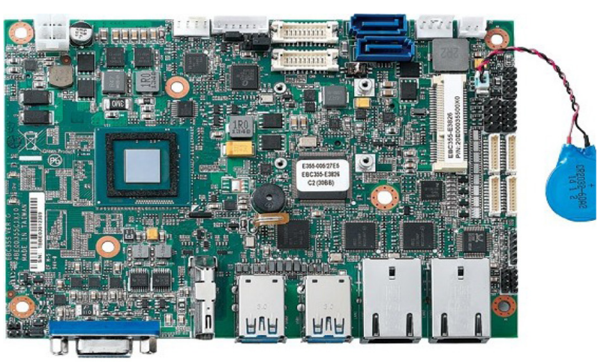

Figure 3. PCB Controller board.

5. Software Architecture

As aforementioned, we choose Windows Embedded CE 6.0 as the near real-time OS for three of core modules; vision module, navigation module, and control module. For this, we design three different WinCE 6.0 BSPs (Board Support Package) for each of three core modules. Furthermore, these three core modules which are connected to each other through Ethernet channel, and constructing a star topology of network structure. Development of a Hovering-Type Intelligent Autonomous Underwater Vehicle AUVs Software frame for each core module consists of thread-based multi tasking structure. For each module, there are various sensors connected through serial and analogue channels[6]. And these serial sensors, according to their accessing mechanism, can be classified into two types: active sensor (frequently output measurement) and passive sensor (trigger mode). For these passive sensors as well as analogue sensors, we read the measurements through Timer routine. And for each of active sensors, we design a corresponding thread. In most of time, this thread is in blocking mode until there is measurement output. And this kind of real-time sensor interface also can be used to trigger other algorithm threads. For example, in the navigation module, there is a thread designed for interfacing with AHRS sensor (100 kHz of output rate). After accessing each of attitudes, gyro, and accelerometer output measurement, the thread will trigger Navigation thread. Moreover, some of these threads are cautiously set with different priority values. As with the most of other AUVs so far, the AUVs has the similar overall software frame, which can be divided into two parts: surface remote control system and the vehicle software system. For surface system, the main functions of it are to monitor the vehicle and deliver the user command. According to the user command (mission command in this case), the vehicle will plan a series of tasks to accomplish the mission. For AUV, its most experimental field is in a small cuboids. In this kind of environment, it is well known that underwater acoustic channel is vulnerable. For this reason, the vehicle is required to possess relatively high level of autonomy, such as autonomous navigation, obstacle avoidance, path planning and so on.

From the control architecture point of view, the software architecture of AUV can be classified into hybrid architecture which is a certain combination of hierarchical and behavioral. As aforementioned, because of the limitation of underwater acoustic communication in

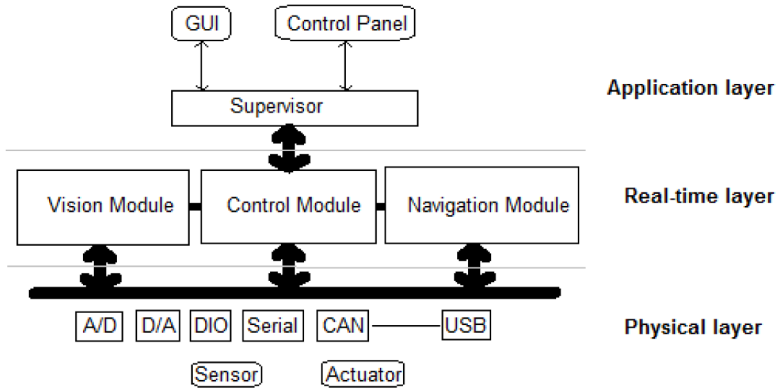

Figure 4. Application Architecture.

the engineering base, it is strongly recommended for the vehicles to self accomplish its mission without any of user interface in the water. For this consideration, the control architecture of AUV is featured as a behavioral architecture based hybrid system. If there is a pattern appeared in a certain area in front of the vehicle, the vision module will recognize the pattern and transmit the corresponding vehicle's pose information frequently to the control module for aiding of path planning. According to the received mission command (user command is usually delivered to the vehicle on the surface through RF channel), the control module arranges a series of tasks to accomplish the mission. Also, this module carries out various thruster controls and other actuator controls. The main task of the navigation module is to carry out the real-time navigating algorithm using acquired attitude, gyro, and accelerometer measurements. Other information including range sonar, depth sensor, underwater vision are served as aiding information for this inertial navigating system.

