

Involving Undergraduate Students in Research Provides them with Ideas for Capstone Projects

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Abstract

This paper describes a NASA-funded project that has provided students in engineering technology and computer science at Texas A&M-Corpus Christi with technical experience and ideas for graduate and undergraduate projects. The project involves the development of a remote-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. The paper briefly describes two undergraduate projects resulting from students' involvement in this research project.

Introduction

Data collection in shallow water areas normally requires setting up sensors in several places. In addition to being redundant and time consuming, this task when performed manually has a high probability of disturbing the test area. Investigators in the Department of Computing and Mathematical Sciences (CAMS) in conjunction with the Division of Nearshore Research (DNR) of the Center for Coastal Studies (CCS) of Texas A&M University-Corpus Christi (A&M-CC) currently collect water quality data in areas with water 3 ft. or deeper, not covered by one of the stationary Texas Coastal Ocean Observation Network (TCOON) stations, from a man controlled boat.

A number of research centers have been developing autonomous boats [1–4]. 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. This paper describes a project undertaken by an interdisciplinary team of CAMS computer science, engineering technology, geographic information sciences, and mathematics professors and students with environmental investigators at DNR to design and develop a remotely controlled boat that continuously and efficiently collects water quality in shallow water areas (6 in-3 ft), rather than using fixed position sensors to make the water quality collections.

First ROV Prototype

Designing the first prototype took into consideration 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. The following paragraphs describe the major components of the system (see Fig. 1).

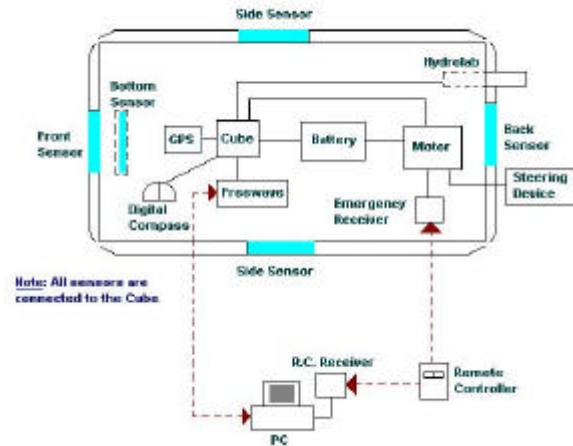


Figure 1. Overall System Diagram

Docking/Control Station

This station is located onshore and consists of a remote controller and a PC. The remote controller transmits data to steer the boat and select its speed. The PC is used to store and process the received data and to display the status of major systems and onboard sensors. The PC display serves as a guide to assist the operator with navigation when objects around or under the boat are detected. The operator is able to direct the boat to investigate areas of interest.

Boat Hull and Mounting

Several issues were addressed before selecting the shape of the boat. These include onboard weight, type of power, condition of the water in which the boat is used in, means of transportation, and the desired draft. Several types of boats were considered, including a V bottom, round bottom, multi-hull, and flat bottom. Since the draft of the boat is one of the most important criteria, a flat bottom was selected. Several types of materials were considered, including aluminum, fiberglass, wood, abs-plastic, and steel. Most materials are too heavy to meet the shallow draft requirement. As a result, a polyurethane foam block was used. Polyurethane has two major advantages: (1) It floats with the least draft, and (2) It can be easily modified and customized by carving it before adding fiberglass. Fig. 2 shows the boat hull. The boat was constructed by carving the foam block and adding a polyester gel coat and fiberglass cloth to strengthen the boat. The top of the boat is carved to fit the battery and the waterproof case contains the electric components. Total weight of the prototype is around 150 lb. The motor was held in place using 3/16" aluminum sheets. The mounting contains two aluminum sheets. One sheet covers the top and the other sheet covers the transom and bottom of the boat. All pieces were configured with reusability in mind and for easy replacement of the damaged parts.

