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Real-Time Control of a Remotely Operated Vessel

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Abstract: - Research in aquatic environments such as estuaries, rivers, and coastal bays presents several challenges to the scientist. One of the pressing issues is how to efficiently and reliably gather data in shallow water areas. 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 operated boat and its control system that allows an autonomous operation.

Key-Words: Wireless data acquisition, remote control, autonomous navigation, control system

1 Introduction

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.

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 project 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 have designed and created two remotely operated vehicle prototypes. The first prototype provided an excellent starting point but had several limitations that needed to be addressed [2]. 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 control system employed RC transmitters and servos to maneuver the boat. 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 prototype and moved the ongoing project closer to its final goals [3]. The only similarity in the design of the two boat 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 for this prototype. This prototype also incorporated a new control system that helped overcome many of the limitations of the first prototype. Recent progress will be described in more detail in this paper.

2 Boat Design

The current boat is shown in Fig. 1. One goal was to make it small and light, so as to be easily deployable by one individual. The shape of the hull was selected to increase stability and reduce the area of the boat that was exposed to wind.

Fig.1 Current boat chassis

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. 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 (shown in Fig. 2), and a rudder control system that contains a servo motor (shown in Fig. 3).

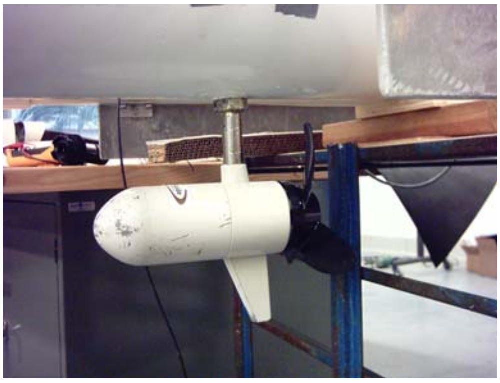


Fig. 2 Trolling motor

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.

3 Control System Design

The control system is built around a powerful controller by National Instruments (NI). The software was developed using the LabVIEW Real Time (RT) development environment.

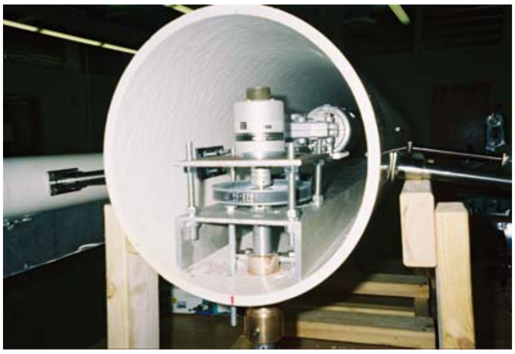


Fig. 3 Rudder control system

3.1 Control system hardware

The National Instruments cFP-2020 was chosen as the controller for the ROV [4]. 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. 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.

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.

3.1.1 GPS

A Garmin 17N is used. This is a waterproof model designed for marine operation. The GPS data is based on the NMEA standard. NMEA stands for National Marine Electronics Association—the standards body that shepherds the standard by which marine navigational devices communicate [5]. 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. Fig. 4 shows the wiring diagram.

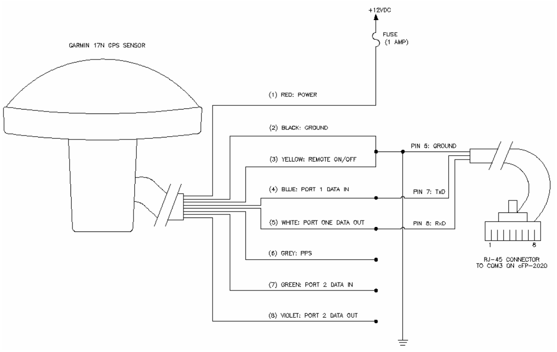


Fig. 4 GPS wiring schematic

3.1.2 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. The depth sensor is connected to the NI controller as shown in Fig. 5.

3.1.3 Inclinometer

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. Fig. 6 shows how the inclinometer is connected to the NI controller.