6. Auto-calibration of Underwater Camera

In underwater computer vision, images are influenced by the water in two different ways. First, while still traveling through the water, light is absorbed and scattered, both of which are wavelength dependent, thus create the typical green or blue hue in underwater images. Secondly, when entering the underwater housing, the rays are refracted, affecting image formation geometrically. When using underwater images in for example Structure-from-Motion applications, both effects need to be taken into account. Therefore, we present a novel method for calibrating the parameters of underwater camera housing[7]. An evolutionary optimization algorithm is coupled with an analysis-by-synthesis approach, which allows calibrating the parameters of a light propagation model for the local water body. This leads to a highly accurate calibration method for camera-glass distance and glass normal with respect to the optical axis. In addition, a model for the distance dependent effect of water on light propagation is parameterized and can be used for color correction.

7. Obstacle Avoidance Framework

The proposed obstacle avoidance framework built into the architecture of Figure is shown in Figure 5. It consists of an environmental map, a planning module, a localization module, sensors and actuators. The environmental map can include *a* priori knowledge, such as the positions of charted underwater obstacles, but also incorporate un-expected threats discovered by sonar. The positions of all obstacles are eventually resolved in the vehicle-centered coordinate frame with the help of the localization module[8]. The planning module is responsible for generating collision-free trajectories the vehicle should follow. This reference trajectory, possibly with reference controls, is then used to excite actuators.

The proposed obstacle avoidance framework supports both deliberative and reactive obstacle avoidance behaviors. Deliberative obstacle avoidance involves the ability to generate and follow a trajectory that avoids all known obstacles between an arbitrary start location and some desired goal location, whereas reactive obstacle

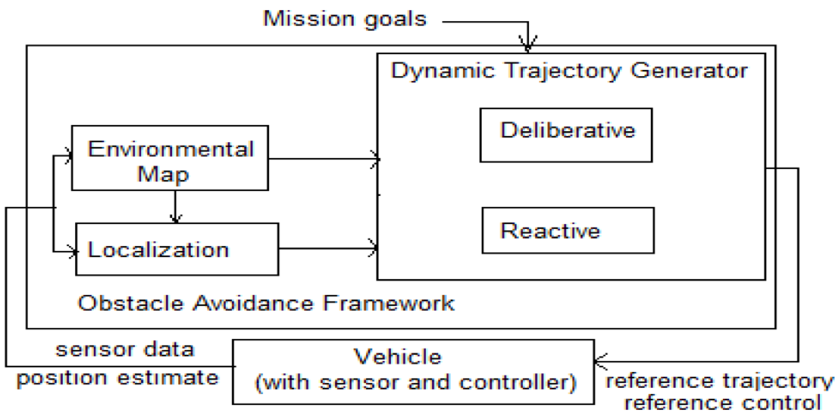

Figure 5. Obstacle avoidance architecture.

avoidance involves the ability to avoid any previously unknown obstacles detected while following this trajectory. Since the sonar system continuously resample's the environment, this reactive behavior can be achieved by a deliberative planner as long as i) it executes fast enough to incorporate all new obstacle information from the sonar, and ii) it generates feasible trajectories which begin with the vehicle's current state vector. Specifically, since the AUV have limited range and limited fields of view in both image planes, new trajectories must be generated continuously (e.g. on some fixed time interval or upon detection of a new obstacle) during execution of the current maneuver to ensure reactive avoidance of new obstacles. As an example of deliberative obstacle avoidance, assume a AUV vehicle is mapping a minefield with side scan sonar prior to a mine clearance operation. For this mission, the goal locations are provided by the sequence of waypoints making up a typical lawn-mowing survey pattern. If an obstacle is detected along a specified track line, the preferred obstacle avoidance maneuver for this mission would be one that also minimizes the cumulative deviation from this track line, since we desire 100% sensor coverage of the survey area. Hence, deliberative obstacle avoidance implies the optimization of some performance index. Likewise, while digital nautical charts or previous vehicle surveys can be used to identify some obstacles a priori, this data is usually incomplete or outdated. Vehicles should be capable of storing in memory the locations of any uncharted obstacles discovered during their mission so that subsequent trajectories can avoid them—even when they are no longer in the sonar's current field of view. Deliberative obstacle avoidance, therefore, also entails the creation and maintenance of obstacle maps.

