Remotely Operated Vessel for Environmental Studies in Shallow Water Areas

Rafic Bachnak and Jack Esparza

***Abstract*—**Data collection in shallow water areas presents several challenges to the scientist. In addition to being redundant and time consuming, this task when performed manually has a high probability of disturbing the test area. Obstacles that are encountered in such environments include difficulty in covering large territories and the presence of inaccessible areas due to a variety of reasons, such as soft bottoms or contamination. There is also a high probability of disturbing the test area while placing the sensors. This paper describes the development of a remotely-controlled, shallow-draft vehicle designed as a supplemental tool for our studies of the South Texas Coastal waters. The system transmits environmental data wirelessly via a radio to a control station in real-time.

***Keywords*—** Wireless control, autonomous navigation, mapping sea bottom.

I. Introduction

RESEARCH in aquatic environments presents several challenges to the scientist. One of the pressing issues is how to efficiently and reliably gather data in shallow water areas. This project was initiated by the Department of Computing and Mathematical Sciences (CAMS) and the Division of Nearshore Research (DNR) at Texas A&M University-Corpus Christi (A&M-CC) to produce a remotely operated vessel that aids in the monitoring and study of the water quality of coastal waterways, estuaries, and bays. Many of these bodies of water are relatively shallow and prevent navigation of a regular size craft with a human operator.

To gather data about the aquatic environment of a particular estuary, a researcher could venture out into the water (either by boat or with the assistance of waders) along with a collection of instruments, taking measurements and recording results. This is a straight forward and simple approach provided one is interested in a relatively small area of study. But what happens when the problem begins to increase in scale or complexity? Perhaps, one needs to study an estuary spanning several square miles. In such a case, one is faced with two options: (1) divide the task up and hire extra researchers, or (2) somehow increase the efficiency and speed with which one works.

Autonomous data logging is another approach. One example is the TCOON system that is in place along the Texas coast [1]. TCOON's network of fixed observation posts works well for monitoring specific locations continuously. For problems where a researcher is interested in an entire area at a specific time, however, a mobile solution is required. A number of research centers have been developing autonomous boats [2–4]. These boats, however, require course planning prior to deployment. As a result, the course is not easily changed once the boat is in the water.

The additional benefit of a mobile system versus a "by hand" approach is the consistency of the results. All readings are taken by the same sensor(s) and all data is processed by the same algorithms. Moreover, the data is easily and consistently entered into a database for analysis? This last step is particularly significant if the system needs to operate in real-time.

Shallow water areas, 12" to 18" inch deep, are of specific concern to this project since they are not always accessible by waders (too deep in some areas) or boats (too shallow in some other areas). Moreover, both waders and boats can have a substantial impact on the area of study.

In an attempt to address the problem of Data Logging in a Shallow Water Environment, researchers at A&M-CC proposed a vehicle that satisfies the following operational requirements: (a) The boat is remotely controlled within the operator's line of sight, (b) It is small and easy to transport in the back of a truck without extra towing equipment, (c) It is stable enough to resist waves and wind, (d) It has the ability to travel through areas with a draft as small as 6 inches, (e) It has sensors to detect objects from all directions (front, sides, back, and bottom), and (f) It transmits data wirelessly to a docking and control station in real-time.

Two boats have been designed and constructed so far. The first prototype provided an excellent starting point but had several limitations that needed to be addressed [6]. The boat had a flat-bottom and was powered by a small trolling motor. A DC motor was attached to the shaft of the trolling motor, allowing the thrust of the motor to be directed. This redirection of thrust allowed the boat to be turned. The problems associated with this design were evident during sea trials. The boat, though relatively heavy, cannot track against the wind and waves and has great difficulty executing a controlled turn or making subtle course adjustments. In addition, the control system, based on RC servo/transmitter technologies, is subject to the inherent limitations of these technologies. Second, the design did not allow programmatic control of the vessel. All details about the vessel's state (speed, position, and heading) are observed by the operator visually, rather than recorded by the vessel and forwarded to the operator.