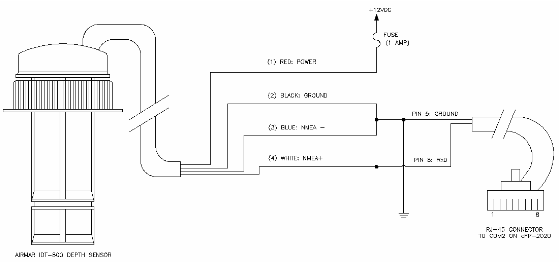


Fig. 5 Depth sensor wiring diagram

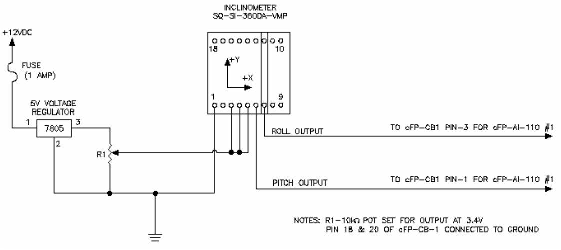


Fig. 6 Wiring diagram for inclinometer

3.1.4 Rotary encoder

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. The wiring diagram is shown in Fig. 7.

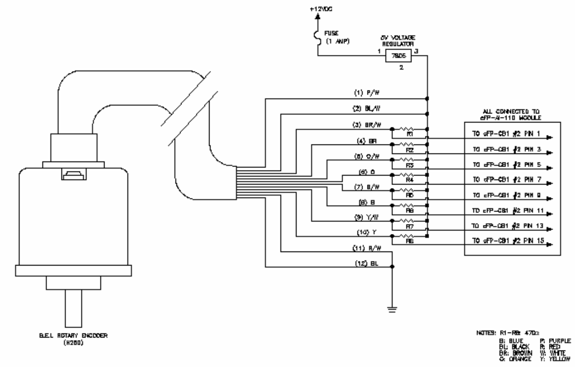


Fig. 7 Wiring diagram for rotary encoder

3.1.5 Radio modems

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.

3.1.6 Motor driver circuits

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. Fig. 8 displays the finished motor control circuits.

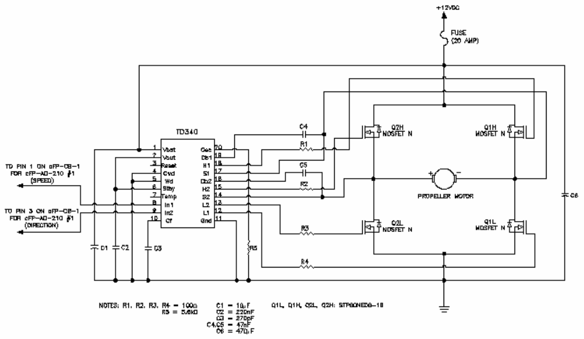


Fig. 8 Propeller motor control schematic

3.2 Control system software

The software for the control system was developed using two primary packages, LabVIEW and Visual Basic .NET 2005. LabVIEW RT is a standalone platform which means that it does not need a Windows based system to operate on.

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. In this way, the control system is very much a distributed system, and as such faces all the challenges of a distributed system—from the unreliability of communications links, to the challenges of synchronizing data between systems.

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. Below is an example of a status sentence. Note that the '|' character is a delimiter.

$2742.7066|N|09719.4375|W|324|90|90|180|1.7|8.1|26.4&

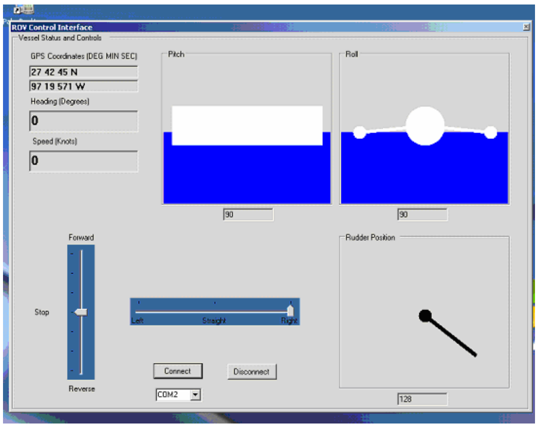
In order from left to right, the fields are latitude coordinates, latitude hemisphere, longitude coordinates, longitude hemisphere, true course, pitch, roll, rudder position, speed in knots, water depth in feet, and water temperature in degrees Celsius. The command sentence contains the throttle and rudder position that the user currently has selected. The sentence is created by the software onboard the laptop and is transmitted every 100 ms. An example follows.

