Autonomous Underwater Vehicle for Researc
and Rescue Operations

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Abstract – **Autonomous under water vehicles are ideal platforms for search and rescue operations. They can also be used for inspection of underwater terrains. These vehicles need to be autonomous and robust to cope with unpredictable current and high pressures. This paper will touch on the issues encountered in designing such a vehicle. Typical solutions as well as new ideas will be discussed to overcome these design problems or obstacles. The paper will also show the implementation of such a vehicle.**

I. INTRODUCTION

Due to the harsh conditions in the oceans it can be very dangerous and difficult for a human to complete underwater tasks like underwater exploration or inspection. This calls for the need for unmanned underwater vehicles to perform these tasks, especially in deeper depths where water pressure can become very dangerous. These vehicles can be either remotely controlled or autonomous. In the case of an Autonomous underwater vehicle (AUV) the navigation system and control system of the vehicle needs to be robust as the vehicle needs to operate by itself in these harsh conditions.

This paper will discuss the design issues associated with such a vehicle and also show typical solutions as well as new ideas to overcome these problems.

The main problems come with navigation in an underwater environment. In the case of areal and land autonomous vehicles one can use a Global Position System (GPS) for navigation. This system does not work in an underwater environment due to the high level of attenuation of the radio signals in water. Other means of navigation needs to be developed and different types of sensors need to be used.

Communication with the vehicle also becomes difficult and an umbilical cord connecting the vehicle to the base station is not always a viable solution. Radio systems cannot be used for the same reason as stated above with GPS. Special underwater wireless communication systems need to be acquired or developed using other means of communication.

The vehicle needs to be able to withstand the immense water pressure and still needs to be maneuverable to accomplish its mission. These design issues will all be discussed in more detail in the following sections.

II. VEHICLE BODY DESIGN

The AUV's purpose is to carry a payload. Th
composition of the payload will be determined by t
of the vehicle but can include instrumentation t
ocean water characteristics, map the seabed or insp
installations such as pipelines. In addition to gath
AUVs can be used to lay underwater cable or
equipment to remote destinations. Basically the ap
the AUV dictates its mechanical design. There are m
developed to date. This section outlines some of t
found in literature.

A. *Kambara*

Kambara's mechanical structure, an open-fra
supporting five thrusters and two watertight encl
designed and fabricated at the University of Syd
simple, low-cost vehicle suitable as a test-bed f
water research in underwater robot autonomy.
thrusters enable roll, pitch, yaw, heave, and surge
It is under actuated and not able to perform
(lateral) motion; it is nonholonomic. The Kambara
figure 1.

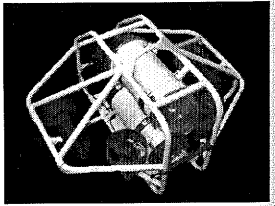


Fig. 1 Kambara (Picture by ANU-Systems Engineeri

B. *ISE Theseus AUV*

This AUV resembles a torpedo in many respect
a propulsion system consisting of one or two thru
surfaces, which act like wings to control the vehic
a pressure hull to contain electronics and po
streamlined fairing to reduce hydrodynamic drag
is shown in figure 2.

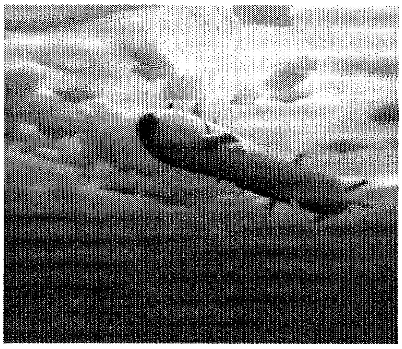


Fig. 2 ISE Theseus AUV [5]

Solar powered Autonomous Underwater Vehicle (SAUVII)

ıutonomous Undersea Systems Institute (AUSI) has eloped a solar powered Autonomous Underwater Vehicle. : goal is to develop an AUV system capable of autonomous erwater sampling with long endurance. SAUV II vehicles e been used in several in-water operations, demonstrating ınologies including underwater networking and cooperative avior. The vehicle is shown in figure 3.

