An Underwater Vehicle for analyzing underwater environment

Varade G.A

Department of Electronics & Telecommunication
Sir Visvesvaraya Institute of Technology, Chincholi, Nasik India.

Abstract

One of the safest ways to explore the underwater is using small unmanned vehicles to carry out various missions and measurements. With the advent of underwater vehicles, the researcher's capability to investigate the deep waters is extremely improved. Today underwater vehicles are becoming more popular specially for environmental monitoring and for defense purposes. Here, AQUA is proposed, which is an amphibious robot that swims via the motion of its legs rather than using thrusters and control surfaces for propulsion, can walk along the shore, swim along the surface in open water, or walk on the bottom of the ocean. The vehicle uses a variety of sensors to estimate its position with respect to local visual features and provide a global frame of reference.

Keywords*:* UnderwaterVehicles (AUV); Site Acquisition and Scene Reinspection (SASR); Degree of Freedom (DOF); Yaw; Heave; Surge; Pitch.

1. Introduction

Oceans are the main resource of the energy that sustains mankind whose future is very much dependent on the living and non-living resources in the oceans. Therefore, various studies have been conducted for ocean exploration and intervention. Underwater vehicles have been a popular and effective means for ocean exploration and intervention as they make it possible to go far beneath the ocean surface, collect first-hand information about how the oceans work, and furthermore perform intervention modeling the impact of weather and ground activities on the water quality, underwater geochemical prospecting, security applications, oil and gas installation monitoring and repair. Also the inspection of pipeline, channels and dam wall, underwater parts of petroleum platforms can be carried out effectively [G. Dudek et al, 2006.].

In recent years, investigation of robotic technologies has shown the utility of robots in various environments, particularly those inaccessible to humans, such as the outer space and deep oceans. In general humans are limited to short visits underwater and only to limited depths. In the fields of ocean development and ocean investigation, various autonomous underwater vehicles have been developed to survey complex and dynamic undersea environments. Many different underwater applications can be automated with the use of these robots. The proposed work describes the development of an underwater aqua robot which can be used for analyzing the underwater environment.

There are numerous research communities working on the design and construction of underwater vehicles for different purposes. Key papers in this field are primarily found in the proceedings of annual conferences. These include the following conferences:

- IEEE Oceanic Engineering Society (OES) Autonomous Underwater Vehicle (AUV) symposia and OCEANS conferences [http://www.oceanicengineering.org].
- AUV Laboratories MIT.

Autonomous Undersea Systems tasks. Underwater environment holds many opportunities for deployment of robotic agents [www.ausi.org/auvs/auvs.html], Thus a robotic vehicle is proposed which has the potential to operate autonomously in underwater environments. Such robots will permit the exploration and monitoring of underwater environments, surveillance of ports,

- Institute (AUSI) [www.ausi.org/auvs/auvs.html].

Also many papers and publications about the Autonomous Underwater Vehicles (AUV) can be found from Center for Autonomous Underwater Vehicle Research of Naval Postgraduate School .The idea for aqua is taken from [G. Dudek et al, 2006.].

A first generation land-based prototype has been constructed and field tested in 2005 by the NPS [Boxerbaum,Alexander S et al, 2005]. A water resistant second generation amphibious prototype design is further enhanced by the use of visual sensors.

2. Modeling of The System

A. THE VEHICLE

AQUA is an autonomous robot performing a typical SASR (site acquisition and scene reinspection) task, in which it walks out into the water under operator control and is directed to a particular location where it will make sensor measurements. Once near the site, the robot achieves an appropriate pose from which to undertake extensive sensor readings. After making the measurements, the robot returns home autonomously. Later, the robot autonomously returns to the site to collect additional data.