8. Navigation

In the last decade, several different UUVs have been developed to perform a variety of underwater missions. Survey-class vehicles carry highly accurate navigational and sonar payloads for mapping the ocean floor, but these payloads make such vehicles very expensive. Vehicles which lack these payloads can perform many useful missions at a fraction of the cost, but their performance will degrade over time from inaccurate self localization unless external navigation aids are available. Therefore, it is interesting to consider collaborative operations via a team of vehicles for maximum utility at reasonable cost. The AUV has been investigating one such concept of operations called feature based navigation. This technique allows vehicles equipped only with a GPS receiver and low cost imaging sonar to exploit an accurate sonar map generated by a survey vehicle. This map is comprised of terrain or bottom object features that have utility as future navigational references. This sonar map is downloaded to the low-cost follow-on vehicles before launch. Starting from an initial GPS[9] position fix obtained at the surface, these vehicles then navigates underwater by correlating current sonar imagery with the sonar features from the survey vehicle's map. The localization accuracy of vehicles performing feature-based navigation can be improved by maximizing the number of times navigational references are detected with the imaging sonar. The following simulation demonstrates how the trajectory generation framework can be tailored to this application. By incorporating a simple geometric model of vehicle having a range of 60m, 30-degree horizontal and operating at a nominal ping rate of 1Hz, a new performance index was designed to favor candidate trajectories[10], which point the sonar toward navigational references in the a priori feature map. For this, we sought trajectories that could obtain at least three sonar images of each feature in the map. Figure 6 shows results of a computer simulation in which the number of times each target was imaged by the sonar has been annotated. The resulting trajectory is feasible (i.e. satisfies turn rate constraints) and yields three or more sonar images of all but two targets.

9. Underwater Communication Network

The underwater data communication link and networking environment presents a substantially different channel to the RF data communication channel in the terrestrial atmosphere. Figure 7 illustrates a typical underwater environment for data transmission using a single transmitter-receiver pair.

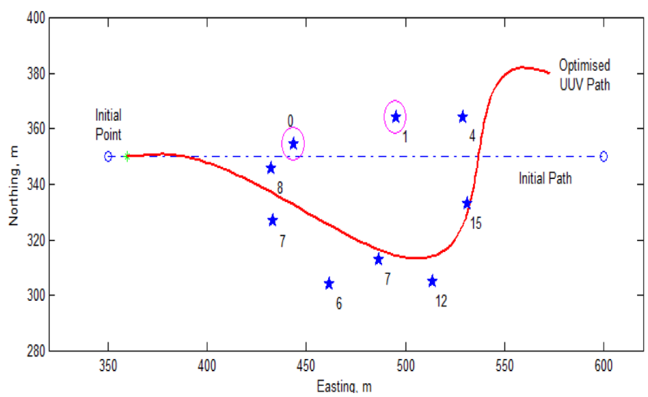

Figure 6. Computer simulation.

The transmitter takes the collected sensor and navigational data and formats it into packets at the Data Source and this is then modulated with the carrier frequency. The modulated signal is amplified to a level sufficient for signal reception at the receiver[11]. There is an optimum amplification level as there is a trade-off between error free transmission and conservation of battery energy. The acoustic power radiated from the transmitter as a ratio to the electrical power supplied to it, is the efficiency of the transmitter and represented by the Electrical to Acoustic conversion block. On the receiver side, the sensitivity of the receiver converts the sound pressure that hits the receiver to electrical energy. Signal detection, includes amplification and shaping of the input to determine a discernible signal. Here a detection threshold needs to be reached and is evaluated as the ratio of the mean signal power to mean noise power. The carrier frequency is then supplied for demodulation, before the transmitted data is available for use within the vehicle for either data storage or for input into the vehicles control and navigation requirements. Underwater data communication links generally support low data rates mainly due to the constraints of the communication channel. The main constraints are the high propagation delay, lower effective and lower bandwidth. The effects of these constraints could be reduced by using short distance links and the use of multi-hop communication techniques to cover longer transmission ranges. For an AUV swarm network, use of the above techniques could be crucial to design an effective underwater network. To develop a multi-node swarm network it is necessary to manage all point to point links using a medium access control medium access control protocol. In a multi-access communication system like a

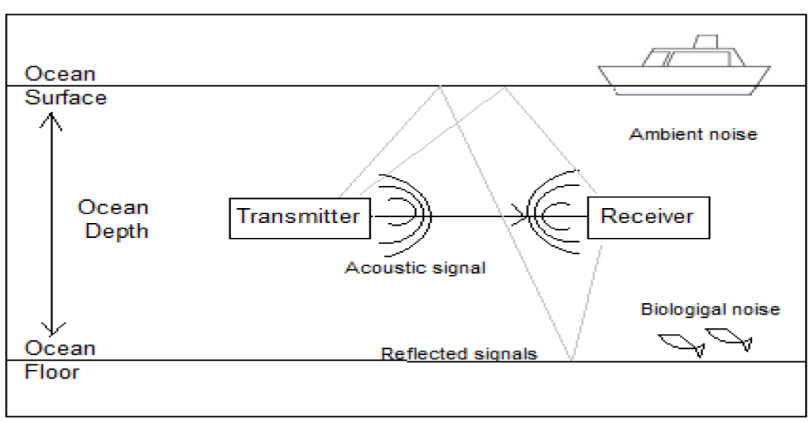

Figure 7. Typical underwater environment.