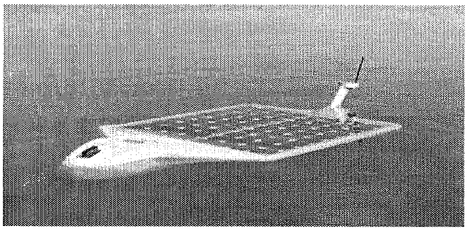
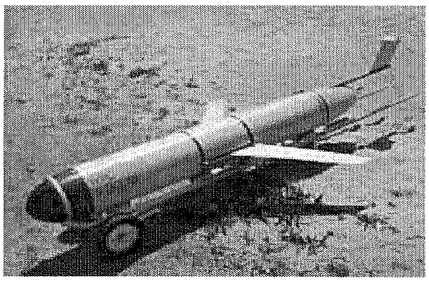


Fig. 3 SAUV II (Pic by AUSI) [6]

Slocum Glider

'he Slocum Glider is an autonomous underwater vehicle ch moves up and down in the ocean by changing buoyancy. ıgs allow steerable gliding, thus horizontal propulsion. The icle traces a saw tooth profile, observing temperature, ductivity, etc versus depth and, at the surface, fix position GPS and communicate via satellite. The glider is shown in ıre 4.



ıg. 4 Slocum Glider (Pic by Woods Hole Oceanographic Institution) [7]

E. *CSIR AUV*

The vehicle body design chosen for this project is a simple rectangular shaped water tight container with a protective frame. Thrusters are mounted on the front, back and sides of the vehicle. The front and rear thrusters are mounted facing upwards to control the depth or vertical movement of the vehicle. The two thrusters on the side are mounted facing forward and can control forwards and backwards motion as well as vehicle yaw. The vehicle design is shown in figure (5).

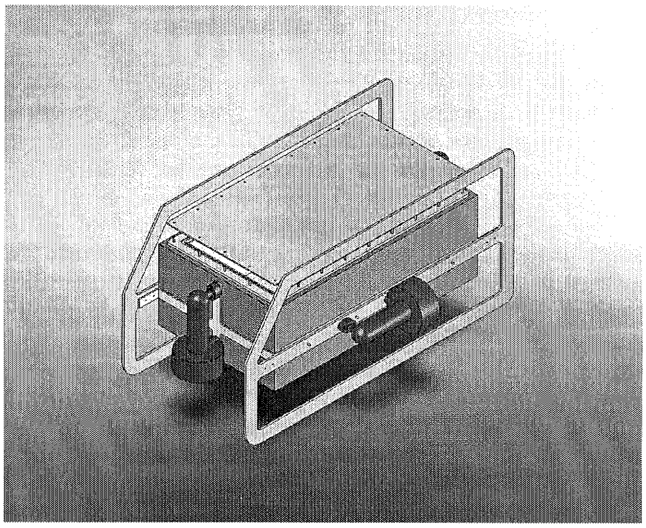


Fig 5. Vehicle design of CSIR AUV

III. ELECTRONIC DESIGN

A. *Controllers and Interfaces*

The system needs to be controlled using a central computing system. An industrial computer or similar system may be suitable for this purpose. In the case of this project the central computing system will be in the form of a Wafer-Luke single board computer. This single board computer utilizes a 1GHz processor and runs Linux as the operating system. It has two RS-232\RS-485 ports and two USB ports that will be used to interface to sensors and other devices. It also contains a general purpose IO port that can be used for digital IO.

Another IO board will also be used to interface to other devices that use communication interfaces not supported by the Wafer-Luke single board computer. These interfaces include I^2C and SPI bus. The IO board also adds more digital IO pins as well as analog to digital conversion. The IO board interfaces to the Wafer-Luke board using RS-232.

B. *Communication system*

An underwater communication system is needed for communication between the base station and the AUV. In many cases an umbilical chord will suffice but in some cases a wireless system is required. Normal radio systems cannot be used due to the high level of attenuation of radio waves in water. A solution to this problem is using an acoustic wireless communication system. This system uses acoustic waves instead of radio waves to transmit data. A drawback of this system is to obtain a long range for communication one will get low data transfer rates due to the lower frequencies used for modulation. This solution has been chosen for the current project. The under water acoustic modem obtained in this case has a range of 3km but a data transfer rate of only 480 bps.

Wi-fi systems may be used for higher data rates or when large amounts of data need to be transferred. In this case, the vehicle needs to surface to make a data transfer using Wi-Fi. A wireless router will be connected to the Ethernet port of the single board computer and may be accessed from the base station once the vehicle has surfaced.

