EML 4905 Senior Design Project

A B.S. THESIS
PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Underwater R.O.V.er

25% Report

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April 11, 2014

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Ryan Wright, Daniel Martinez, and Edgar English and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract:

This project is an attempt to develop a Remotely Operated Vessel (ROV) for underwater exploration. To provide some guidelines this ROV is being developed according to the Marine Advanced Technology Education (MATE) competition requirements, with emphasis on being able to freely improve the dynamics of this particular design. The requirements being attempted include surveying, research, and recovery of objects. Design constraints will primarily be concerned with providing power to the ROV from the surface, maintaining dimensional constraints and being able to reach a predetermined depth. With the growing applications of ROV's on a daily basis and the scope of their requirements, considerations in the development of this project are being focused towards maintaining a minimal cost and increasing the ability to freely modify the ROV to include other tasks within their potential to assist in reducing the need to invest in multiple ROVs.

1 Introduction

1.1 Problem Statement:

This project is being designed to compete in the MATE ROV competition in the Explorer (Advanced) class. The ROV being designed must be capable of performing tasks such as:

- Identifying and surveying a shipwreck based on evidence found within the structure
- Collecting biological samples and replacing sensors underwater
- Recovering objects such as litter and anchors

These tasks are grouped with other minor requirements and a time frame of 15 minutes to complete each task. This project is being developed to complete all of these tasks with the consideration of being able to modify the platform slightly to add more applications to the capabilities of this design.

1.2 Motivation:

The motivation to design an ROV comes from the fact that as engineers we are constantly trying to push the development of technology. With ROV's there is already an established industry which has many opportunities for growth and bettering the understanding of our underwater environment. Part of the reason much growth is possible comes from the fact that many of the instruments used are industry specific with minor attempts at expanding the applications for these tools. This project requires a collective use of the engineering knowledge attained such as Fluid Mechanics, Mechatronics, Materials, Mechanics of Materials, Manufacturing and Dynamics. With the applications of this knowledge our design will be effective and successful. The combination of the designers on this project also fuels the motivation with experience from scuba diving and the Navy.

1.3 Literature Survey:

In 1982 ROV technology began to take form due to advances in fiber optic communications and robotic control systems. The motivation to push for ROV development came brought many benefits to underwater exploration. These benefits range from extended times conducting research and reduced risk involving diver injuries (5). Historically ROVs have had a vast area of applications, but each ROV is specifically built for a particular task set. In the 1990's *Ventana* was utilized to study offshore fault lines along the Pacific and North American tectonic plate lines. It is configured with a hydraulic drill and a storage compartment to enable rock collection and has multiple camera attachments to increase the observation potential (3). *Okeanos Explorer* is used for exploring shipwrecks and utilizes an ROV rated for approximately 6km depth. This ROV is nearly 10ft by 10ft in dimensions and includes a manipulator arm (4). The Navy utilizes the SeaFox and other ROVs to run more accurate sonar and video feed back of potential mines to the operating ship to assist in neutralizing ocean mines. This application helps make shipping lanes throughout the world safer (6).

Primarily the MATE competition recommends "Underwater Robotics: Science, Design & Fabrication" by Moore, Bohm and Jensen. This textbook serves as a well thought collective representation of many design considerations in developing many ROV's from simple Do-It-Yourself approaches to an introduction to some of the more complex systems utilized by various facilities.

1.4 Project Objectives:

This project is being designed to compete in the 2015 MATE ROV competition. With the guidelines given by the competition it is required that the design reaches a depth of approximately 30 feet. This design also must be capable of conducting basic underwater surveying through video from the ROV to the operator and object retrieval. In addition to completing these tasks our team has added personal objectives such as creating a modular design to increase the potential applications of the ROV. Additionally an attempt will be made to implement an easy to use control system to reduce complexities in ROV operation that requires specialized schooling often provided through the current manufacturers. One of our final personal goals is to keep cost at a minimum, currently basic observational ROV "Do It Yourself" Kits start at approximately $850 USD.

2 Design Development

2.1 Conceptual Design:

Primarily the design thought process was guided by minimizing the effects of drag in a 3 dimensional operational field and enhancing maneuverability to ensure the ROV can freely move throughout a heavily constrained environment such as around reefs and within shipwrecks. Drag can be reduced primarily by minimizing the surface area normal to the direction of travel. Maneuverability can be increased by having multiple thrusters located throughout the design with positioning contributing to rotational and translational movement.