swarm network a transmission channel is shared by many transceivers in an orderly fashion to transmit data in an interference free mode. When a network is scaled up to support N number of AUVs then it becomes necessary to control multiple point to point or point to multi-point links. To control the transmission of data it is necessary to design an effective medium access control protocol which can control transmission of information from different AUVs. The design of a medium access control protocol in a swarm network could be more complex if a multi-hop communication technique is used.

The multi-hop communication technique will allow a scalable network design as well as it can support long distance transmission without the need of high power transmitter and receiver circuits the main factor used to select an optimum path in a wireless network is the sensor-noise radio which indicates the quality of a link[12]. Similarly the medium access control protocol will use the transmission channel state information to develop an optimum packet access technique. To effectively design these protocols it is necessary to understand the properties of short range underwater channel characteristics. Before moving into the protocol design issues we will first evaluate the short range underwater channel characteristics in the following Sections.

10. Underwater Multipath Characteristics

Multipath signals, in general, represent acoustic energy loss; however, for communication systems it is the Inter Symbol Interference (ISI) that will also be detrimental at the receiver as it can significantly increase the error rate of the received signal. Multipath signals are created underwater through various mechanisms described in this section, so that, at the receiver many components of the original signal will arrive at different times due to the different length of propagation paths the multipath signals have taken. It is this delay spread of the signal component arrivals that can cause ISI to occur if they overlap with previous or future signal arrivals which will cause symbol corruption or loss and therefore bit errors. As the speed of sound propagation is very slow in an acoustic channel this delay spread can be significant. There are two major mechanisms responsible for creating multi-path signals and these are: reverberation, which refers to the reflections and scattering of the sound signal; and ray bending, which is a result of the unique sound speed structure in the oceans which create temperature gradient channels that trap acoustic signals. Multi-path signal formation is therefore determined by the geometry of the channel in which transmission is taking place, the location of the transmitter and receiver, and importantly the depth at which it is occurring. In shallow water, multi-path is due predominately to reverberation whereas in deep water it is dominated by ray bending, although reverberation will occur in deep water if the transmitter and receiver are located near the surface or bottom.

There are several physical effects which create reverberation underwater:

- Multi-path propagation caused by boundary reflections at the sea-floor or sea-surface
- Multi-path propagation caused by reflection from objects suspended in the water, marine animals or plants or bubbles in the path of the transmitted signal
- Surface scattering caused by sea-surface (waves) or sea-floor roughness or surface absorption, particularly on the sea bottom depending on material
- Volume scattering caused by refractive off objects suspended in the signal path Ray bending, causes various propagation path loss mechanisms in deep water depending on the placement of transmitter and receivers. The propagating acoustic signal bends according to Snell's Law, to lower signal speed zones.
- Deep Sound Channel, sometimes referred to as the Sound Fixing and Ranging channel, where acoustic propagation occurs above and below the level of minimum sound speed, when the sound rays continually are bent towards the depth of minimum speed.
- Convergence zone, in deep water areas when the transmitter is located quite close to the surface and the sound rays bend downwards as a result of decreasing temperatures until the increase in pressure forces the rays back towards the surface.
- Reliable acoustic path, which occur when the transmitter is located in very deep water and receiver in shallow water.
- Shadow zones that are considered a special case, as these zones are void from any signal propagation. This means that in Shadow zones a receiver may not receive any signal at all.

