Design and Implementation of an Underwater Remotely Operated Vehicle (uROV)

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Abstract

We propose to improve upon the Underwater Remotely Operated Vehicle developed by Maila Sepri and Samantha Brody in the Spring of 2005. The uROV will be remotely controlled by a joystick and operate using an internal battery pack and new propulsion system. Environmental sensors will wirelessly send data to a nearby computer so that the uROV's position can be tracked and recorded. The uROV will be an excellent addition to the robotics lab and can also serve as a basis for robotics competitions in the future. The project will approximately cost $376 dollars and will be supervised by Professor Carr Everbach.

Introduction

Our project aims to create an uROV that is able to navigate Ware Pool and send its depth, velocity, and rotational direction to a computer so that its path can be recorded. Currently, the range of motion of the uROV is hindered by the wires that connect it to an external battery pack and that connect its sensor outputs to a computer. We will eliminate this handicap by rebuilding the uROV with a battery pack attached and design a wireless interface between the sensors and the computer. The sensors will consist of accelerometers, gyroscopes, pressure sensors, a compass module, and a water sensor to detect leaks. Because the bilge pumps on the old uROV did not provide the necessary thrust, a new propulsion system will be built. The current control circuitry that provides power to the propulsion system and sensors will also be redesigned to conserve space. To control the movement of the uROV, a wireless joystick will be used.

The next section is a detailed technical discussion of the uROV's system design and electronic components. The project plan section details the expected hours each task will take to complete and then organizes this data into a timeline according to the Critical Path Method. The qualification section describes the team members' experience and skills that are relevant to the project. The final section is a summary of the costs that are necessary for project completion.

Technical Discussion

The Underwater Remotely Operated Vehicle (uROV) will build on the successes and learn from the failures of two previous Senior Design Projects, the Indoor Aerial Robot[1] and the Underwater Remotely Operated Vehicle.[2] Some background concepts were obtained from the Autonomous Underwater Vehicle Competition[3] competitors, specifically the Low Cost Underwater Vehicle from the University of Hawaii[4]. A modular concept is useful in visualizing the components comprising the uROV. In addition to the structure of the vehicle, the individual elements shown in Figure 1 below will be discussed.