A biologically inspired robot capable of both legged and swimming motions[C. Prahacs et al., 2005; M.Theberge & G.Dudek, 2006] AQUA is based on RHex, a terrestrial six-legged robot developed between 1999 and 2003, in part by the Ambulatory Robotics Lab at McGill University in collaboration with the University of Michigan, the University of California at Berkeley, and Carnegie Mellon University [R.Altendorf et al, 2001; U Saranli et al, 2001]. In addition to surface and underwater swimming, AQUA's capabilities include diving to a depth of 30 meters, swimming at up to 1.0 m/s, station keeping, and crawling on the bottom of the sea. Unlike most underwater vehicles, AQUA does not use thrusters for propulsion; instead, it uses six paddles, which act as control surfaces during swimming and as legs while walking. The paddle configuration gives the robot direct control over five of its six DOF: surge (back and forth), heave (up and down), pitch, roll, and yaw. Like a bicycle or an automobile, it lacks the capacity for lateral (side to side or sway) displacement. Its operators use an onboard inclinometer and a compass to control the robot's motion underwater. The robot is approximately 40 cm long, 30 cm wide (at the fins), and 13 cm high. It has an aluminum waterproof shell and displaces about 16 kg of water. Onboard batteries provide more than three hours of continuous operation. Figure 2.1 shows the internal structure of AQUA.

The hardware also consist of the pressure &

temperature sensors. A visual sensor is also to be incorporated. The visual sensor has a associated secondary sensor that will capture the images neglecting the buoyant force of water.

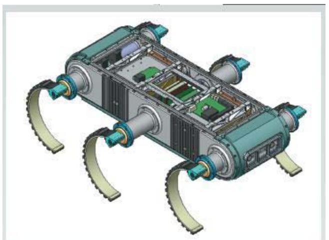

Fig.2.1 AUQA- an amphibious robot

B. BLOCK DIAGRAM AND DESCRIPTION

The block diagram as shown in figure 2.2 gives us the short idea of working of underwater robot. The brief description of block diagram is as follows.

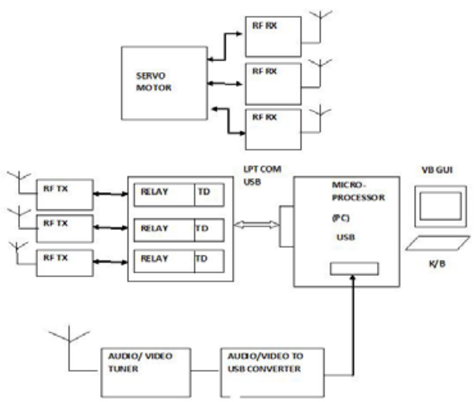

Fig 2.2 System block diagram

a. Power supply Unit*:*

Any system requires power for its operation. Here the robot has its own power supply. A 12volt battery has been used as the source voltage for the power of different modules on board the robot.

b. RF Transmitter/ Receiver Module*:*

A RF transmitter and receiver module is used for the wireless communication between the end user and the robot. RF module also used for transmission of video feedback to the control unit form the robot unit.

c. PC with keyboard:

The movement of robot is controlled by keypad of the PC at the control unit.. Using the keypad of the PC the end user can control the movements of the robot.

d. Servo Motors:

Motors are used for the movement of the robot from one place to another. The robot wheels are run by the servo motors, thus providing locomotion to the robot.

e. Search Light:

The robot is also equipped with a searchlight, which is used for night mode or where visibility is low. A control signal is generated by the application, which is sent by the processor to switch the light on and off.

f. Wireless Camera:

The wireless camera is used to get live video. The camera includes wireless transmitter module having 2.3 GHZ carrier frequency. This is used to send video feedback to the computer screen.

C. SENSOR SUITE

When designing autonomous underwater systems one of the more important aspects is the sensor suite. When one is working on a tight budget it can be crippling. A simple echo sonar unit alone can be from USD$2000 upwards. Here we look at some cheaper options. The most expensive is the sonar unit. There is however a commercial unit used by fishermen to find fish that retails at under USD$30. This unit, the Smart Cast made by Hummingbird, can be modified to create an echo sonar unit with a range of 30mA simple search can produce low cost pressure sensors to determine the depth of the robot .Navigation can be an issue. Ordinary GPS will not work underwater and underwater sonar; (a GPS on the surface with underwater sonar location) is expensive and limits the range of the robot. A dead reckoning system using accelerometers can be simply designed and the robot can surface for a GPS fix when errors get to large. These three systems allow a robot to know its location, to navigate to another location and to perform obstacle avoidance. The systems here have been designed to work with a robot as described in Joordens, et al.[Boxerbaum et al.,2005].