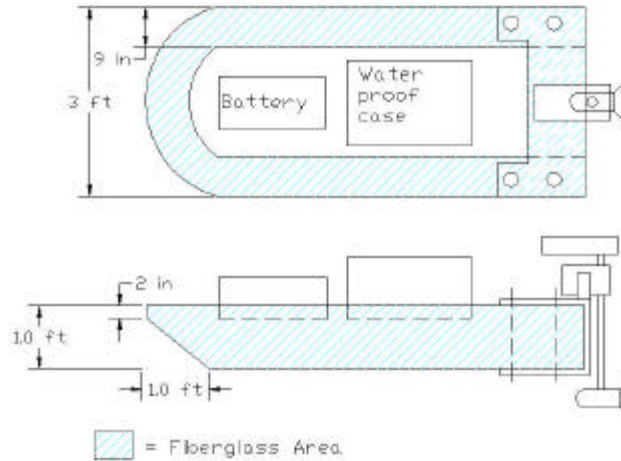


Figure 2. Boat Hull Dimensions

Propulsion System and Steering

A MotorGuide model GWT36 electric trolling motor is used to propel the prototype (refer to Fig. 3). This motor is rated for salt water operations and can handle a weight as heavy as 1500 lb. It has a hand-controlled steering and 5-speed forward and 2-speed reverse. The motor was easily modified for remote control.

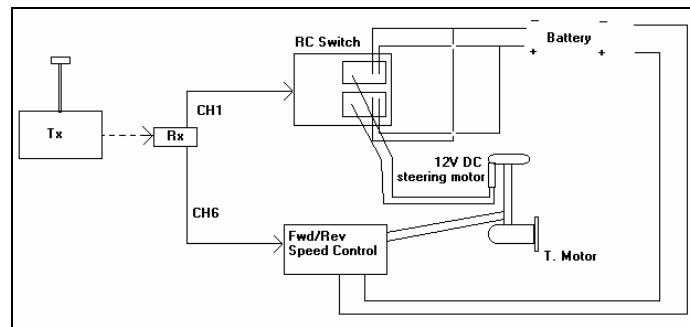


Figure 3. Propulsion Control

The remote control function is accomplished via a Futaba® 6-channel FM radio. Only two channels are used. One channel controls the steering via a high torque servo and pushrod that connects to the shaft of the motor and the other channel controls forward and reverse speed via a remote control switch. The control switch consists of two relays that open and close according to the pulse signal of the Receiver (Rx). To improve the design, the servo harness was replaced by a 12 VDC steering motor that has a worm gear built in and the use of an RC switch to control the direction, left and right.

Power Requirements

Two batteries are used to power the system: A marine battery that operates the motor and another small battery to operate other onboard electric components, such as radio, embedded PC, sensors, and GPS. The system operates at medium speed with the 98Ah

marine battery for about 4.8 hrs without recharging. An estimation of system power is shown in the following table.

| SYSTEM COMPONENT | REQUIRED CURRENT (A) |
|------------------|----------------------|
| TROLLING MOTOR | 20.00 |
| RC SWITCH | 0.22 |
| SERVO | 0.13 |
| RECEIVER | 0.14 |
| TOTAL | 20.36 |

Embedded PC and Sensor

The onboard PC consists of a stack of PC/104 modules with analog-to-digital conversion capabilities and serial port interfaces. The PC/104 acts as a central control unit and interfaces with the radio and all onboard sensors, including the GPS and digital compass. The water quality sensor is a Hydrolab® designed to be used in fresh, salt, or polluted water. This instrument measures several parameters, including temperature, pH, dissolved O₂, and salinity. Some Hydrolab® models include a pump via a tube to take the water through the process onboard. Such a device is useful in shallow water areas since the Hydrolab® is not have to be immersed in water.

Testing the First Prototype

A sea trial was performed in February 2003 at the man-made beach area at the university (See Fig. 4). The boat is shown in Fig. 5 and acquired data is displayed on the operator's laptop as shown in Fig. 6. The purpose of this test was to check the steering mechanism and remote controller. Both the steering mechanism and the remote controller met all expectations. As a result of this test, however, minor modifications were made as follows.

1. It was noticed that the shaft of the trolling motor can easily come loose if the motor hits the bottom. This is due to a gap between the waterproof box and the attachment that connects the motor and steering gear. To address this problem, a spacer that reduces the gap but increases the flexibility of the motor was introduced. This modification also made detaching the motor from the steering gear easier. This is desirable for maintenance and repair.