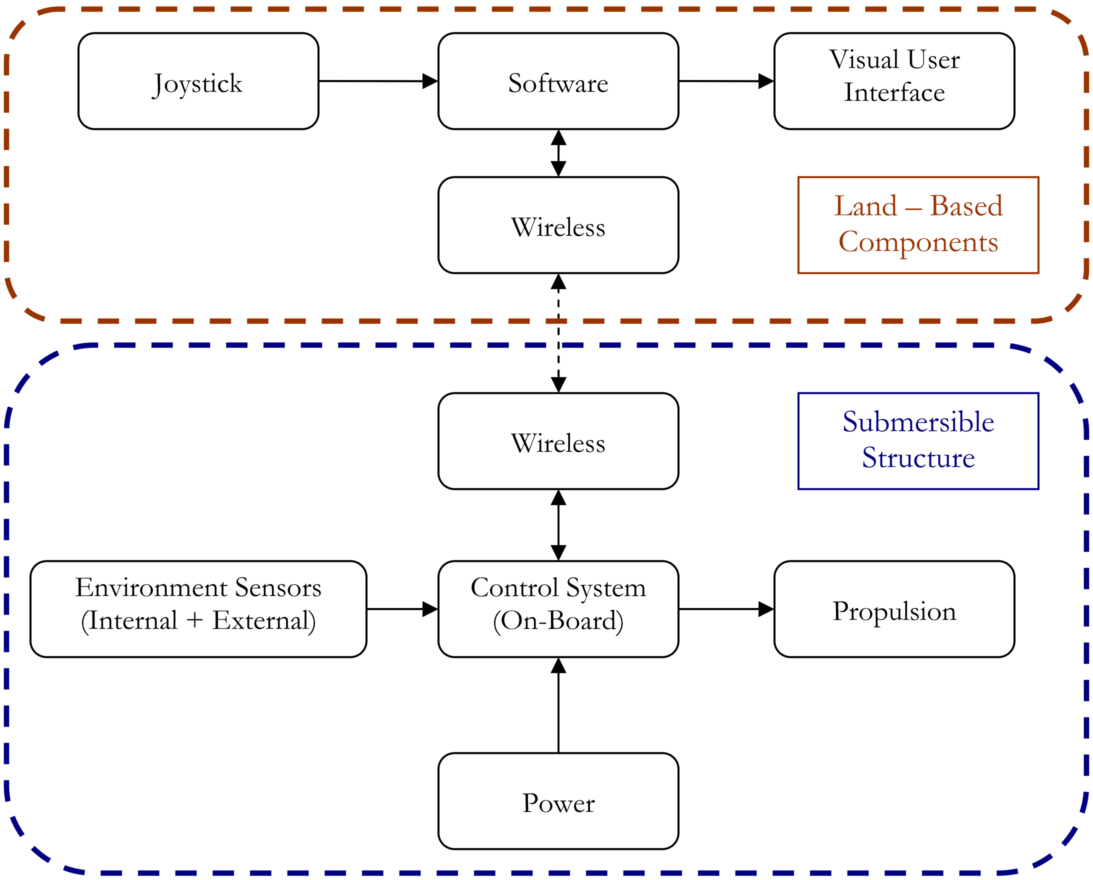

Figure 1: Modular view of the uROV systems

[1] Design and Construction of an Indoor Robotic Blimp for Urban Search and Rescue Tasks. G. Hollinger, Z. Pezzementi, A. Flurie, B. Maxwell. Swarthmore College, 2005.
[2] Design and Construction of an Underwater **ROV**, S. Brody, M. Sepri, Swarthmore College, 2005.
[3] http://www.auvsi.org/competitions/water.cfm
[4] LUV: The Low Cost Underwater Vehicle. A. Sehgal, J. Kadarusman, L. Fife. U. of Hawaii, 2004.

Sensor System

Sensors are of critical importance to the uROV and are one of the core systems around which the rest of the vehicle is designed. Hence, it is important that every component meet all of the requirements set forth in order to achieve proper operation of the robot. The sensors can be divided into being assigned two essential functions.

The first role of the sensory system involves quantifying the vehicle's position relative to the global environment. This is assumed to be a dynamic and volatile body of water. As such, it is imperative for this subsystem to be robust in situations involving the ineffectiveness of one or several sensors. This goal will be accomplished by having a redundant orientation system which involves the Devantech CMPS03 magnetic compass[5] and two Analog Devices ADSRS401 iMems gyroscopes[6]. One of the gyroscopes will complement the compass so as to retain the horizontal planar orientation if there is a problem with the magnetic field. In this case the gyroscope can be used to retain the relative azimuth even though the absolute measure is unavailable. The second gyroscope will be used to orient the robot in the vertical plane. Two Analog Devices ADXL203 iMems dual-axis accelerometers[7] will be used to measure acceleration in all three axes. Both the gyroscopes and accelerometers are of the highest sensitivity available and should therefore be sufficient for our purposes. The fifth and final sensor for the external environment will measure the water pressure exerted on the outside of the uROV, which can then be translated into a depth measurement. This pressure transducer will most likely be determined be a Measurement Specialties MSP-300 or MSP-600 model[8].

The second function of the sensor system is responsible for monitoring internal conditions of the uROV. Due to the damage water can do by seeping into the compartments, leak sensors are essential in any location enclosing the printed circuit board (PCB) or batteries. Such a sensor consists of two parallel lines drawn using a conductive pen[9] spaced approximately 0.5 centimeters apart. If a voltage is applied to the two strips, a leak is detected since the system will form a short circuit once water connects the two strips.

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[5] http://www.robot-electronics.co.uk/shop/Compass_CMPS032004.htm
[6] http://www.analog.com/en/prod/0%2C2877%2CADXRS401%2C00.html
[7] http://www.analog.com/en/prod/0%2C2877%2CADXL203%2C00.html
[8] http://shop.msisensors.com/xmcart/controls/images/msi/2001733.pdf
[9] http://www.jameco.com/wcsstore/Jameco/Products/ProdDS/263716.pdf

Lastly, due to the heat generated by the voltage regulators and MOSFETs in a closed compartment, temperature monitoring is beneficial for recognizing overheating. This is easily implemented using one or both of the gyroscopes since each has an intrinsic temperature sensor for calibration. Figure 2 graphically illustrates the sensory system.