a) SONAR

In order to work on an echo sonar unit for collision avoidance several Hummingbird Smart Cast remote sonar sensors, which are normally used by fisherman to determine the depth of the water and if there are any fish in the area, where acquired. The goal is to use these sonar sensors to keep track of the surroundings of the robot as it maneuvers underwater. In other words, the sonar devices can be used as the "eyes" of the underwater robots. In order to do this, the lab had to reverse engineer the inner workings of the sonar devices. This can be done by opening up the sonar sensor, analyzing its circuit, connecting the pins of the sonar sensor's microprocessor to an oscilloscope, reading the patent for the sonar sensor, and interpreting the information gathered.

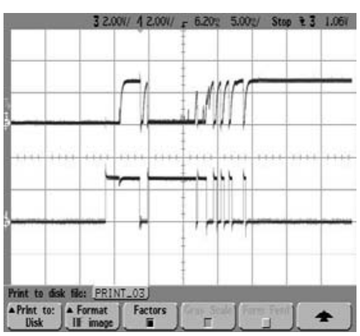

Fig. 2.3 Sonar unit output

The sonar sensor gathers information by sending out pulses of sound and receiving the reflected echoes of these sound waves back through a piezoelectric crystal (quartz) transducer. The transducer converts the sound waves that are reflected back to the sonar device into analog voltage signals. These voltage signals are then converted into digital voltage signals. The receiving microprocessor of the Smart Cast sonar system uses the time that it takes for the sonar pulses to be reflected back to determine the distance between the sonar device and the object that the sonar pulses are being reflected off of. The width, or strength, of the pulses is also used by the microprocessor to determine the relative size of the object that the sonar pulses are reflecting off of. For example, the longest pulse width will indicate that the object is the seabed, whereas smaller pulse widths could indicate that the object is a small fish (Fig. 2.3).

The top trace is the signal on the sonar transducer. The lower trace is the sonar units output. The first pulse is a synchronization pulse. The following pulses are acoustic echo returns. The time between the synchronization pulse and the following pulses is the time of a round trip of an acoustic wave from the sonar unit to the object and back. The width of the pulse equates to the magnitude of the return echo. Thus the largest width represents the sea bed if it is in range. Other returns are either fish, other robots or are caused by spurious reflections.

The distance measurements gathered by the sonar sensor, and interpreted by the microprocessor, are then sent through a serial connection to a computer and displayed on screen by the HyperTerminal program that normally comes standard with Windows' operating systems.

b) pH SENSOR

The high accuracy pH probe IH20 is used as a pH sensor which has output voltage from -412mV to 412mV. The theoretical output of the IH20 pH probe is approximately 59.16 mV/pH at 25°C, i.e. for acid output voltage is positive, for neutral it is null and for bases it becomes negative with 59mV per unit pH starting from null. This output voltage is affected by environmental temperature thus it is required to compensate the temperature factor. The necessary arrangement is done to compensate the temperature effect. Output of IH20 sensor is converted into 0~2.5V range which is further given to processor for processing.

3. Possible Communication Approaches with Underwater Robot

The possible approaches of developing an underwater robot depend on the type of communication technique used. Underwater communications can be implemented in various ways as:

a) Electric Current Communication

The electric current method uses the fact that seawater is a conductive medium. The modulated signal wave is applied to a pair of transmitting electrodes that launch a current field in the channel. If this current field is strong enough, the receiver could measure a potential difference and receive the signal. Since electric current noise is extremely low in seawater, small current field amplitudes are sufficient to receive information and large data rate is achievable. Large currents are needed on transmitter side to generate current fields strong enough to penetrate a sufficient distance in the water. It completely fails in non-conductive like for e.g. non-salty water.

b) Fiber-Optic Communication

Optical fibers are generally used for communication. The phenomenon of total internal reflection is used to transfer signals from one end to other. The signal to be transmitted is first converted into light waves and then it is passed into the fiber tube at its opening. The light signal then follows a series of total internal reflections and transmitted forward. At the rear end of the fiber tube the light signals are converted back to their original form. Thus in this way any signal can be easily passed through optical fiber. It is the most reliable and efficient technique of communication.