Thus the geometry of the channel being used is a major determinate of the number of significant propagation paths and their relative strengths and delays. Apart from the Shadow Zones where no signal or multipath components of the signal can reach the receiver, the receiver may receive the direct signal and a combination of various multipath signals that have been reflected, scattered or bent. It is these multiple components of the signal that are delayed in time due to the various path lengths that may create ISI and errors in symbol detection[13]. For very short range channels that will be used in AUV swarm operations, multipath will be influenced also by the range-depth ratio, which is expected to produce fewer multipath signals at the receiver. In addition some improvement can be gained through directing the beam of the transmitted signal and the directional properties of the receiver this will require an additional level of complexity for mobile AUV's due to the need for vehicle positioning before sending or when receiving a signal. Most of the discussion so far has focused on time-invariant acoustic channel multipath where deterministic propagation path models have been developed for the various reflective and ray bending path options. These are significant in themselves with multipath spreads in the order of 10 to 100 ms. where projector and hydrophone are separated by 100m and are at a depth of 100m, the delay spread between the direct path and the first surface reflection is ≈ 28 ms. Multipath in an underwater channel, however, also has time-varying components caused by the surface or volume scattering or by internal waves in deep water that are responsible for random signal fluctuations. Unlike in radio channels, the statistical characterizations of these random processes in the underwater channel are in their early development stages. Experimental results have shown that depending on the day, the location and the depth of communication link, the results of multipath can follow one of the deterministic models discussed here to worst case coherence times in the order of seconds. Another source of time variability in an underwater communication channel occurs when there is relative motion between the transmitter and receiver as will be briefly discussed in the following sub-section.

11. Design Techniques for Swarm Network

A short range underwater network is essentially a multi-node sensor network for interaction between the collection of underwater vehicles. To develop a functional sensor network it is necessary to design a number of protocols which includes medium access control, data link control and routing protocols. A typical protocol stack of a sensor network is presented in Figure 8. The lowest layer is the physical layer which is responsible for implementing all electrical/acoustic signal conditioning techniques such as amplifications, signal detection, modulation and demodulation, signal conversions. The second layer is the data link layer which accommodates the medium access control and data link control protocols. The medium access control is an important component of a sensor networks protocol stack, as it allows interference free transmission of information in a shared channel. Design of the data link control functionalities are very closely linked to the transmission channel conditions. The network layers main operational control is the routing protocol; responsible for directing packets from the source to the destination over a multi-hop network. Routing protocols keep state information of all links to direct packets through high sensor-noise radio links in order to minimize the end to end packet delay. The transport layer could use standard protocols such as Transmission Control Protocol or User Datagram Protocol. The application layer hosts different operational applications which either transmit or receive data using the lower layers[14]. To develop efficient network architectures, it is necessary to develop network application and network layers. The following subsections will present medium access control and routing protocol design characteristics required for underwater swarm networking.

12. Medium Access Control Protocol

Medium access protocols are used to coordinate the transmission of information from multiple transmitters

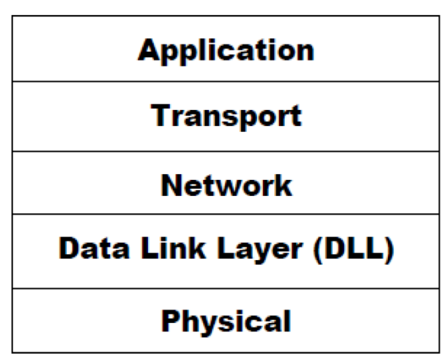

Figure 8. Network protocols.

using a shared communication channel. The protocols are designed to maximize channel usage by exploiting the key properties of transmission channels. The protocols can be designed to allocate transmission resources either in a fixed or in a dynamic manner. Fixed channel allocation techniques such as Frequency Division Multiplexing (FDM) Or Time Division Multiplexing (TDM) are commonly used in many communication systems where ample channel capacity is available to transmit information. For low data rate and variable channel conditions, dynamic channel allocation techniques are generally used to maximize the transmission channel utilization where the physical transmission channel condition could be highly variable. Based on the dynamic channel allocation technique it is possible to develop two classes of protocols known as random access and scheduled access protocol. The most commonly used random access protocol is the Carrier Sense Multiple Access widely used in many networks including sensor network designs. Most commonly used scheduled access protocol is the polling protocol. Both the Carrier Sense Multiple Access and polling protocols have flexible structures which can be adopted for different application environment[15]. As discussed in this chapter, the underwater communication channel is a relatively difficult transmission medium due to the variability of link quality depending on location and applications. Also, the use of an acoustic signal as a carrier will generate a significant delay which is a major challenge when developing a protocol.

13. Conclusion

Autonomous off-board sensor systems are attractive candidates to complement high-value assets in underwater surveillance and the ability to integrate them into a scalable, persistent, and cost-effective networked system. AUVs are currently not yet capable of operating autonomously in potentially complex dynamic environments. This paper has described the on-board signal processing including a navigation and network communication which were successfully implemented. The vehicle has been designed and simulation has been studied by computer analysis as per the required parameters and condition. The simulation of swarm network communication and navigation multipath trajectory has been performed. Future work will be focused on fully automatic underwater vehicle with robot arm manipulator for the application of underwater surveillance and mineral studies.

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