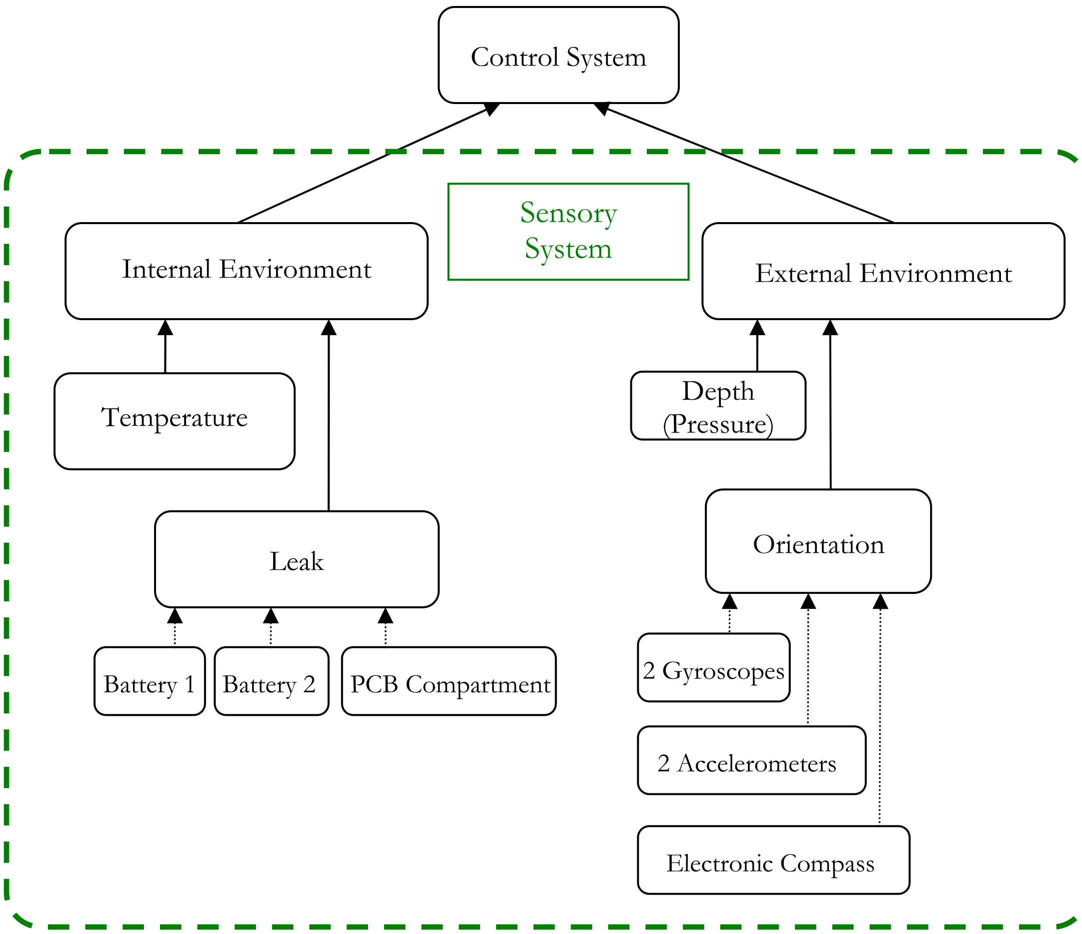

Figure 2: Sensory System

Control System

The control system of the uROV has to be able to manage a wide array of input and output signals. A PIC microcontroller remains the best balance of cost, processing power, complexity, and power consumption. After consideration of the inputs and outputs required for sensors and propulsion control, respectively, the Object-Oriented PIC appears to be the best solution. Specifically, the OOPic "S" Board[10] is the most appropriate style, containing a prototyping area allowing customization of Input/Output ports and easier integration with the control circuitry required by the uROV.