c) Radio Communication

The wireless transmission has been accomplished by using transmitters and receivers. These transmitters work at 434MHz and have the following features: Operates from 2.7-5.2 VDC, Low Power Consumption, Ultra-Compact Direct Serial Interface, Supports data-rates up to 5 Kbps. The control data from the transmitter is sent to Wireless Transmitter i.e. through serial port, then transmitted to the receiver installed on the base of the robot. The transmitter sends the control data to the processor which then controls the movement of motors. The major disadvantage of RF technology is limited range.

d*) Electromagnetic Waves Communication*

The reason why mainly electromagnetic waves are used in classic wireless air channel in their fast propagation speed, in the wide usable frequency spectrum and in the small environment noise compared for example with acoustics, factors that all lead to high possible data rates. Furthermore, the electromagnetic wave has the ability to propagate without a carrier medium and the electric-magnetic field conversion enables, in general, very large communication ranges. Thus large transmission power and the short possible communication distances are required while using electromagnetic waves underwater.

e) Acoustic Communication

The most common method to communicate underwater is the acoustic approach. In this method a sound projector converts electric signals into pressure signals and a hydrophone receives the pressure signals and converts them back into electric signals. The sound projectors and hydrophones are often called transducers since they are able to act both as a hydrophone and a projector but in most cases a device is matched to one of the two functionalities. Both hydrophones and projectors are mostly built by using piezoelectric material. Sound has by far the largest underwater propagation range compared to the used transmission power. Acoustic propagation faces lots of problems compared to radio communication.

Table 4.1 shows the frequency ranges and data rates supported by different communication techniques.

Communication Technology	Frequency Range	Data Rate
1. Electromagnetic Waves	Above 2.4 GHz	100 Mbps
2. Optical Communication	0.1 – 6 GHz	400 Mbps
3. Acoustic Communication	20 KHz – 200 KHz	40 Mbps

4. Acoustic Vehicle Localization

A. Scenario For Underwater Localization

Underwater acoustic channels are characterized by harsh physical layer environments with stringent bandwidth limitations .The variable speed of sound and the long propagation delays under water pose a unique set of challenges for localization in UWSN .Radio Frequency RF can work at the most on the ocean surface but fails for underwater [G. Dudek et al., 2006.] hence RF is not preferred for underwater scenario. For UWSN acoustic communication is preferred over optical and RF communication. Following are the reasons why acoustic communication is preferred over RF and optical waves: RF waves can travel in sea only at extra low frequencies (30-300 Hz). Hence large antenna and high transmission power is required. Other reasons are limited bandwidth, propagation delay (5 orders of magnitude greater than on terrestrial), very high bit error rates and temporary loss of connectivity. Hence, message exchanges between submerged UWSN nodes and surface nodes needed for localization must be carried out using acoustic communications.

There are many other challenges faced by UWSNs. The underwater channel is severely impaired, especially due to multi-path and fading. Battery power is limited and usually batteries cannot be recharged. Solar energy cannot be exploited. The issue of energy efficiency and the optimal data packet size/length in underwater wireless network communications in the context of effective and efficient data transmission is highlighted in . UW sensors are prone to failures due of fouling and corrosion. Sensor nodes have very limited storage capacity. UW sensors may need to be able to do some data caching as the underwater channel may be intermittent and while the readings from UW sensors are often correlated. Spatial correlation is more unlikely to happen in underwater networks due to the higher distance among sensors. Unfortunately, underwater acoustic channels are characterized by long propagation delays, limited bandwidth, motion-induced Doppler shift, phase and amplitude fluctuations, multipath interference, etc.

To overcome the above challenges in underwater scenario, few architectures and localization methods proposed are surveyed [www.ausi.org/auvs/auvs.html]. Most of these methods concentrate on localization based on the architectural behavior (Anchor node positioning / mobility) or network behavior (Centralized / Decentralized). Our algorithm, apart from being distributed in 3D, extends to improve over the results obtained during trilateration method.