C. Actuators

The main actuators on almost any AUV are normally the thrusters. They control almost all movement of the vehicle. Different vehicles may use different type of thrusters and some vehicles may not use thrusters at all. An example of such a vehicle is a glider which is entirely buoyancy driven. These vehicles normally have lower power consumption but they may be less maneuverable.

Thrusters are otherwise used to control the position of an AUV accurately, whether the vehicle needs to hover at a given altitude or maneuver through tight spaces. Thrusters may be positioned facing different directions to achieve actuation in any direction. In the case of this project the vehicle utilizes two thrusters facing forward and two facing upwards. The forward facing thrusters can be used for forward and backward motion as well as control of vehicle yaw. The upwards facing thruster can be used for up and downwards motion as well as controlling vehicle pitch.

Vehicle buoyancy is controlled using two piston tanks inside the vehicle. They can be filled with water to increase the total weight of the vehicle and thus make the vehicle sink or float. They will be used to achieve a state of neutral buoyancy so that the vehicle will maintain its depth when all thrusters are switched off. This will also make the vehicle more power efficient since no unnecessary power is needed to maintain a given depth.

The hardware interface diagram is shown in figure 6. The figure also contains the sensors and their different interfaces which will be discussed in the following section.

IV. SENSOR SYSTEM

A. Sensors

The sensors discussed in this section will be sensors used for navigational purposes only. As stated earlier, a GPS unit cannot be used in an underwater environment due to the high levels of attenuation of the radio waves in water. This means that other navigational sensors need to be used for navigation and vehicle tracking. A popular sensor used for navigation and vehicle tracking in AUV's is an inertial measurement unit (IMU). The IMU contains three accelerometers and three gyroscopes placed on the three axes of movement. It can therefore measure linear acceleration in any direction as well as rate of rotation around any of the three axes. The data can be integrated over time to find the actual movement of the vehicle in all six degrees of freedom (DOF). This includes linear movement in three dimensions as well as rotation around all three axes, or roll, pitch and yaw.

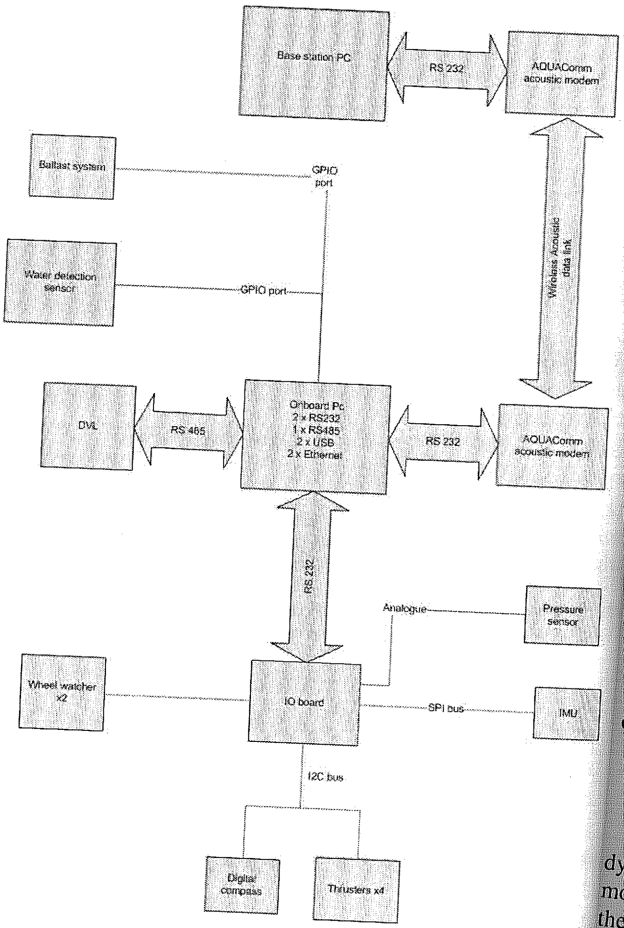


Fig 6. The system hardware interface diagram.

The problem with this type of sensor is that because of the integration, measurement errors add up over time and cause sensor drift. This can be very problematic for a vehicle that needs to navigate on its own.

Another commonly used sensor to measure the movement of an underwater vehicle is a DVL. This type of sensor bounces acoustic pulses off the bottom and uses it to calculate the velocity and direction of the vehicle's movement. If the starting position of the vehicle is known one can easily use this information to calculate the current position of the vehicle. This type of sensor may be affected by underwater currents and it is also sensitive to sensor drift. These sensors are described in more detail in [1].