One of the primary reasons for selecting the OOPic over other controllers is the ease of communicating with I^2C compliant devices, which include the Devantech compass and the WCM controller. I^2C is an acronym standing for Inter-Integrated-Circuit and is a serial computer bus used to attach low speed peripherals to a processor. For the electronic compass, the only alternative to the I^2C interface involves measuring the pulse width of the signal emitted by the sensor. Such a measurement is beyond the scope of most PIC microcontrollers. Furthermore, the WCM is specifically designed for compatibility with the I^2C interface of the OOPic.

Two other important considerations include the OOPic's seven Analog-to-Digital (A/D) converters and PWM capabilities. Since most of the sensors have an analog 0 to 5 volt output reading, it is imperative to be able to convert and process the data. As mentioned previously, pulse width modulation will be used for graded propulsion system control. Although only two pins on the OOPic have intrinsic PWM capability, objects in the code exist to facilitate PWM outputs on all of the pins.

The OOPic will be responsible for rudimentary calculations involved in maintaining the robot moving on course or remaining stationary, depending on the user input. This will be accomplished using feedback from the sensory system. Furthermore, the OOPic will be responsible for emergency maneuvers such as immediate surfacing due to a leak detection or low battery voltage.

Wireless

Two Wireless Communications Module[11] (WCMs) Transceivers will be used to link the uROV to the computer running the user interface without the need for a hard link as in the past. The WCMs will be the same as those used on the blimp project, which were easily integrated with the OOPic. Since RF signals do not propagate well through water, a buoy will be constructed in order house the antenna of the WCM. Acoustic modems were

[10] http://www.oopic.com/connects.htm
[11] http://www.totalrobots.com/pdfs/DS-WCM(Totalrobots).pdf

researched to bypass this problem, however these are out of the budgetary scope and size constraints of this project.

Propulsion System

One of the main modifications from the previous design involves the propulsion system. In their original configuration, the bilge pumps had a one-directional output stream that was difficult to direct and regulate. As a solution to this problem, the new propulsion system will use modified bilge pumps as waterproof motors for driving propellers. The low-cost propellers will be constructed from common computer case fans. This will allow greater flexibility in the speed of the fans, as well as adding the capability of using the motors in the reverse direction.

Power

For robustness, there will be three power sources on the robot. Two of these will be 12 volt, 12 amp-hour batteries[12] used to power the propulsion system. Such a configuration will aid in equally distributing weight throughout the uROV frame. The third battery will be a Lithium-Polymer 7.4V, 1.5 amp-hour pack[13] used to power the control system. This will ensure sensor feedback and communication with the user even if both propulsion batteries fail. If the control system allows, this battery can also be used to power the bilge pumps for a short period of time.

Structure

The structure of the robot will be based on last year's ROV design with some modifications. The same PVC piping will comprise the frame, however the brittle plastic grating previously used to mount the bilge pumps will be replaced by a stronger metal equivalent. In order to protect the electronics and batteries, either a custom housing will be constructed from PVC piping or enclosure boxes with an Ingress Protection (IP) rating of at least IP-68 will be used. SEACon waterproof connectors will be used to connect all sensor and motor wires passing through the watertight enclosures.

Software

The Swarthmore robotics software developed by Dr. Bruce Maxwell's research will be used to implement control and tracking of the robot. It will also be used to interface with the joystick and the WCM module.

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[12] http://www.batterymart.com/battery.mv?p=SLA-12V12-X2

Project Plan

The following table summarizes the activities with their respective dependencies and resultant actions which they feed. The chart also states the expected duration of each action.