Figure 4. Man-Made Beach Area



Figure 5. Sea Test

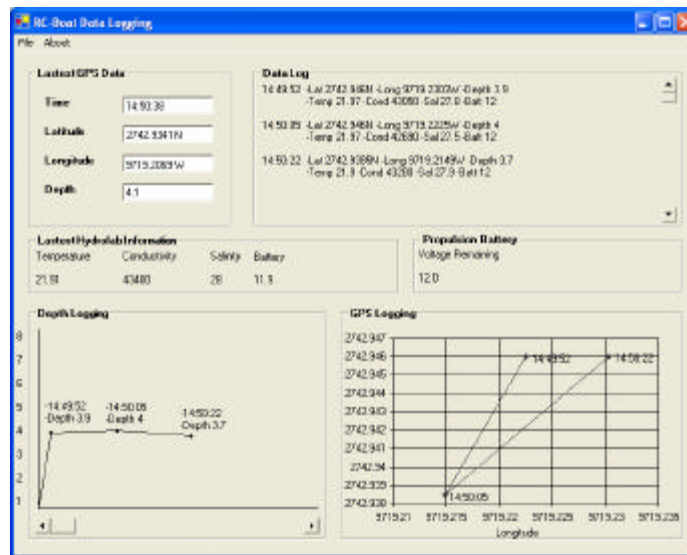


Figure 6. Graphical User Interface

2. It was also discovered that once the boat is in the water, the operator can not determine the direction of motor. This is especially true if the boat is heading toward the operator. This made controlling the boat a challenging task. To resolve this problem, a flag was added to assist in determining the direction of trolling motor.
3. The propeller was not totally submerged. This resulted in cavitation, the formation of low-pressure bubbles in liquids from rotation of a propeller. To resolve this problem, the angle of the trolling motor was slightly adjusted through its mounting.

The Second Prototype

The first prototype provided an excellent starting point but had several limitations that needed to be addressed. 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 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. The second prototype was a completely new design that moved the project closer to its final goals. 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. The boat is shown in Fig. 7. The shape of the hull was selected to increase stability and reduce the area of the boat that was exposed to wind.



Figure 7. 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, 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.

Control System

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. National Instruments cFP-2020 was chosen as the controller. 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. 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. 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.

GPS

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.

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.

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.

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.

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.

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.

System software

The software for the control system was developed using two primary packages, LabVIEW and Visual Basic .NET 2005. 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.

Graphical user interface (GUI)

The GUI was developed in Visual Basic .NET with the front panel as shown in Fig. 8. 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.

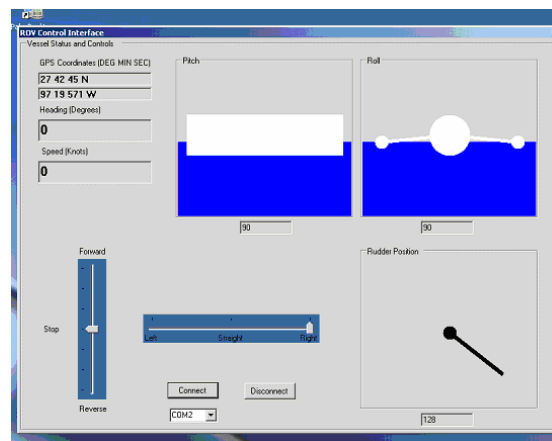


Figure 8. GUI while ROV is Running

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.

Testing the Second Prototype

Sea trials of the ROV 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 the protected beach area next to the A&M-CC campus. 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. 9 shows the boat during the test.

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.



Figure 9. ROV Sailing

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 at a rate of approximately four times a second. 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 is now capable of moving the rudder through a limited range of rudder positions, from 45° left of center to 45° right of center. 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.

Student Projects

Five graduate students and eleven undergraduate students have worked at times on the ROV boat project since 2002. The first prototype was led by Wien Lohachit who graduated in 2003 and the second prototype was led by Daniel Davis who graduated in 2005 [6, 7]. Both Lohachit and Davis were graduate students in Computer Science. One undergraduate capstone project was completed by Cody Ross, Mike Englert, and William Wright in spring 2005 and another one is being implemented by Marc Mendez who plans to graduate in spring 2006. The following pages briefly describe these two projects.

Project 1: Front Panel for Remotely Operated Shallow Water Boat

This capstone project was completed by three undergraduate students in spring 2005 [8]. Students designed and developed a system that monitors ROV equipment to detect bad fuses, shorts, and low battery power. The system used the 8051 microcontroller and custom circuitry. There is a low battery indication circuit, a short circuit detection circuit, and a blown fuse detection circuit. An overall block diagram of the system is shown in Fig. 10. The 8051, constantly monitors the status of the low battery indicator circuit, the blown fuse indicator circuit, and the short circuit detection circuit. When one of these cases becomes evident, a signal is sent to the 8051. The 8051 sends a signal to the front panel which lights the correct LED and displays the problem detected on the LCD display. The 8051 is connected to the LCD via RS232 serial cable. The LCD actually contains an onboard microcontroller. The software was written using Keil uVision2 and coded in assembly language.