The second prototype was a completely new design and corrected several of the problems that troubled the first

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prototype [7]. The only similarity in the design of the two prototypes was that they both used the same trolling motor for propulsion. A cylindrical hull, along with a pontoon on each side of the hull, was used to make up the body of the boat. This prototype also incorporated a new control system that helped overcome many of the limitations of the first prototype. The current prototype is capable of moving the rudder through a limited range of rudder positions, from 45° left of center to 45° right of center. This paper will presents results of mapping shallow water areas using this boat.

II. Boat Design

The current boat is shown in Fig. 1. The shape of the hull was selected to increase stability and reduce the area of the boat that was exposed to wind. This ROV is made of 12" outside diameter (o.d.) PVC pipe and has two outriggers that are constructed of 5" o.d. PVC pipe. Total length is approximately 60 inches, the width is around 46 inches, and the height is approximately 36 inches.

Fig. 1 Current boat chassis

The main body of the craft contains the controller with its 16 attached modules, one 12-volt marine battery, GPS transceiver, one 2hp trolling motor, and a rudder control system that contains a servo motor. An aluminum beam is placed along the length of the craft to serve as a platform for the processors, batteries, trolling motor and rudder control mechanisms as well as the GPS system. The vehicle weighs approximately 180 pounds.

III. Control System

The The control system is built around a powerful controller by National Instruments (NI) and the most recent version of the software was developed using the LabVIEW Real Time (RT) environment. The National Instruments cFP-2020 was chosen as the controller for the ROV. The cFP-2020 communicates by way of an auto configuring 10/100 Ethernet connection and offers three RS232 serial ports, an RS485 port, as well as discrete digital input/output terminals. Another asset of the cFP-2020 is the LabVIEW RT software that is embedded in the controller. With LabVIEW RT, applications can be downloaded to the controller and run independently of a PC.

The NI cFP-BP-8, a backplane, is used to connect several modules to the cFP-2020 controller (see Fig. 2). There are four different modules connected to the backplane and controller. The first module is the cFP-AI-110, which is an 8-channel analog input module for direct measurement of millivolt, low voltage, or milliampere current signals. It features filtered low-noise analog inputs, and incorporates 16-bit resolution. The inclinometer is connected to one of these modules, while the rotary encoder is connected to the other.

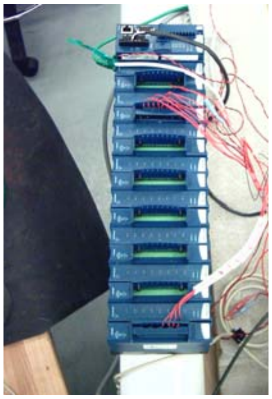

Fig. 2 Controller and its modules

The cFP-PWM-520 is the second module connected to the backplane, and is a pulse width modulation (PWM) output module. This module is not currently used. A relay module is also connected on the backplane. It is the cFP-RLY-421, and is not currently used. The final expansion module used is the analog output module cFP-AO-210. The cFP-AO-210 includes over-current detection for wiring and sensor troubleshooting, as well as short-circuit protection for wiring errors. This module is used to connect the motor control circuits to the controller.

A. Global Positioning System

A Garmin 17N is used. This is a waterproof model designed for marine operation. The GPS data is based on the NMEA standard. The 17N sensor can transmit positional information as often as once a second and at speeds of up to 9600 baud. Moreover the unit can be programmed to output as many or as few different GPS sentences as the user requires. The depth sensor is a IDT800-P17-RETR manufactured by Airmar. It is capable of measuring a minimum depth of 0.4 meters. The sensor also measures the temperature of the water in degrees Celsius. Just like the GPS, the depth sensor sends its data using the NMEA standard.

B. Depth sensor

The depth sensor is a IDT800-P17-RETR manufactured by Airmar. It is capable of measuring a minimum depth of 0.4 meters. The sensor also measures the temperature of the water in degrees Celsius. Just like the GPS, the depth sensor sends its data using the NMEA standard.

C. *Inclinometer Rotary Encoder*

SignalQuest's MEMS Inclinometer is used to provide constant monitoring of the ROV's pitch and roll. This small chip provides measurement of 180 degrees of pitch and 360 degrees of roll to one degree of accuracy. In order to get feedback about the position of the rudder, a rotary encoder was employed. The device was built by BEI, uses the Gray code, and features 8 bit resolution. The rotary encoder was mounted directly above the rudder and connected to the rudder shaft by way of a flexible coupling.