Some systems have also been implemented where beacons with fixed positions have bean deployed. These beacons transmit their position and the vehicle calculates the distance to all beacons from which it received the position signals and thus etermines its own position at the point where all these circles tersect i.e. triangulation.

Additional sensors that can be used are digital compasses, hich can measure the yaw of a vehicle directly. One can clude a pressure sensor to measure the water pressure outside e vehicle and use this information to calculate the depth of e vehicle. One can also include inclinometers or tilt sensors measure the roll and pitch of the vehicle.

The sensors chosen for this project include an IMU, DVL, ressure sensor, digital compass. The sensor interfaces are hown in figure 1. The IMU used in this case is a very low cost MU. The system will also include a Wheel Watcher sensor to easure the position of the rod on the piston tanks to etermine how full they are.

Sensor Fusion

Once the data from all sensors have been collected they must e combined to determine the position of the vehicle in all six OF. Since many sensors measure more or less the same thing r the same DOF, we use some form of sensor fusion to ombine the data obtained from these sensors to calculate an timate of the vehicles position or orientation.

This paper proposes the use of a Kalman-Bucy filter to ombine sensor data and estimate the vehicles current position. he prospect of sensor fusion also improves on the easurement of vehicle position by using data from more than ne sensor to calculate a more exact estimate of the vehicle osition than just with a single sensor. The Kalman filter can eliver the required estimates in an optimal way. The Kalman r Kalman-Bucy filter is discussed in [2] and [3].

V. NAVIGATION SYSTEM

To implement a successful navigation system the vehicle ynamics needs to be modeled and controllers for vehicle ovement needs to be derived. The system model depends on e shape of the vehicle as well as the actuators and its position n the vehicle.

Advances in vehicle navigation will enable new missions for nderwater vehicles (commercial, scientific, and military) hich were previously considered impractical or unfeasible. he motivation for improving underwater vehicle navigation ises from the need to expand the capabilities of these vehicles nd further increase their value to oceanography. Future mprovements in underwater vehicle navigation will enable us optimize the infrastructure necessary for navigation and nable submersibles to optimally achieve specific objectives. hese improvements will increase the value, quantity, and cost fectiveness of scientific data obtained with these vehicles.

Detailed information on the navigation methods described elow can be found in [1].

Acoustic Navigation (Time of Flight)

This section describes Acoustic Navigation Techniques used day.

A. Long Baseline Navigation (LBL)

In this type of navigation a vehicle triangulates its position from acoustic ranges within a network of surveyed transponders. At present, the best method for obtaining sub-centimeter XY position sensing is to employ a high-frequency LBL system. Traditionally, LBL transponders have been moored on the sea-floor, on the hull of a surface ship, or on sea-ice. Recently researchers have reported using a network of surface buoys equipped with a global positioning system (GPS) unit and a LBL transponder to track underwater vehicles. A system that employs a network of these buoys to estimate the position of an AUV and employ an Extended Kalman Filter to compensate for latencies resulting from the finite propagation speed of sound in water has also been reported.

B. Ultra-Short Baseline Navigation

The modest infrastructure required for USBL navigation,(i.e a hull mounted transducer) has resulted in its widespread utilization in a variety of scientific, industrial, and military underwater vehicles. USBL systems require alignment calibration of the transponder and ship's positioning system (typically GPS), although the recent development of USBL transponders with integrated GPS systems could minimize this error. Supplementing the vehicle range and bearing measurements with range and bearing measurements from a fixed sea floor transponder has been shown to improve the precision of USBL navigation.

C. Acoustic Modems

The development of acoustic modems that provide both range measurements and data telemetry has enabled research in which multiple vehicles (typically AUVs) can share navigation data. A system where one AUV is used as a master that uses a conventional LBL system to compute its position has been proposed. The slave vehicles employ USBL to estimate their position relative to the master vehicle using an acoustic modem to transmit the position measurement of the master AUV to the slaves. Others propose having the slave vehicles employ dead reckoning with position corrections provided from the master vehicle via an acoustic modem.

D. Single Range Navigation

An increasing number of single-range navigation systems have been proposed as a practical method for bounded-error XY navigation. This growing interest is due largely in part to improved dead-reckoned (DR) vehicle capabilities, such as the advent of Doppler sonars. Alternatively, work in single-range navigation systems has explored the use of synchronous-clocks strategies for the direct measurement of one-way time-of-flight from an acoustic source.

