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Control Aspects of Unmanned Underwater Vehicles Deployed for Tsunami Surveillance and Detection

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***Abstract*— Recent decades have witnessed increased interest in design and testing of Underwater Unmanned Vehicles. Significant advances in various related science disciplines have propelled the development of more sophisticated, yet reliable and practical underwater vehicles. A great variety of vehicle types and applications has been produced along with a wide range of innovative approaches for enhancing the performance of unmanned underwater vehicle. The purpose of this paper is to describe and provide an overview of the features, challenges and risks of controlling UUV and the main accessories and components involved in it for tsunami detection.**

Keywords—Unmanned underwater vehicles, Tsunami detection, Fuzzy logic system, proportional-integral-derivative controller, Seismometers, Electro acoustic transducer,Tsunameter.

I. INTRODUCTION

The ocean covers about two-third of the earth and has great effect on the future existence of all human beings. About 37% of the world's population lives within 100km of the ocean. The ocean is generally unnoticed as we focus our attention on land and atmospheric issues; we have not been able to explore the full depths of ocean. The underwater explorations can be easily done by Autonomous underwater vehicle as it is difficult for human beings due to high water pressure and unpredictable under water activities. Autonomous underwater vehicles [1] fall in to mobile robotics sector and are of brilliant importance to the present world.

An Autonomous underwater vehicle is a robot [2] which travels underwater without requiring input from an operator. Autonomous underwater vehicle constitute part of a larger group of undersea systems known as unmanned underwater vehicles, a classification that includes non autonomous remotely operated underwater vehicles- controlled and powered from the surface by an operator.

An Unmanned underwater vehicle (UUV) [3] is a robotic device that 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.

Fig 1: An Unmanned Underwater Vehicle

UUV for underwater research have been under study and development over the past few years. Due to the risks to human life the underwater operation are gradually replaced by unmanned submersibles. Unmanned vehicles are widely used in military and civilian segments.

II. KEY CHARACTERISTICS

The following are some of the main characteristics that any UUV should have

1. Reliability: A UUV should perform the desired mission.

2. Robustness: A UUV should be prepared to handle for any unexpected situation during the mission.

3. Modularity: A UUV should be flexible enough for any modifications.

4. Endurance: Efficient energy should be planned so that a UUV can last until the mission completion.

III. ROLES OF UUV

Prior to their design, it will be necessary to know what type of mission the UUV will be deployed for and their expected contribution to overall force effectiveness. Data compilation and situation assessment will rely on fusion of data gathered by variety of sensors. They also depend on timely propagation of data back to all units so that individual and coordinated actions can be taken to maximize their effectiveness.

Defensive role requires UUV to be deployed independently or in a group, to act as remote data gathering node and agent capable of taking specific actions. It includes detection and identification of mines or tracking enemy submarines.

IV. APPLICATIONS, CHALLENGES AND RISKS

A. Applications:

Sustained growth in the design of UUV [4] and development of new technologies has caught the attention of the industry and scientific communities. From the interest in gathering scientific data from the bottom of ocean to the interest in finding oil and minerals, the potential applications of UUV are increasing, as more sensors and systems are added. Some of the applications are:

1. Intelligence, surveillance & Reconnaissance (ISR):

ISR encompasses acquisition, collation and distribution of information, such as intelligence, target detection and mapping data. The possible missions of UUV are intelligence collection, Underwater surveillance and salvage operation & Bio-chemical and nuclear detection.

2. Survey missions:

The desire to keep man away from the danger areas during mining hunting, identification and disposal has propelled development of UUVs. Survey missions are used to identify drill sites to extract oil, pipelining.

3. Tactical Oceanography (TO):

Collection of oceanographic data including ocean bottom characteristics and environment conditions are very important for mission planning. Long term observation of water characteristics will provide better communication and operational capabilities.

4. Undersea Search & Survey:

It involves detecting of mines, ship wrecks, pipelines, cables etc and objects of interest lying on sea bed.

B. Challenges and Risks:

The deep ocean environment represents a major challenge in the development of an unmanned underwater vehicle. For example, limited power constraints, disturbances caused by water currents, complex hydrodynamics and limited external communications represents just few challenges to be addressed while developing UUV.

Preventing failures in the both hardware and software systems in UUV is crucial as it minimizes the risks of damaging or even losing the vehicle in deep ocean.

V. MAJOR UUV COMPONENTS

This section describes the main system and components required by an UUV.

1. Data Acquisition System

1.1 Sensors:

The group of sensors can be classified into two major categories:

a. Navigation assistant devices

b. Exploration/ observation devices

The first sub-group includes such as a global positioning system receiver, Doppler velocity log (DVL), one or more sonar modules, depth sensors, compass and gyroscope. The GPS receiver is used to approximate the vehicles position while it is on the surface, while DVL is used to approximate the vehicles position when it is submerged. The depth sensor is used to approximate the vehicles depth under the sea.

The second subgroup is composed by sensors that allow the UUV to register and log data related to oceanic environment.