D. *Radio Modems and Motor Driver Circuits*

The ROV's wireless transmission system is composed of two 900MHz, spread spectrum radio modems manufactured by Freewave. These transceivers use the RS-232 to interface with the cFP-2020 controller as well as the user's computer. Both the rudder and the propeller operate at 12V, but they require a great deal of current, far more than the controller can handle. Furthermore, it is desirable to be able to control the speed of both motors. For these reasons, two driver circuits were created to control the speed and direction of both the rudder and propeller motors. The circuits differ only in the way they connect to the controller and accomplish their tasks using pulse width modulation (PWM) to control the speed of the motors. These circuits are built around a MOSFET driver, TD340, and four high current MOSFETs configured in an H-Bridge to direct the flow of current through the motor.

E. *System software*

The software for the control system was developed using LabVIEW. From a high level, the software running the control system can be understood as two major loops that run continually. One executes onboard the cFP-2020 controller, transmitting the status of the ROV and handling the commands sent by the user, and the other executes on the user's laptop, displaying the status of the ROV and relaying commands to the vessel. Though the two major software pieces of the control system are very different, they share a common protocol for communication, allowing them to mesh neatly. This protocol takes the form of two character strings, the "command sentence" and the "status sentence". Both are ASCII based and begin with a '$' character and end with an '&' character. The status sentence contains a series of variables reflecting the state of the ROV. It is created by the controller aboard the vessel and transmitted every 100 ms.

F. *Graphical user interface (GUI)*

The GUI was developed in labView with the front panel as shown in Fig. 3. The vessel's pitch, roll, and rudder position are displayed in real-time. In the upper left hand corner, a grouping of fields displays the GPS position of the ROV, its current true course, and its speed as determined by the GPS. The vertical and horizontal track bars represent the throttle control and rudder control respectively, and allow the user to change the speed and direction of the boat. The software displays the status of the boat, updating the text fields, and graphics in real-time.

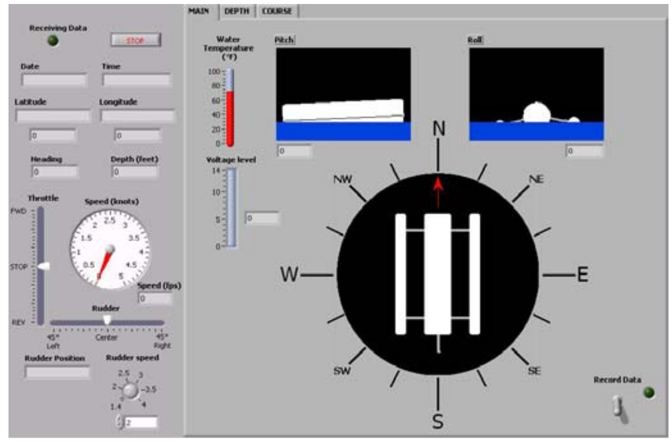

Fig. 3 GUI while ROV is running

IV. Testing The System

Recent tests were conducted on March 25, 2006 (Fig. 4). Fig. 5 shows the flow of data and control signals and Fig. 6 shows the plot of the course for the test. Fig. 7 shows the depth map for the scanned area, which was around 40' by 40'.