$4|1&

In the command sentence, the first variable is the throttle and the second is the desired rudder position.

3.2.1 Graphical user interface (GUI)

The current system GUI was developed in LabVIEW with the front panel as shown in Fig. 9. 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 (labeled "Heading"), and its speed as determined by the GPS. The vertical and horizontal track bars represent the throttle control and rudder control respectively. Near the bottom center of the screen are "Connect" and "Disconnect" buttons along with a dropdown menu to select the COM port that the transceiver is connected to. To connect to the ROV, the user selects the appropriate COM port and presses "Connect". The software begins displaying the status of the boat, updating the text fields and graphics in real-time. The controls also become active, allowing the user to change the speed and direction of the boat's propeller as well as the position of the rudder.



GPS Coordinates (DEG MIN SEC)
27 42 45 N
97 19 571 W
Heading (Degrees) 0
Speed (Knots) 0
Pitch 90
Roll 90
Rudder Position 128
COM2

Fig. 9 GUI while ROV is running

To begin moving the boat, the operator uses the mouse to adjust the throttle track bar or use the 'w' and 's' keys. Moving the throttle up, the ROV will move forward at incrementally faster speeds. Returning the throttle to the middle position will stop the motor. Moving the throttle down past the mid point shifts the ROV into reverse.

In order to change the position of the rudder, the user can use the mouse to adjust the rudder track bar or use the 'a' and 'd' keys. Moving the track bar left or right moves the rudder to the "left rudder" or "right rudder" positions (225° and 135° respectively). Centering the control returns the rudder to the "centered" position (180°). To disconnect, the user simply presses the "Disconnect" button.

3.2.2 Embedded LabVIEW RT VIs

As mentioned previously, the code that is embedded in the cFP-2020 controller was developed in LabVIEW RT. The main VI that drives the ROV is named "embedded serial".

This VI controls initialization of communication resources, calls the other subVIs that perform the smaller tasks necessary for the ROV to operate, and determines how often these tasks are performed.

3.2.3 Embedded serial VI

The embedded serial VI is the main program. Fig. 10 below shows a snapshot of the VI block diagram. On the left outside the while loop are the configuration options for three serial ports being used. At the top is the port, COM1, that communicates with the control GUI via the radio modems. In the middle, is the port, COM3, which talks to the GPS. At the bottom is the port, COM2, that talks to the depth sensor.

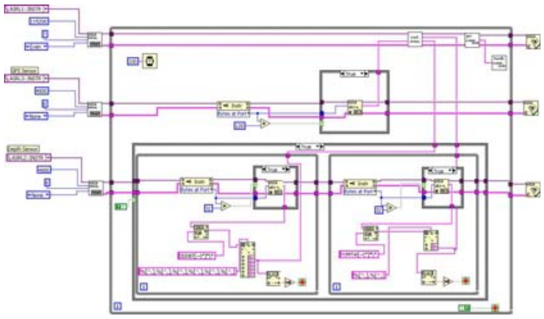


Fig. 10 Embedded serial VI block diagram

Within the loop, which executes every 100 ms, is the logic that checks whether enough data has arrived from the GPS and depth sensor to be worth reading (128 bytes in each of these cases). The other subVIs are also within the main while loop. Each is connected to the serial port that communicates with the GUI. The other sub-VIs that make up the complete program are a Transmit status VI, an Inclinometer read VI, an Encoder read VI, a Get commands VI, and a Handle commands VI.

4 Sea Trials

Sea trials of the control system and ROV chassis took place on the 17th of April, 2005. The wind had been blowing at 20 knots for two days, and the sea was choppy even in a protected beach area next to the A&M-CC campus (see Fig. 11). The ROV was carried into the water and launched while under control of a laptop located onshore. After the vessel was under its own power, it was steered toward the eastern gap in the jetties.

The ROV navigated along the jetties, at times obscured from sight by the rocky jetties or waves. The test was successful and the boat's handling was straightforward and responsive. The ROV, however, collected about a cup of water during an hour and a half of sailing. Fig. 12 shows the boat during the test.