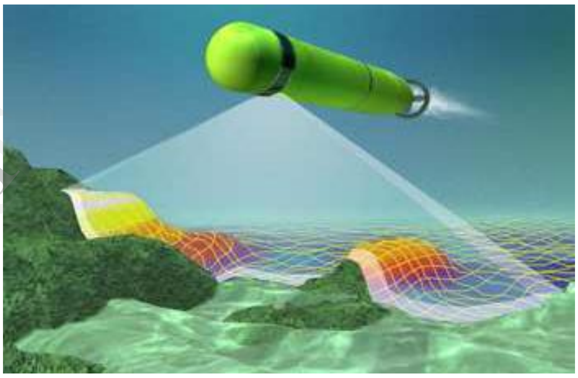

Fig 2: UUV with Sonar Scanning

1.2 External communication:

Radio waves cannot penetrate water very far, so as soon as an UUV dives, it loses its GPS signal. Due to the environment constraints in the deep sea, acoustic communication is the most feasible strategy used to exchange data between the UUV and external world. For this reason most commercial UUV use an acoustic modem to send and receive data.

1.3 Vision System:

The vision system of an UUV can be used for two main purposes: To assist the navigation system and to record images and explore the ocean. The vision system can be used to collect valuable information from the deepest parts of the sea.

2. Propulsion:

An UUV is driven through water using a propulsion mechanism [5] that creates thrust by moving water at some velocity. However, propulsion is one of the main sources of power consumption. Therefore, selecting the appropriate mechanism depends on factors such as the size, cost, power consumption and produced thrust.

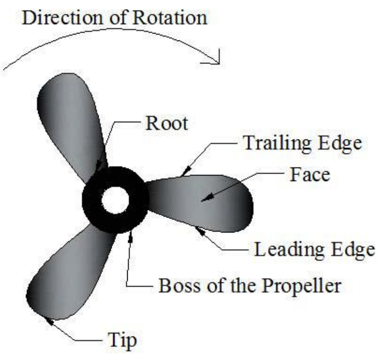

Fig 3: UUV Propeller

3. Pressure and Hydrodynamic HULL:

UUV structure makes the vehicle rigid and provides strong points for control surfaces, thrusters, batteries and other UUV components while permitting internal components to be accessed. Pressure hull enables UUV to withstand sea pressure as it descends into the ocean. The pressure to which an UUV is subjected increases linearly with depth. At 6,000 m, the sea pressure is about 4.4 tons per square inch, whereas at 300 m sea pressure, it is about 441 per square inch. So, the hull of UUV is fabricated from lighter materials such as aluminum.

Hydrodynamic hull design reduces drag as UUV moves through the ocean. Minimizing drag to maximize speed and endurance is one of the design objective along with controlling flow over the UUV body for efficient propulsion.

4. Power and Energy System:

The power requirements [6] of an UUV until recently were being met with by the use of silver zinc batteries. However, due to their higher costs and limited shelf and cycle lives, they are being replaced with lithium ion or lithium polymer batteries.

5. Manoeuvring System:

Control surfaces, thrusters are generally used for UUV manoeuvres. For hovering, lateral or vertical movement multi thrusters are utilized.

VI. IMPORTANCE OF CONTROL OF UUV

An Unmanned underwater vehicle (UUV) speed and position control system [7] is subjected to an increased focus with respect to performance and safety due to their increased number of commercial and military applications as well as research challenges in past decades, including underwater resources exploration, oceanographic mapping, geographical survey etc. It is obvious that all kinds of ocean activities will be greatly enhanced by the development of an intelligent underwater work 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 to develop its own control strategies without human intervention. The control [8] of UUV presents several challenges due to a number of factors. The first difficulty comes from the inherent nonlinearity of the underwater vehicle dynamics. Many uncertainties contribute to the prediction or calculation of hydrodynamic coefficients. The underwater vehicle dynamics is strongly coupled and highly nonlinear due to added hydrodynamic mass, lift and drag forces acting on the vehicle. Meanwhile, additional challenge comes from the underwater external disturbances.

VII. DIFFERENT CONTROL SCHEMES

The property of any controller should have good performance and robustness. Many types of control schemes have been used to design controllers for UUV so that it can work effectively.

While many of the controllers are designed based on a series of single-input and single-output (SISO) linear system models [9], but a few nonlinear control designs have also been implemented in order to achieve better performance and robustness against uncertainties in the modeling of UUV.

VIII. UUV CONTROL METHODS

Various control techniques have been proposed for UUV both in simulation environment and actual in water environment. Among them are fuzzy sliding controls, model predictive, neural networks, non linear, adaptive control, proportional-integral-derivative controller (PID).

IX. CONTROL SYSTEM

To maintain the stable movement of the UUV, a robust control system is specifically needed. One of the most mature control system for UUV is PID control [10] as feedback control. The attitude control system is one of the most critical parts of UUV. It is in charge of regulating the depth, speed of the vehicle.