Fig. 4 ROV under sail

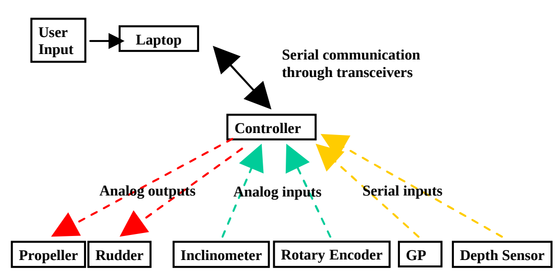

Fig. 5 Data Flow

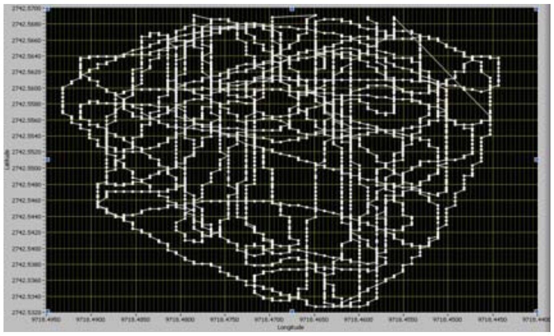

Fig. 6 Navigation Course

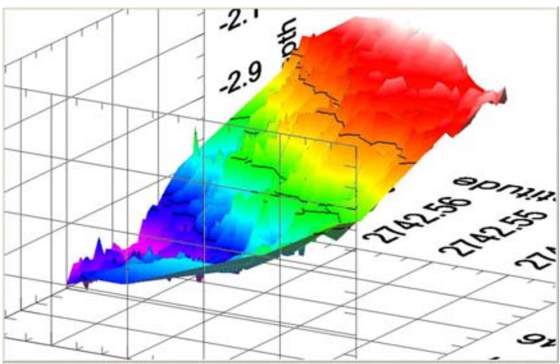

Fig. 7 Depth Map for the course in Fig. 6."

V. Recent Progress

In an effort to increase buoyancy and simultaneously gain draft, modifications to the craft entailed the removal of all instruments and their corresponding electrical systems, modules, mounting brackets, trolling motor and servos. Upon disassembling the internal mechanics of the ROV, the following tasks were performed.

1. Change steering control interface to a chain-driven gear drive from a belt drive.
2. Mount a plate to cover the chain drive so positioning index module may be mounted to interface with the steering operation of the servo motor used to drive the steering system. Use standoffs to mount the desired chain drive cover.
3. Raise the motor to allow for operation in shallower water, effectively changing the operation parameters. Make a new motor mounting surface suspended within the hull of the ROV to allow for the new mounting position of the motor. Make supports to restrain the new motor mounting surface.
4. Shape the stern of the boat to allow for adaptation of new operation parameters.
5. Seal any holes left in the hull of the craft due to the modifications made to the operation and mechanical system configuration.
6. Centralize and minimize the space needed for operation control systems and data micro processing equipment.
7. Reduce the craft's equipment's overall weight to allow for better buoyancy and control.

The major part of the main body of the craft remained intact but it did receive part of the projected modifications at the stern to help address the problem of draft and creation of turbulence of the waters that are going to be researched and studied. Several parts were fabricated for specific purposes for this project including an end cap for the stern, to seal it upon re-shaping to allow for the desired height of the propulsion motor. An aluminum support cage was also fabricated to allow for the centralization of the ROV's operation control system circuitry and related apparatus. The support cage also allowed for a compact space in which to attach other electrical components to minimize hull "floor" space taken up by said components. The retro-fittings involved the removal of a section of the PVC body by removing a portion of the pipe and cut an angle section (approximately @ thirteen degrees) that extended approximately half of the diameter and twelve inches (toward the bow) into the length of the craft. A sheet of Plexiglas was fitted to be able to serve as the mounting platform and receive the trolling motor and its servos, to serve as the propulsion and guiding system for the craft. The rudder mechanism has all been removed and eliminated, saving the servos that will drive and turn the trolling motor to guide, direct and help navigate the craft through the estuaries. The trolling motor has now been reconfigured by developing a gear coupling and chain drive mechanism that has been fitted and attached to the shaft of the trolling motor. The belt system that was used to turn the rudder has been eliminated, with the servos serving as the drives for the trolling motor.

The new mounting point of the trolling motor has been moved to the rear, away from the sensors and GPS systems and by doing so have gained approximately twelve inches of draft. The depth and temperature sensors, along with the GPS system are to remain together at the front of the craft. The motor mount was constructed from a piece of cedar wood due to its light weight, availability, and durability. Subsequently, the mount was to be made stationary at roughly the centerline of the hull of the ROV, so restraints were made to restrain the mount. A total of eight half clamp mounts were made, from pieces of the PVC tubing trimmed off of the ROV during reshaping. The same tubing was used so that the curvature of the hull could be followed as closely as possible and thus gives the best support for the motor mount. Four of the clamps were screwed into the hull of the ROV below the position of where the mount was to be stationary, and four were placed above, to allow for equal pressure in the opposite direction, effectively restraining the motor mount.