Activity	Needs	Feeds	Duration	Effort	Action
A	-	B	1d	2h	Evaluate present condition of previous ROV
B	A	C	3d	6h	Research sensors and specialized parts
C	B	D, F, H, J	7d	14h	Choose and obtain optimal parts
D	C	E	14d	28h	Prototype and evaluate propulsion system (Re-order parts as necessary)
E	D	G	3d	6h	Finalize and construct propulsion system
F	C	G, I	3d	6h	Design and construct submersible structure
G	E, F	O	1d	2h	Attach propulsion system to submersible structure
H	C	K	7d	14h	Individually test sensors on breadboard
I	F	O	3d	6h	Waterproof & attach battery to submersible
J	C	P	64d	128h	Program PIC microcontroller
K	H	L, M, N	14d	28h	Design and build control circuit on breadboard
L	K	P	56d	112h	Create PC software
M	K	O	3d	6h	Implement wireless link
N	K	O	14d	28h	Design and order PCB for control circuit
O	G, I, M, N	Q	7d	14h	Physically integrate and waterproof all components
P	J, L	Q	7d	14h	Implement feedback control algorithms
Q	O, P	R	7d	14h	Test in Ware Pool
R	Q	-	7d	14h	Write presentation and report

Table 1: CPM Network Chart

Figure 3 on page eight is the initial network that allowed us to determine the critical path. Figure 4, on the next page as well, is the Milestone Chart that demonstrates how we will be able to finish our project by May 1st.