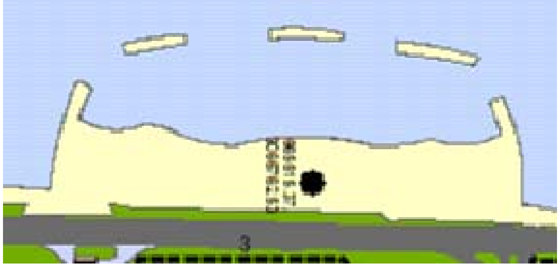


Fig. 11 Map of beach area

The ROV's maximum operational time is calculated to be around 2 hours at full throttle. After this time the voltage drops off and the propeller moves slower. It is worth noting, however, that the control system will continue to function long after the battery is no longer able to propel the boat at a reasonable speed.

Fig. 12 ROV under sail

5 Progress and Future Work

There have been several changes done to the prototype since the sea trial in April. The most notable of which is a new control interface that has been created using LabVIEW 7.1. Another noteworthy addition is one of adding a depth sensor to the front of the ROV. A Panasonic ToughBook CF-29 laptop was also purchased for this project. The ToughBook was chosen because the LCD screen on the IBM ThinkPad was difficult to see when the ROV was being tested outdoors due to the sun. The ToughBook is also water and sand proof and sand proof.

The depth sensor was tested for accuracy by filling a large drum full of water, and then placing the sensor in it. The value it was giving was compared to what the actual water depth was, which was found using a tape measure. The two values were very close to each other, and were off by only a couple of inches. However, this was due to the signals echoing off of the sides of the drum. When the depth sensor was tested in a large pool, it gave more accurate readings.

The embedded VIs on the controller were revised to accommodate the depth sensor. The major upgrade to the software was a new version of the interface which was created in LabVIEW. This new version is still a work in progress. It is reading all of the data being sent by the controller, and sending the correct control sentence to the controller, but it is doing both of them too slowly.

Real-time video is being added to the ROV. The system consists of the Compact Vision System from National Instruments and two cameras. Another improvement that is being worked on is rudder position control. The ROV should offer a limited number of rudder positions that the user can choose from (e.g. 270°, 225°, 180°, 135°, and 90°) and is responsible for moving the rudder to the desired position on its own. The previous version of the control system provided only three positions for the rudder: left, right, and center.

A major aim of the project is to develop functionality that allows the ROV to navigate on its own 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 more of a possibility.

Real-time mapping of the ROV's position is a natural and obvious function for the control system to provide in its GUI. Visually representing the boat's position on a map gives the user valuable navigational insight and would be critical if the ROV is to operate outside of visual range. The ideal mapping system would not only display the ROV's position on a map, but would also allow the user to direct the boat, perhaps by selecting waypoints or paths for the vessel to follow.

6 Conclusion

This paper describes the development of a remotely-operated boat for wireless data logging in shallow water areas. The control system allows integrating additional capabilities as well as the foundation for autonomous operation. The boat paves the way for sophisticated data collection systems in shallow water areas and contributes to research in a number of fields, including oceanography, studies of contaminated environments, and hazardous areas.

Acknowledgement

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References:

[1] Division of Nearshore Research, Texas Coastal Observation Network Homepage, http://tcoon.cbi.tamucc.edu/Main/HomePage, visited in November 2004.

[2] R. Bachnak, C. Steidley, A. Sadovski, C. Rao, W. Lohatchit, C., "A Platform For Environmental Data Acquisition in Shallow Waters," Proceedings of the 51st International Instrumentation Symposium, ISA, May 9-13, 2005, Knoxville, TN.

[3] D. Davis, An Improved Control System for Mobile, Marine Sensor Platforms, Graduate Technical Project Report, A&M-CC, Corpus Christi, TX, May 2005.

[4] National Instruments. NI cFP-2020 – Products and Services, http://sine.ni.com/apps/we/nioc.vp?cid=13446&lang=US, visited in November 2004.

[5] National Marine Electronics Association, NMEA 0183 standard, http://www.nmea.org/pub/0183/index.html, visited in November 2004.