Internally, the aluminum channel beam that was used to mount the modules has been removed and scavenged to smaller sections to be able to have more room for the batteries and power the systems. The processing modules have been gathered into a closer fitting bundle, along with the transceiver making the unit more compact and affords for quicker removal and installation. The main package and their functions have remained the same, but have been configured to allow succeeding packages of different sensing devices for future data collecting.

A. Modifications to the control system

On the electrical side, changes had to be made to the circuit board that was first used. Some of the electrical components failed to work properly. Before actually making any new electrical changes, we connected together the equipment then tested the power distribution of the HUB. It was noticed that there was a Mosfet burned out which stopped some circuit flow to pass through the boat properly. So parts were replaced and a new circuit board was built with the corresponding wiring diagrams previously used (Figs. 8 and 9). This ultimately resulted in a smaller circuit board and reduced the weight of the boat. It also defeated the purpose of mounting the control hub to the rear of the boat. Now we can mount just the bottom portion of the HUB and connect the new circuit board to the top. This allows fixing any connection problems to the control board can be easily access without taking out the whole HUB.

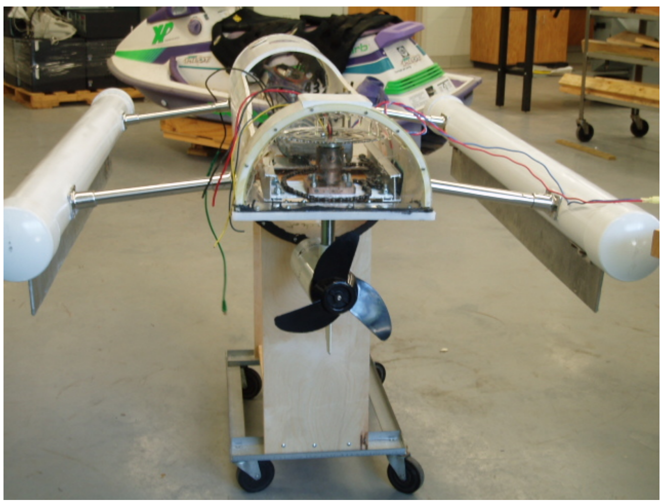

Fig. 8 Modified bow

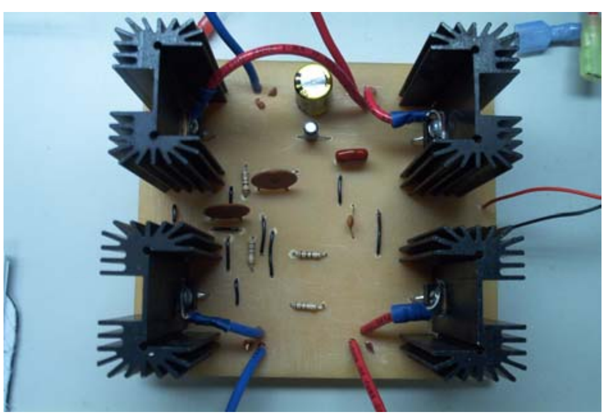

Fig. 9 MOSFET

VI. Future Work

B. Autonomous navigation

Autonomous controls have been an issue of fundamental research in a broad field of systems and applications for years now. Electronic engineering concepts demonstrate that it is feasible to design a vehicle that can have limited human interaction and possibly become fully autonomous through applied technology and research. Programmable autonomous control is of course a desired future aspect of this project as a whole in order to operate the ROV on a set of instructions virtually with no human interaction.

With the National Instruments controller that is currently in place the ROV has the capabilities of having program guidelines and instructions placed inside the Compact FieldPoint hardware through the LabView application. Through a carefully designed set of instructions we can enable stand-alone operation for a period of time. A programmed interface can guide the vehicle on a path based on a grid and various tests in order to limit and/or control distance traveled, degree of turn at set points, and similar distance travel for return. However, unforeseen circumstances of course cause many potential hazards to the stand-alone operation of the machine. To an extent, the dedicated processor running in near real-time gives us a manageable reliability for guidelines set and provides stability for distances and paths that will be traveled. Control and analysis functions will also be able to operate congruously recording desired information along the entire path.

