Chapter 1
Introduction

Unmanned Surface Vehicles (USVs) are self contained unmanned untethered vessels that can transit on the surface of the water autonomously or through remote control. Unlike conventional manned surface vessels that are usually large and costly to build and operate, USVs are typically smaller in size and lower cost resulting from the reduced payload requirement extending from being unmanned. In manned vessels, much of the volume is necessary to support the activities (such as control, navigation, maintenance, and mission related tasks), and sustainment (such as berthing, feeding, and entertainment) of the human occupants that recursively increases the size, volume, and power requirements. USVs have no such requirements and therefore are typically many times smaller and more efficient than manned surface vessels.

In the last two decades significant effort has been invested in the development of Unmanned Underwater Vehicles (UUVs), while only a small effort has focused on Unmanned Surface Vessels/Autonomous Surface Vessels (USVs/ASVs). The major efforts in the design of USVs have focused in two areas: platforms for hydrographic data acquisition (Chaumet-Lagrange 1994; Manley 1997; and DSOR 1998), and GATEWAY platforms that provide positioning and communications capabilities through the air-sea interface for UUVs (DSOR 1998; ISR-IST and Oliveira 1999).

The work presented in this book is part of a larger project that aims to develop a combination oceanographic and GATEWAY USV. In particular, a low-cost high rate position measurement system is implemented to increase the navigation, acoustic positioning, and oceanographic capabilities of the overall system.

1.1 Autonomous Surface Vessels for Hydrographic Data Acquisition

Prior to 1994, little work focused on the development of surface robots. At this date, the Port of Bordeaux Authority and the University of Bordeaux began developing a USV to provide hydrographic data to serve engineers and researchers involved in the study of the sea (Chaumet-Lagrange 1994). This USV measures 5m in length, travels at speeds up to 15 knots, and has a range of 10 km. In the same year, the USV named ARTEMIS (Manley 1997) was developed

C. Gelin: A Low-Cost, High Rate Motion Measurement System, NAMESS 1, pp. 1–6.
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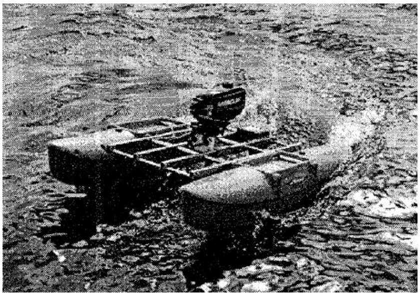

Fig. 1 Autonomous Surface Craft ACES.

at the Massachusetts Institute of Technology. ARTHEMIS is 1.37m long, has an endurance of 4 hours, and has a maximum speed of 2 to 2.5 knots. A micro-processor and a digital compass were installed to provide rudimentary navigation and control functions. A USV for autonomous coastal exploration (ACES) was developed 3 years later by the Massachusetts Institute of Technology (Manley 1997) that used a 1.8m catamaran hull form to enhance roll stability and provide greater payload (Figure 1). The electronics suite and control software were directly transferred from the ASC (Autonomous Surface Craft) ARTEMIS and incrementally improved. Since 1997, worldwide interest in the analysis of mesoscale ocean dynamics has rapidly increased, leading to an interest in long range USVs capable of sustained oceanographic measurement. In June 1998 the 7m hull prototype USV CARAVELA was launched by IMAR/University of the Azores with capabilities that include a 2000 nautical mile range with at a 5 knot cruise speed, the project was completed in 2002.

1.2 Gateway USVs

One of the major challenges in the navigation of underwater vehicles is obtaining precise and reliable geographic positioning (Grenon, 2001). Dead-Reckoning (DR) aided with Doppler velocity measurement has been, and remains, the most common method for underwater navigation for small vehicles (Babb, 1990). DR uses a set of navigation instruments to estimate the vehicle's position by integrating the body-fixed velocity, accelerations, and angular rates with respect to time. Instrument error and bias lead to position error that increases exponentially with time. Thus, current DR systems require frequent position recalibrations. The Global Positioning System (GPS) provides measurements of geodetic coordinates for air and surface vehicles and it is often used to correct positioning error. However, underwater vehicles cannot use GPS for inflight navigation because GPS signals only penetrate a few centimeters past the air-sea interface. Thus, underwater vehicle navigation systems are limited to periodic position update from the GPS when they surface and extend an antenna through the air-sea interface.

Alternatively, Long-Base-Line (LBL), Short-Base-Line (SBL), and Ultra-Short-Base-Line (USBL) acoustic positioning systems are often used in the place of the GPS for underwater inflight position measurement. The distance between the active sensing elements is generally used to define the acoustic position system. LBL has a baseline length from 100m to 6000m while SBL and USBL have a baseline length of 20 to 50m, and less than 10cm, respectively. LBL arrays of geographically stationary acoustic beacons of known position on the ocean floor (LBL) or surface (inverted LBL) are used to triangulate vehicle position. If a LBL is used, the UUV is restricted to operate within the beacon grid to obtain geodetic position data. Offshore deep water deployment of LBL arrays is difficult and if moored on the surface, buoyed beacons are not clandestine and therefore vulnerable if deployed in a hostile theater.