Secondary considerations are making the design modular and maintaining a low cost to make this product more easily attainable. To achieve a modular platform a skeletal frame was a primary consideration to allow many mounting points for various hardware configurations. With considering maneuverability and minimizing cost it was decided to have the ROV able to travel vertically and along a primary horizontal axis with turning controlled by 2 horizontal thrusters to enable turning by powering motors in opposite directions or varying speeds. By eliminating a sideways travel path additional thrusters are eliminated. This basic motion decided requires the use of three thrusters with additional thrusters for additional operational directions or rotations.

Other considerations are buoyancy, waterproofing electronics, operator feedback, gripper operation, and the control system. A neutrally buoyant design was determined to be ideal in order to minimize the operation of the vertical thrusters to maintain depth. In addition to the magnitude, the central point of buoyancy must be determined which will help the

ROV maintain its natural underwater orientation. To keep the ROV upright it was determined to locate the center of buoyancy slightly towards the top region of the ROV with center of mass being slightly towards the bottom region of the ROV. To waterproof the electronics a pressure vessel must be designed which will provide positive buoyancy so location will be towards the upper region of the ROV. This pressure vessel must hold all of the required electrical components and upon researching the various controllers that may be implemented was decided to hold at least a 3"x 5" chipset. Operator feedback would have to require information relating to the status of the ROV, which would be moisture to monitor potential shorting, power status, depth due to pressure changes, and a camera to see where exactly the ROV is going. These sensors are a moisture sensor, a volt/ammeter chip, a barometer and a webcam. It was decided to house the webcam in a separate but similar pressure vessel as the other electrical components to add symmetry to the ROV, which will help keep the location for buoyancy relatively close to the center of the ROV design. As the application of the gripper was assessed it was realized that it must be able to change its orientation to freely grab objects underwater, but movement of the gripper would require moving the camera. In addition to moving the camera the servo motors used to move the gripper would have to be waterproof which adds to more cost and complexity to the overall design. To overcome this, the decision to make the entire ROV tilt was made which required adding a 4th thruster oriented in the vertical axis.

Based on being able to have a secondary vertical thruster the net thrust in the vertical axis can be divided between two thrusters. In addition an estimated cost of servos being approximately $70 for moving the arm versus $40 for an additional thruster makes this decision a potential feature to reduce expenses.

2.2 Design Alternatives:

Decisions regarding thruster configurations are critical towards the operational requirements for an ROV. There are 2 primary orientations for the thrusters which are a direct drive, where thrust is directed normal to a surface, and vector oriented thrusters, where the thrusters are aimed at various angles from the ROV to propel the ROV in various directions operating by the sum of the forces creating a resultant force in the desired direction of travel. Because of the added cost of multiple thrusters and the attempt to minimize cost this project was designed using direct thrusting techniques.

The initial design was to reduce some maneuverability over typical commercial configurations by removing thrusters that are not required for basic operation. This design had 3 thrusters, 1 for vertical direction and 2 for horizontal, which critically saves component costs. When assessing this design with the required tasks it was decided that the gripper arm must be able to move. Because of this at least one additional waterproof servo is required and a secondary camera or a primary camera with a pan tilt feature would be required. Upon pricing components it was discovered that this would add an additional expense to the design and add additional failure points which contributed to deciding against this design.

When brainstorming a way to eliminate an entire manipulator arm from the design one configuration was discovered to enable the ROV to tilt with varying the thrust from the rear of the ROV. This design required 4 thrusters for horizontal movement and would require a 5th for vertical control. Because of the potential for adding cost to the project and the possibility that controls may become difficult to configure, this design was eliminated. This design's operational means were saved and implemented towards the final design.

2.3 Proposed Design:

The primary design accounts for a vertical and a primary horizontal travel path, and accounts for rotating about the vertical axis and horizontal axis giving a significant amount of control to the operator. This was done by implementing a front and rear thruster in a vertical orientation and a right and left thruster in a horizontal orientation. By implementing the thrusters in this manner many capabilities of the ROV are still preserved and thruster requirements are reduced.