All acoustic time of flight navigation methods require:

- Careful placement of transponders fixed or moored on the sea floor, on the hull of a surface ship, or on sea-ice.

- Accurate knowledge of the sound velocity.
- They are fundamentally limited by the speed of sound in water — about 1500 m/s.
- They are costly and time consuming to install.
- They limit the vehicle's operation since the vehicle has to operate within their range.

B. Doppler Navigation

The development of high-frequency, multi-beam Doppler sonars that provide bottom velocity measurements provide researchers with velocity measurements for near-bottom (18–100 m) navigation. This has enabled the development of a wide variety of Doppler-based navigation techniques. Doppler velocity measurements are also employed to improve state estimates in Inertial Navigation Systems (INSs) and state estimators.

C. Inertial Navigation

Inertial measurement units (IMU) offer excellent strap-down navigation capabilities, but their power consumption and cost has, until recently, precluded their widespread use in civilian oceanographic vehicles. Typically, IMUs employ Doppler velocity measurements and position measurements from GPS or acoustic navigation systems to correct for errors in the IMU state estimate. IMUs are often employed in high-precision surveys and when vehicles are deployed under ice-caps or in the mid-depth zone.

D. Global Positioning System (GPS)

GPS provides superior three-dimensional (3D) navigation capability for both surface and air vehicles, and is widely employed by oceanographic research surface vessels. The GPS system's radio-frequency signals are blocked by sea water, thus GPS signals cannot be directly received by deeply submerged ocean vehicles. However, GPS commonly aides a variety of underwater vehicle navigation techniques, including surveying of acoustic transponders, position correction for IMUs, alignment calibration of Doppler sonars, and surface LBL systems.

E. Navigation State Estimators

While many of the techniques reported within employ data from sensors, Navigation State Estimators differ in that they supplement these measurements with information from a kinematic or dynamic model.

A. Stochastic Model-Based State Estimators

Stochastic state estimators, specifically optimal unbiased estimators such as the Kalman Filter and the EKF, are increasing employed in underwater vehicle navigation. To date, most implementations of these estimators have employed kinematic plant models. Typically, these estimators utilize data from navigation sensors. These estimators employ knowledge of process and measurement noise to compute optimal gains. More recent developments in general nonlinear stochastic state estimators include Unscented Kalman Filters (i.e. Sigma-Point Kalman Filters) and Monte Carlo Methods (i.e., Particle Filters).

B. Deterministic State Estimators

The deterministic state estimator problem addresses exact (non-stochastic) plant and measurements models, and focuses on the development of exact asymptotically stable estimators. An advantage of this estimator over the stochastic estimators is that it exploits exact knowledge of the vehicle's nonlinear dynamics.

C. Terrain Based Navigation

Terrain relative or landmark relative navigation uses real-time sensing and a terrain or landmark map to determine vehicle position. Although most terrain relative navigation techniques employ time-of-flight sonars as the principal navigation sensor, a few reported studies employ optical sensing.

D. Simultaneous Localization and Mapping (SLAM)

Over the past decade, a significant research effort within the terrestrial mobile robotics community has been to develop environmentally-based navigation algorithms that eliminate the need for additional infrastructure and bound position error growth to the size of the environment — a key prerequisite for truly autonomous navigation. The goal of this work has been to exploit the perceptual sensing capabilities of robots to correct for accumulated odometric error by localizing the robot with respect to landmarks in the environment. One of the major challenges of the SLAM problem is (a) defining fixed features from raw sensor data and (b) establishing measurement to feature correspondence (the problem of data association). Both of these tasks can be nontrivial — especially in an unstructured underwater environment. Natural, unstructured environments such as the sea floor pose a more challenging task for feature extraction and matching.

VI. CONCLUSION AND FUTURE WORK

In this paper the design and development issues of an AUV was discussed. Many known problems have been brought forward and some typical solutions for these problems was given. Different vehicle designs has been shown and discussed and the chosen design for the current project was also given.

Future work can still be done on the Navigation system and different methods can be tested under different circumstances. Other type of sensors may be implemented to find a lower cost solution as some sensors may be very costly. In this case algorithms for sensor fusion may also be improved to compensate for the inaccuracy of low cost sensors.

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