Protocol for communication between the laptop computer and onboard execution of instructions operate at a comparably fast transmitting speed, performing commands at high speeds and directing the vehicle through an accurate path. Although, exterior factors play a major role in the vehicles ability to actually operate on a set path autonomously following programmed instructions that tell the ROV at what distances and to what extent turns and/or stops should be made. Various obstacles can have a dramatic effect on accurate execution of programming parameters by the vehicle such as water current, failure of communication connection, loss of power, actual obstacles that may be underwater and impossible to see, and other objects in the water.

In order to determine the possible functionality of automatic operation of the vehicle through program driven instructions, a precise table of measurements will need to be obtained through detailed operation and testing of the ROV. For example in order to tell the ROV to go 100 feet and turn at a 90 degree angle it will be necessary to know how long, at what speed, and against what amount of current it takes for the vehicle to move a set distance, along with at what rudder degree for a given period of time, it takes to turn a certain degree. Once distance and angle tables are determined through ongoing use and control practice with the vehicle. Programming can begin to be implemented combined with data tables in order to set advanced paths for the vehicle such as shown in the following diagrams.

Performing these basic shapes will allow initial testing that can be performed locally in the OSO bay. Using timetables along with the GPS coordinates to begin setting up travel data tables for the machine. Basic findings could potentially lead us to operational implementation of code on the vehicle that will run it autonomously on set paths possibly even out of view of an operator.

Future work will be needed to survey programming languages and their effectiveness in conjunction with the National Instruments hardware and LabView VI's to determine what languages will give us the best performance. Also, decisions for programming will need to be made regarding formats, as using an assembly language development system for operation code could potentially be the most accurate code, but may be too time consuming. A major consideration is to have the craft become autonomous, to the point that possibly that the craft will not only be capable to be programmed to operate in areas under study and have the ability to maneuver independently using visual cues or sensors around obstacles in its path.

VII. Conclusion

This paper describes the design and development of a remotely-operated shallow-water boat for wireless data logging. The design and development of the boat has had a great deal of student involvement. Overall, this project provides a valuable contribution to research in a number of fields, including oceanography studies, contaminated environments, and hazardous areas. A major goal is to further develop the ROV's capabilities to allow it autonomous navigation, when given a destination or a series of destinations (waypoints). As this new programmatically driven control system becomes more mature and the boat chassis in which it is embedded becomes more reliable, autopilot functionality becomes a possibility.

Acknowledgment

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He is a registered Professional Engineer in the State of Texas and has been involved in engineering education for more than 16 years. His experience includes working for Koch Industries in Corpus Christi, Texas, three summer fellowships with NASA at Johnson Space Center, Houston, Texas, and two summer fellowships with the Navy at the Naval Air Systems Command, Patuxent River, Maryland. Recently, he spent a year at Johnson Space Center as a NASA Administrator Fellow where he investigated eddy-current inspection systems for use on the International Space Station. From 2002 to 2005 Bachnak served as the Director of FUSE (Furthering the Underrepresented in Science and Engineering), a program to improve the recruitment of underrepresented students and to attract them to science and engineering careers.

Dr. Bachnak has served professional organizations in several capacities, including Chair of the Instrumentation Division of The American Society for Engineering Education (ASEE) and member of the Robert G. Quinn Award for Excellence in Engineering Education committee. He has also been active in The Gulf-Southwest Section of ASEE and served as Chair for the 2005 Annual Conference and Section Chair in 2006. Bachnak also serves as a TAC/ABET Program Evaluator and have so far conducted 4 on site accreditation visits. He is a senior member of The Institute of Electrical & Electronics Engineers and has served on the Board of Directors of the IEEE Corpus Christi Section in a variety of positions, including Chair, Vice Chair, Treasurer, and Secretary.

Jack Esparza is a Research Assistant and has been working on this project since spring 2005. Jack is expected to graduate with a B.S. degree in Control Systems engineering Technology from Texas A&M University-Corpus Christi in Spring 2008.