B. Localization using SASRS

A critical problem in a SASR task is relating scene structure recovered at different times to a common (global) reference frame. To localize the robot within a global frame, the AQUA project has developed a global acoustic localization sensor. The acoustic localization component consists of arrays of commercially available omnidirectional hydrophones attached under a surface floating buoy, the absolute position of which can be measured via a combination of GPS, compass, inclinometers, and inertial sensors. Suppose that the vehicle is augmented with an acoustic source. Using time-delay estimation on a planar hydrophone array receiving sounds the vehicle emits, one can estimate the direction line in a 3D space emanating from the array's reference point and pointing toward the vehicle. If multiple arrays are available, the sound source's position as the intersection of their respective direction lines can be estimated. Computationally, the optimal estimate of the source position is the point that has minimal overall distance from these lines. The overall distance to the unknown source position $P(x, y, z)$ is a quadratic function leading to a linear system of equations in x, y, and z that can be solved using standard techniques. To calculate reliable time delays between the arrivals of the sound signals, two channels of audio data from two different hydrophones are correlated and peaks of the correlation function are identified.

The peak's location corresponds to the time-delay estimate. Before correlation, the sound signals are filtered to reduce noise and then a signal variance test is performed to detect the presence of a sound source. Valid time delays from a hydrophone pair must be no greater than the maximum time delay, equal to the length of the baseline divided by the speed of sound in water. This reduces the likelihood of false peaks. The final step for the time-delay estimation is to cluster the time delays estimated from a number of consecutive, no overlapping signal time windows. The outliers are to be discarded and the mean value over the remaining windows can be computed as the final time-delay estimate. Experimental results include software simulations, pool tests using hydrophones, and in the air using microphones with geometry similar to the pool (properly scaled to account for the different sound propagation speeds in the two media).

5. Results

The robot can sustain in terrestrial as well as aquatic environment. Its gives an indication on entering water. **AQUA** is tested in purely aquatic environment.

Changes in depth of the vehicle, caused by coupling motion can be compensated by manual control by means of a joystick generally causing a relatively high oscillatory motion in depth, but during the test cases with the model developed in Simulink, it is observed that to control the vehicle at a certain depth is quite hard when the operator has to give a turning command to a desired position in yaw. It becomes harder to perform a desired mission if both depth change and turn maneuver is needed.

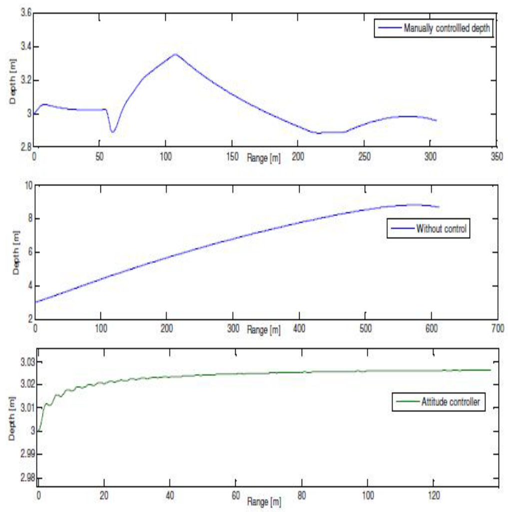

Fig. 5.1 Depth change of vehicle during its mission for manual, automatic attitude controller and without any control.

Figure 5.1 illustrates three different test missions of the vehicle including manual control, attitude control, and without any control. Both of them are trying to keep the vehicle's initial depth of 3 meters. These three tests are performed with a propeller speed of 750 rpm. It can be seen from the mentioned figure that the attitude controller has the most efficient behavior which settles the depth in range of 120 meters and with an error of 20 cm while the other manual and free controls are settled the vehicle in its desired depth in 300 and 600 meters respectively. On the other hand as discussed at the second paragraph, initial negative pitching moment causes the vehicle to settle at a depth of 9 meters if no control is applied.

6. Conclusions and Future Scope

A. CONCLUSIONS

AQUA is tested in both terrestrial and aquatic modes. The robot encounters as it enters and exits the water. The robot, its visual sensors and all other components can be tested in deep water as well. The robot along with its sensors can give appreciable results even in less clear waters.3-D visualization environment is used to illustrate the motion of the underwater vehicle in a 3-D environment. MATLAB is used for implementing the full 3-D solid model of the underwater vehicle into the simulation package. One of the important results by means of six Degrees Of Freedom (it is simulation of the fins of aqua using MATLAB for acquiring control over the motion of aqua) simulations is contribution to the understanding of the coupling effects between the degrees of freedoms such as effect of yawing motion on the rolling motion of the vehicle.