In a Short-Base-Line (SBL) system, arrays of transducers are hull-mounted on large vessels and typically separated by several tens of meters. Such large vessels are easily detected, leading to a non clandestine solution. Alternatively, in an Ultra-Short-Base-Line (USBL) positioning system, arrays of transducers are separated by up to several centimeters, and potted into a single small hydrophone array. Low system complexity and small size makes USBL an ideal tool to help navigate UUVs because they are easy to deploy and small enough to be clandestine. In addition, there is no need to deploy arrays of transponders because there is only a single transceiver (Vickery 1998). Thus, the USBL is an ideal UUV acoustic positioning system for GATEWAY type USVs. USVs are ideal mobile GATEWAY platforms that can provide communications and positioning to UUVs through the air-sea interface when mounted with a USBL and acoustic modem. Unfortunately, little work exists on operating UUVs and USVs in a cooperative manner. One such system, the Advanced System Integration for Managing the Coordinated Operation of Robotic Ocean Vehicles (ASIMOV) project, was developed with the objective of achieving coordinated operation of an Autonomous Surface Craft (ASC) and an UUV for marine data acquisition while ensuring a fast communication link between the two vehicles (ISR-IST 2000).

Fig. 2 Autonomous Surface Craft DELFIM, part of the ASIMOV project, designed, and built by the Institute for System and Robotics, beginning in 1998

In this project, two robotic ocean vehicles are used: the DELFIM ASC and the INFANTE AUV. The DELFIM ASC is a small catamaran that is 3.5m long and 2m wide, with a mass of 320 Kg (Figure 2). The DELFIM performs automatic marine data acquisition and serves as an acoustic relay between submerged craft and a support vessel. Besides operating as a communications link, the DELFIM has a stand-alone sensor suite capable of maneuvering autonomously and performing precise path following while carrying out automatic marine and bathymetry data acquisition. This sensor suite includes on-board systems for navigation, guidance and control, and mission control; an Ultra Short Baseline unit (USBL) to position the AUV; an RF above water communication link; and a high data rate underwater acoustic communication system. Navigation is done by integrating motion sensor data obtained from an attitude reference unit, a Doppler logger, and a DGPS. Transmissions between the

AUV, this ASV, the fixed GPS station, and the control center installed on-shore are achieved with a radio link that has a range of 80 Km. In order to achieve higher bandwidth acoustic co-mmunications between the USV and the AUV, the vertical channel (high data rate underwater acoustic system) is used.

1.3 Proposed System

FAU has designed a multi-purpose oceanographic and GATEWAY USV that is a low cost mobile surface platform (Figure 3). The system is integrated with a motion measurement package (the focus of this work) to aid in navigation, control, and enhance acoustic performance. This USV also contains a USBL and acoustic communication system to provide position updates and allow UUVs to communicate while in transit and surveying. It is also possible to interact with the underwater vehicle to change the mission through an operator communicating with the USV via an RF uplink from shore or a distant vessel (Leonessa 2002). Finally, the onboard sensors, including an Acoustic Doppler Current Profiler (ADCP), provide oceanographic measurements.

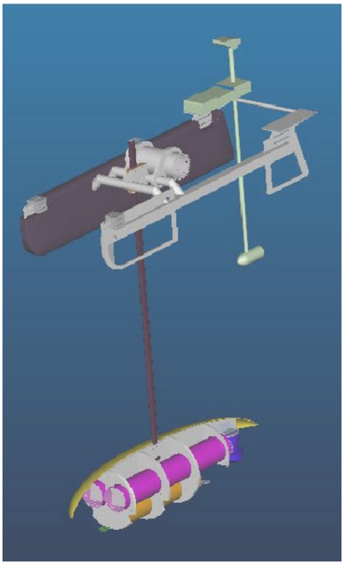

Fig. 3 Diagrammatic representation of the FAU Autonomous Surface Vessel

1.4 Problem Statement

The USBL acoustic positioning method involves measuring the range and bearing from a vessel based transceiver to a single, remote underwater transponder that automatically responds to an incoming signal. The remote underwater transponder, mounted on a mobile target, is positioned using data from the vessel's GPS and onboard sensors. To do this, the geodetic position of the underwater vehicle is calculated using the known surface vessel location (provided by the onboard sensor suite) and the measured relative position and bearing between the surface vessel and the remote underwater transponder mounted on the underwater vehicle/mobile target. Range between the AUV and ASV is calculated by measuring the time taken from sending a transponder interrogation signal to receiving its reply. The phase comparison on an arriving ping between individual elements within a multi-element (3 or more elements) transducer is used to determine the bearing from the USBL transceiver to the remote beacon.