Figure 11 shows an overall schematic of the hardware circuit. The design can accommodate a combination of seven short circuits and fuse indicators. All indicator circuits are connected through an OR gate. This allows a one pin connection to the microcontroller, the External Interrupt 1 pin. Once the microcontroller is interrupted the system will poll through the pins connected into the OR gate, pins 21 through 24. The blown fuse indicator circuit is located in the top left of Fig. 11. A voltage regulator was connected to the positive side of the fuse block. This creates a signal that is five volts which is inverted and connected to the OR gate. When a fuse is blown or removed, the signal becomes high which will trigger an interrupt. The battery level indicator circuit is comprised of a basic comparator circuit using an LM741 Op-Amp. The battery level indicator is located on the bottom left in Fig. 11. The circuit compares the input value, connected to the main battery, to a set value. When the battery level drops below the desired level an interrupt is triggered.

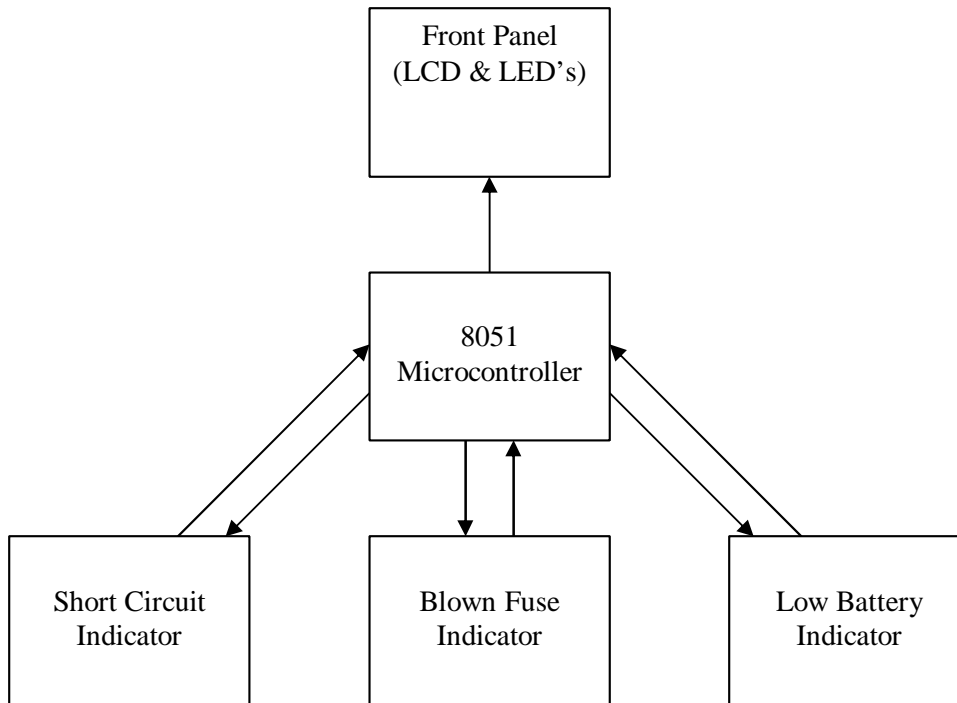


Figure 10. Overall Block Diagram

The short circuit indicator is comprised of a modified Wheatstone bridge configuration. The circuit will be balanced with the known resistance of the circuit to be monitored. When a short circuit occurs, the resistance of the circuit will drop and the balance of the bridge will be broken thus triggering an interrupt. The final circuit section is for the operation of the LED's. The circuit uses a 3904 transistor. When the microcontroller sends a low signal through the inverter the transistor is switched "on" allowing the ground of the LED to connect which illuminates the LED.

Project 2: Control System for a Remotely Operated Jet Ski

The plan for this project was developed in Fall 2005 by Marc Mendez [9] and the actual implementation will take place in spring 2006. This project involves modifying a jet ski, equipped with several sensors, to be remotely operated. The modifications to the Jet Ski will have to be to the starting, steering, and throttle systems. A National Instruments Compact FieldPoint Controller will be aboard the Jet Ski to receive the user's instructions from a laptop. The controller will also collect data from the sensors and send that information back to the user's laptop through a wireless transceiver. A video system will be implemented into the Jet Ski to help the operator with proper navigation. The software will be developed using LabVIEW. It will consist of two different programs communicating with one another, one running from the controller, and the other will be a graphical user interface that runs from the user's laptop. This will allow the user to control the Jet Ski as well as view the data that it is transmitting.