The user is able to switch between the controllers and can also inhibit the control commands using the buttons on the joystick. So the controlled and uncontrolled performance of the vehicle can be observed during the simulation. Some test cases are performed after completing the simulation package. The results of these simulations are stored including the given commands and the respective responses of the vehicle throughout the simulation.

B. FUTURE SCOPE

Likewise, an underwater sensor network consisting of a group of aqua robots can be formed. For proper target tracking and avoiding collision of the vehicles in a network collision avoidance algorithm can be implemented as in [Yonghui Hu et al., 2009].The AUVs can be located properly using proper sensitization algorithm. Here localization will be a must-to-do task to get useful location aware data. Different underwater localization techniques can be used as in [C. Alt et al., 2001].A simple underwater robot model can be used for underwater tank cleaning [Schjølberg and T. I. Fossen,1994] or water pipeline cleaning purposes [Tamiya Fukushima Tamotsu Ogasawara et al.].Another future work can be the development of a real underwater platform to see the real performance against the obstacles and other types of constraints that must be avoided in real life missions for specific undersea operations.

References

[1] G. Dudek, P. Giguere, and J. Sattar, (2006) “Sensor-Based Behavior Control for an Autonomous Underwater Vehicle, Proc. 10th Int’l Symp. Experimental Robotics, Springer-Verlag.

[2] Autonomous Undersea Systems Institute, a survey of different Autonomous Underwater Vehicles, August 2009http://www.ausi.org/auvs/auvs.html.

[3] Boxerbaum, Alexander S., Werk, Philip, Quinn, Roger D., Vaidyanathan, Ravi (2005) “Design of an Autonomous Amphibious Robot for Surf Zone Operation: Part I, Mechanical Design for Mulit-Mode Mobility” submission for IEEE ASME AIM2005 conference, Monterey,California, USA, 24-28 July 2005.7.

[4] Center for Autonomous Underwater Vehicle Research. (2005) http://www.cs.nps.navy.mil/research/auv/auvframes.html, Last accessed date: August 2007.

[5] C. Prahacs et al., (2005) “Towards Legged Amphibious Mobile Robotics,”J. Eng. Design and Innovation (online), vol. 1, part.

[6]. M. Théberge and G. Dudek, (2006) “Gone Swimming’,” IEEE Spectrum, June 2006, pp. 38-43.

[7]. R. Altendorfer et al. (2001), “RHex: A Biologically Inspired Hexapod Runner,” Autonomous Robots, vol. 11, no. 3, 2001, pp. 207-213.

[8] U. Saranli, M. Buehler, and D. E. Koditschek, “RHex: A Simple and Highly Mobile Hexapod Robot,” Int’l J. Robotics Research, vol. 20, no. **7**, 2001, pp. 616-631.

[9] Yonghui Hu, Wei Zhao, and Long Wang,” Vision-Based Target Tracking and Collision Avoidance for Two Autonomous Robotic Fish”, IEEE transactions on Industrial Electronics, VOL. 56, NO. 5, MAY 2009.

[10] Laboratory at MIT Sea Grant, http://auvlab.mit.edu/, Last accessed date: September 2007.

[11] C. Alt, B. Allen, T. Austin, N. Forrester, R. Goldsborough, M. Purcell, and R. Stokey (2001), “Hunting for mines with REMUS: A High performance, affordable, free swimming underwater robot,” in Proc. MTS/IEEE Conf. Exhibition on OCEANS, Honolulu, HI, Nov. 2001, pp. 117–122.

[12] Ocean Engineering Society. http://www.oceanicengineering.org/, Last accessed date: September 2007.

[13] I. Schjolberg and T. I. Fossen (1994), “Modeling and control of underwater vehicle- manipulator systems,” in Proc. 3rd Conf. Marine Craft Manouvering and Control, Southampton, U.K., 1994, pp. 45–57.

[14] Tamiya Fukushima Tamotsu Ogasawara", Minoru Kubota, Masaru Totsuka, Bank-foot Water Channel Cleaning Work Truck - Sediment absorbing robot and dehydration plant.