[13] http://www.hobby-lobby.com/kokam.htm

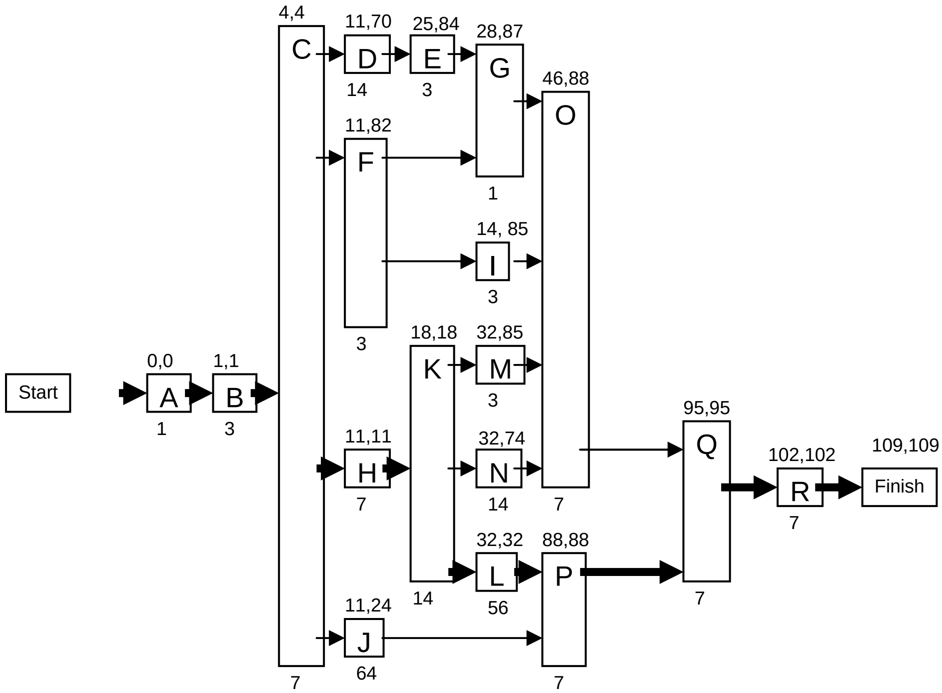

Figure 3: Initial CPM network

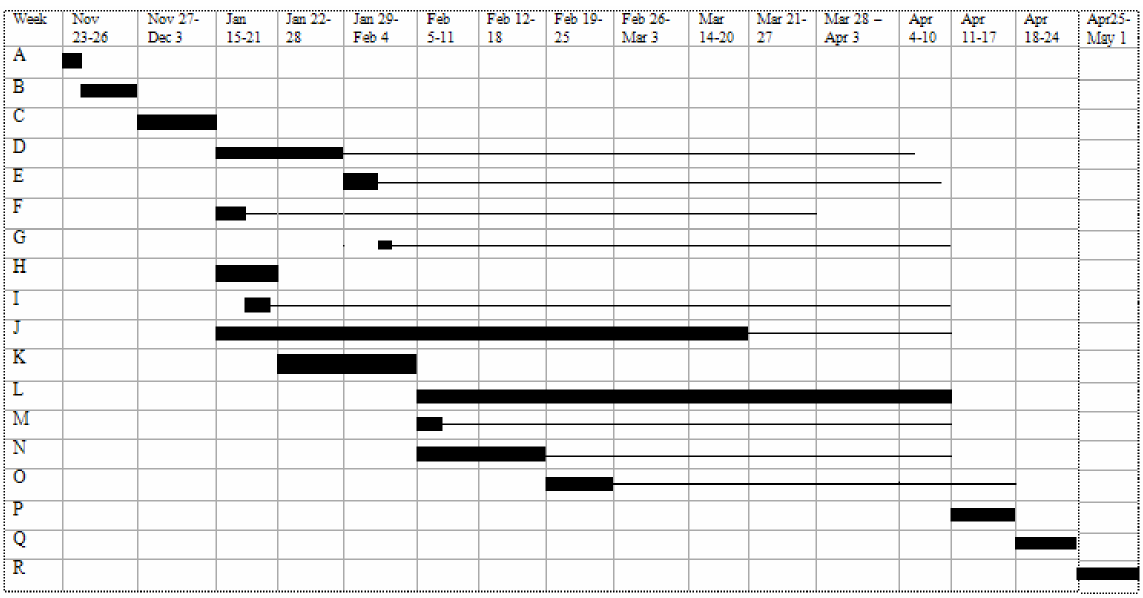

Figure 4: Milestone Chart

Project Qualifications

Alexey Rostapshov is a senior engineering student whose course work has emphasized circuit design and implementation, programming, and robotics. Alexey worked with Maila Sepri and Samantha Brody on the ROV in the Spring of 2005 and has intimate knowledge of the ROV design.

Tyler Strombom is a senior engineering student. His electrical engineering elective courses at Swarthmore have given him experience with PIC microcontrollers, circuit design and implementation, as well as basic programming knowledge of Matlab and C/C++. While at the University of Edinburgh in Scotland, Tyler gained experience with DC and AC motors/generators and power distribution. He has two years of shop experience and is proficient with a Bridgeport, lathe, drill press, and other basic shop tools.

Project Cost

The total project cost is tabulated on the next page as Table 2. The final cost is estimated to be approximately $376.

Table 2: Total Cost of uROV Project

System	Part	Quantity	Retail Cost (Ea.)	Total Retail	Actual Cost	Supplier
Power	12V, 12Ah Battery (SLA-12V12)	2	$20.95	$42	$42	www.batterymart.com
	1500 mAh, 7.4V Lithium-Polymer Battery (FM15002)	1	$31.20	$31.20	$31.20	www.hobby-lobby.com
Control	Printed Circuit Board	1	$40.00	$40.00	$40.00	
	Common Electrical Components	Various	Nominal	Nominal	$0 (In-House)	
	OOPic-II+	1	$69.95	$69.95	$69.95	www.superandroidrobots.com
Sensors	iMems Gyroscope (ADXRS401EB)	2	$50	$100	$0 (sample)	Analog Devices (www.analog.com)
	iMems Accelerometers (ADXL203EB)	2	$30	$60	$0 (sample)	Analog Devices (www.analog.com)
	CMPS03 Magnetic Compass	1	$51	$51	$51	Acroname Robotics (www.acroname.com)
	MSP-300 or MSP-600 Pressure Sensor	1	$60-$110	$60-$110	$110	Measurement Specialties (www.msispec.com)
	Conductive Pen (P/N 263716)	1	$13.99	$14	$14	Jameco (www.jameco.com)
Wireless	Wireless Control Module (WCM) Transceiver	2	$100	$200	$0 (In-House)	Total Robots (www.totalrobots.com)
Propulsion	Rule 500 Pump	6	$18.95	$113.70	$0 (In-House)	C.G. Edwards & Co. (www.cgedwards.com)
	Muffin fans	6	$2.99	$17.94	$17.94	www.newegg.com
User Interface	Joystick	1	TBD	TBD	$0 (In-House)	
Structure	SEACon Waterproof Connectors	10	TBD	TBD	$0 (Donation Expected)	www.seacon-usa.com
	Grating	TBD	TBD	TBD	TBD	
	PVC Piping	Nominal	Nominal	Nominal	Nominal	