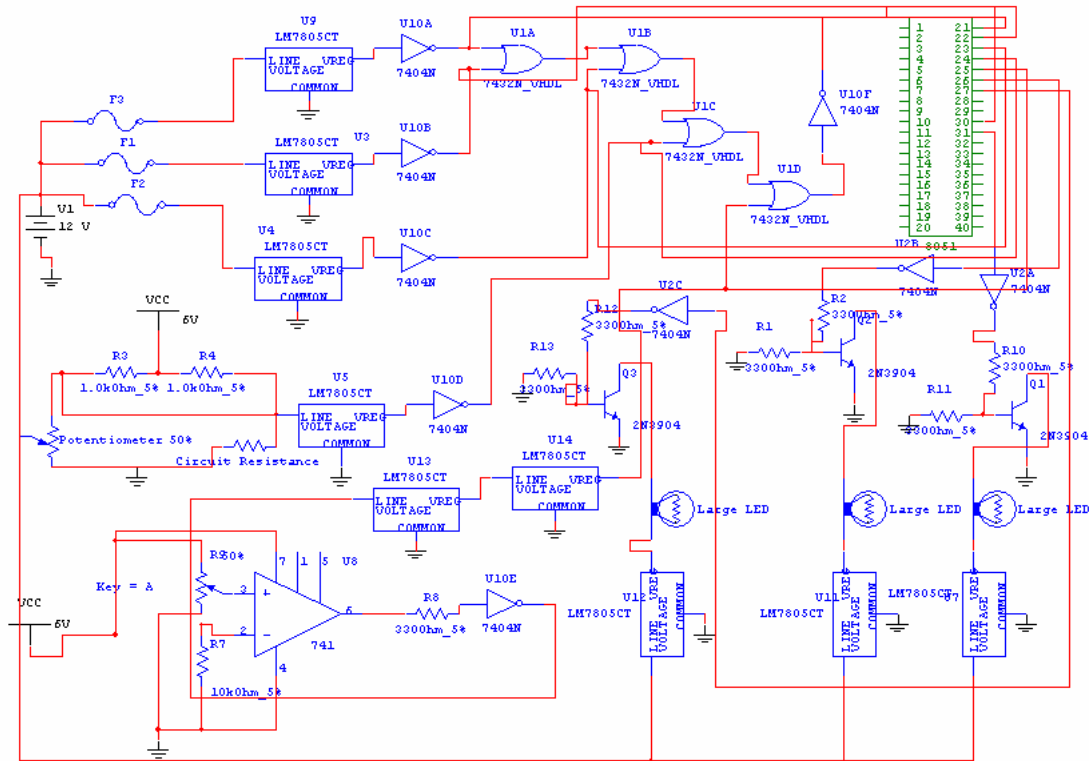


Figure 11. Overall Schematic

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. Undergraduate engineering technology students have also used the boat to come up with projects that satisfy their course requirements. Overall, this project provides a valuable contribution to research in a number of fields, including oceanography studies, contaminated environments, and hazardous areas.

Acknowledgement

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BIOGRAPHY

RAFIC BACHNAK

Rafic (Ray) Bachnak is Professor and Coordinator of Engineering Technology at Texas A&M University-Corpus Christi. He received his B.S., M.S., and Ph.D. degrees in Electrical and Computer Engineering from Ohio University in 1983, 1984, and 1989, respectively. Dr. Bachnak was previously on the faculty of Franklin University and Northwestern State University. He is a member of ASEE and Sigma XI and a senior member of IEEE and ISA.

MIKE ENGLERT

Mike Englert is a recent graduate of Texas A&M University – Corpus Christi. Mike graduated with a BS in Control Systems Engineering Technology in May 2005. He worked on the ROV boat project from Spring 2004 to spring 2005.

MARC MENDEZ

Marc Mendez is a senior at Texas A&M University – Corpus Christi in the Control Systems Engineering Technology program, and will be graduating in May 2006. He has worked on the ROV boat project since Spring 2005.

CODY ROSS

Cody Ross is a recent graduate of the Control Systems Engineering Technology Bachelor's of Science program. Cody was involved in this and other ROV related projects from fall 2002 to spring 2005.

WILLIAM WRIGHT

William Wright is also a recent graduate of the Control Systems Engineering Technology Bachelor's of Science program. He worked on the ROV project in spring 2005.