The USBL hydrophone is mounted to the USV on a long rigid strut a distance from the GPS antenna. As a result, as the USV moves and responds to ocean waves, the USBL will also move. If the USBL is to provide accurate positioning, the position and orientation of the hydrophone must be measured at a high rate to correct the measured bearing and position offsets. However, standard GPS receivers are unable to provide the rate or precision required when used on a small vessel. To overcome this, a high rate and high precision position and orientation measurement system is developed. The work integrates a set of low cost inertial sensors and a GPS receiver to calculate the USV's inertial motion. This will be used to correct/transform USBL based position and bearing measurements even when the surface vessel is required to operate in rough seas. Fundamental to any navigation and control system is the measurement of the vehicles geodetic position, orientation and velocity in 3 or 6 degrees of freedom. The system developed in this book provides this information. Included in the navigational instrumentation suite is an ADCP that measures the water velocity, but it can also measure the speed of the USV over the ocean floor.

ADCPs measure the relative velocity between its sensor heads and the water using the Doppler shift and time dilation of an acoustic pulse. By transmitting acoustic pulses at a fixed frequency and listening to the Doppler shift of echoes returning from sound scatterers in the water, water velocity estimates can be made. While ADCPs non-intrusively measure water flow, they suffer from the inability to discriminate between motions in the water column and self-motion. When mounted on a moving platform, the measured velocity is the sum of the platform velocity and the water velocity. Thus, the vessel motion contamination needs to be removed to analyze the data and avoid long average times. The system developed in this book provides the motion measurements and processing to accomplish this task.

1.5 Contributions

The work presented in this book integrates a set of instruments and develops a software package that measures and calculates the motion of the USV (Unmanned Surface Vehicle) to aid in the navigation and control and enhance the performance of the USBL positioning system. As well, the motion measurement system actively controls the onboard ADCP and corrects the water velocity measurements for ship motion contamination - ship surge, sway, heave, roll, pitch and heading. The simplicity of the data acquisition system allows it to be easily deployable and adaptable to new applications after setting the correct initial parameters.

The motion measurement system of the USV consists of an Inertial Measurement Unit (IMU) with accelerometers and rate gyros, a GPS receiver, a flux-gate compass, a roll and tilt sensor, and an ADCP. Interfacing all the sensors is challenging because of their different characteristics. Some of the instruments have digital output (Compass/ADCP/GPS) while others have an analog output (IMU/tilt sensor). Among the sensors using RS232 serial port communication two different output formats are used. The TCM2 compass and the GPS use the NMEA 0183 (National Marine Electronics Association) standard while the RDI

ADCP uses ASCII (American Standard Code for Information Interchange) or binary output. The baud rate for the sensors are selectable, the TCM2 has a baud rate from 300 to 38400 baud, the ADCP from 300 to 115200 baud and the GPS from 4800 to 19200 baud. Thus, considering the characteristics of each instrument, a data acquisition system is developed that synchronously decodes data from all the instruments and converts them into a consistent format.

These sensors cannot be used independently to measure the position of the vehicle and provide sufficient information for control and USBL motion correction. For example, the GPS provides accurate positioning, but its update is too slow and its resolution too coarse. The accelerometers are able to measure linear motion over a wide range of frequencies, but their signals contains bias and low frequency drift that cause position error to increase as the square of time. However, these sensors both measure linear translation and they have complimentary characteristics that can be used to reduce or eliminate their individual errors when they are combined. Thus, integration and data fusion methods are used to combine the measurements from the sensors to estimate the position of the vehicle (Driscoll 2000), in real-time. Using these techniques, a software package is developed where useful sensor measurements are preserved and erroneous data is rejected at all frequencies and the resulting, merged signal is drift free.

Finally, the motion measurement system is used to remove the USV motion contamination in the ADCP measurements. To accomplish this, the motion measurement system is used to control the ADCP by commanding it to ping at a set rate and decoding the measurements returned by the instrument. The single ping water velocity measurements are decoded, motion corrected, and converted into an earth fixed frame.

1.5.1 Book Outline

This book consists of six logically progressing chapters. Chapter 1 provides an introduction and motivation of the work, as well as, outlines the contributions of this work; Chapter 2 presents the different sensors and the data acquisition system; Chapter 3 covers the data processing; Chapter 4 illustrates the results of individual sensor tests; Chapter 5 presents and discuss the result of the data fusion of the sensors to obtain the position and velocity of the USV as well as the motion correction of the onboard ADCP; and Chapter 6 draws conclusions and suggest future work.