Several challenges are need to be taken into consideration while designing the attitude controller, such as non linear nature of the vehicle dynamics and disturbances generated by water currents in the ocean. Typically, the attitude control system is executed in a different CPU that will separate the mission controller. This separation allows the mission controller to send commands to the attitude controller to define the vehicle's depth, and position. Several methods have been analyzed in order to simplify the operation.

PD and PID controllers are often used in the development of UUVs. In most cases, this approach seems to be fairly accurate as the system is capable of minimizing the disturbances generated by water currents. PID control is an autonomous control method. It provides robust control against disturbance. The calculation of the PID coefficients is dependent on the response of the actuators and the propulsion system of the vehicle. The dynamic control analysis tends to be a complex task, especially for large UUVs; However, PID control is not optimal for UUV, since it's a passive control method. Although classical control strategies provide fairly good results, the control system should be able to adapt and learn from the environment and the non-linear characteristics of the vehicle dynamics. Thus, fuzzy logic control system will be introduced in the feedback system for UUV to create a fuzzy interference system (FIS).

Fuzzy logic control system [11] is an expert system. Based on preset rules, it can provide well planned solution according to real time input as parameters. Some of the key advantages of fuzzy control systems are: ease of implementation and testing, simplicity and robustness. Moreover, the control system can be implemented without knowing the responsive characteristics of the UUV. The fuzzy logic system uses a set of *if-else-then* rules based on the current state of the vehicle. After weighting the firing value for each rule, the overall output for the control system is computed.

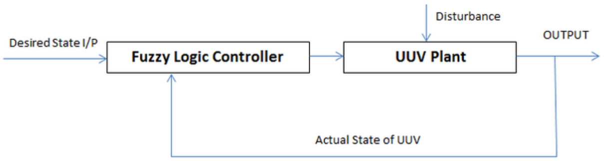

Fig 4: Block Diagram of Fuzzy Logic Controller

X. TSUNAMI SURVEILLANCE SYSTEM

UUV can be used to provide early warnings of tsunamis [12] [13] generated by undersea earthquakes. The UUV system consists of seismometers [14] and tsunameter [15].Seismometers pick up tremors and movements like earthquakes in earths crust and tsunameter is usually a pressure sensor at sea-bottom, capable of detecting long waves of very low amplitude. Seismic sensor works continuously by measuring the water pressure on the seafloor, the pressure is a result of the weight, water depth and the density of the water column. It is designed to take pressure readings every 15 seconds. When the measured value does not match with the preset value in the module then it will switch into alarm mode. An electro acoustic transducer is used in UUV which converts electrical to acoustic signal or vice versa. This electro acoustic transducer sends data to the central computer i.e. surface station. Then the surface station will send the data to the satellite and then form the satellite the data will be sent to the tsunami warning centers and mass media.

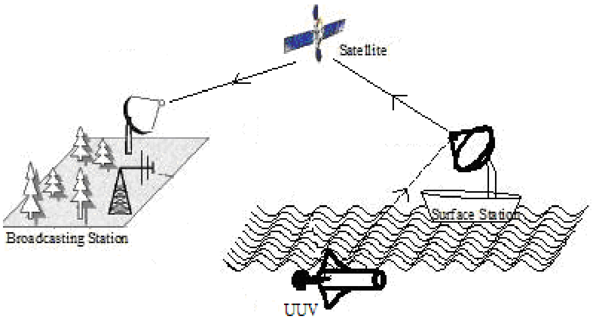

Fig 5: Tsunami Surveillance System

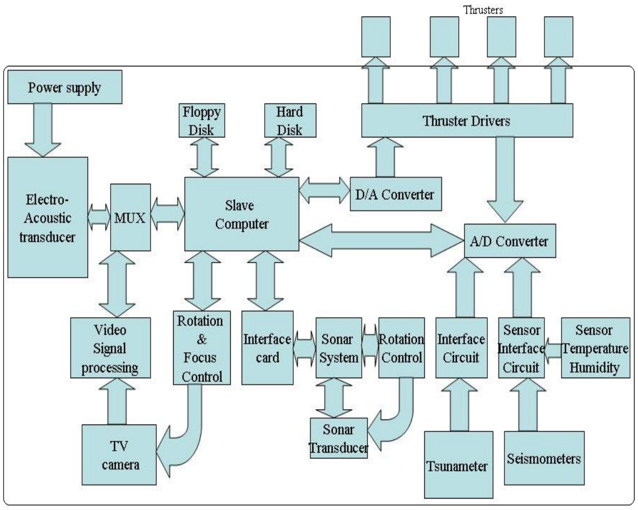

Fig 6: Block diagram indicating the subsystems included in UUV for tsunami detection

XI. CONCLUSION

Although the development of UUVs started several years ago, the development of several key technologies has been rather slow. The development of UUV is a multidisciplinary & complex task. The present study confers recent progress in the control technology for unmanned underwater vehicles. As such the control of UUV for tsunami detection is quite a challenging task and in the above paper control algorithms starting from PID to Fuzzy systems were explored. There is possibility of combined control system for seismic and vehicle control is possible for the future study.

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