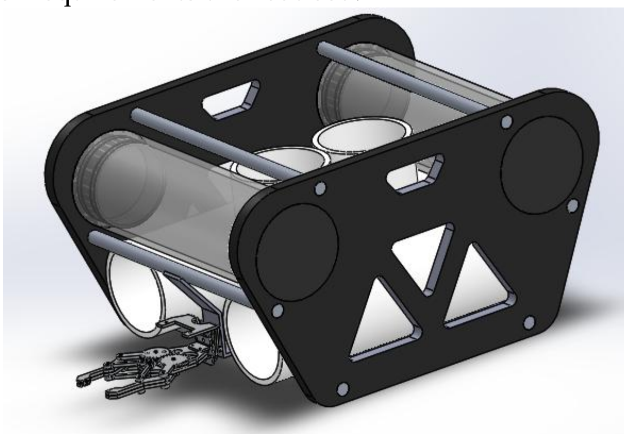

Figure 1: ROV design

Gripper: https://grabcad.com/library/robotic-arm-7/files/Brazo/Gripper

As seen in the image the white tubes are an arbitrary duct for thrusters to account for space from industry trends with smaller ROV thrusters. Once the thruster configuration was established, the electrical components were arranged and a frame was developed. This design accounts for arbitrary dimensions which will enable the ROV additional locations for mounting features such as onboard power, wireless communication, additional armatures for tasking, and additional sensors. Component configurations can be seen in Figure 2 (Appendix). This block diagram shows the basic connections between each of the components including power and communication lines. The selection of the microcontroller allows for easily being able to add additional accessories and accessories to the ROV system which adds to this unit being highly modular.

2.4 Analysis:

The primary structure and electrical housings were then imported to ANSYS CFX and SolidWorks Fluid Analysis and placed in a stream of 3 m/s water which provided the reactive force as a value of 130N. This was also checked in ANSYS CFX which established 132N as a reactive force at 3m/s.

Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress	Use In Convergence	Delta	Criteria
GG Max Velocity (X) 1	[m/s]	3.184	3.129	3.029	3.184	24 %	Yes	0.125	0.030
GG Max Velocity (Y) 1	[m/s]	2.806	2.801	2.788	2.806	100 %	Yes	0.019	0.030
GG Max Velocity (Z) 1	[m/s]	4.703	4.697	4.678	4.743	68 %	Yes	0.065	0.044
GG Normal Force (X) 1	[N]	-0.228	-0.333	-0.740	-0.104	42 %	Yes	0.178	0.074
GG Normal Force (Y) 1	[N]	84.543	82.514	78.298	84.603	51 %	Yes	6.304	3.206
GG Normal Force (Z) 1	[N]	129.928	129.032	127.472	129.928	100 %	Yes	2.455	6.987
GG Force (X) 1	[N]	-0.223	-0.320	-0.725	-0.089	44 %	Yes	0.170	0.074
GG Force (Y) 1	[N]	84.088	82.042	77.822	84.142	51 %	Yes	6.320	3.206
GG Force (Z) 1	[N]	134.379	133.359	131.700	134.379	100 %	Yes	2.679	7.120

Table 1: Forward Drag Simulation

To validate the results the following drag calculation was performed.

$$F_d = 1/2(\rho * C_d * A * V^2)$$

Equation 1: Drag Force Equation

With the projected frontal area equal to approximately 0.0298m, a desired velocity of 3 m/s^2, and water density of 998kg/m^3 and applying a drag coefficient of 1 the required force is 133.83N. This study is not including the sloping edge or curved face of the cylinder that generates friction and utilizes a worst case scenario for drag on a basic rigid body. This value due to symmetry within the model is essentially double for vertical thrust required.

2.5 Further Analysis Plans:

In addition to the current analysis to determine required power to sustain a given speed more analysis must be conducted. Primarily the pressure vessels for the electrical components must be tested to make sure they will meet depth requirements for the competition. This will be done by simulations in either ANSYS or SolidWorks. Computations must also be performed for the ROV drivetrain. These tests are thrust calculations on the propellers in addition to a conversion of brushless motor specifications to a more standardized value of RPM's and Horse Power.

$$RPM = Volt * Kv(rating\ of\ motor)$$

Equation 2: RPM Conversion of Brushless Motor

$$Horse\ Power = \frac{Amps * Volts}{745.7(\frac{Watt}{HP})}$$

Equation 3: Horsepower Equivilence

$$F_{Thrust} = Density * Area(stream) * Velocity * (Velocity - InitialVelocity)$$

Equation 4: Thrust Equation

Once these computations are completed a structural analysis on the design can be performed to validate the structure is capable of the loads applied from the motors.

3 Materials and Costs

3.1 Required Components:

The structure for the ROV is planned to be composite sides with either aluminum or composite connecting rods. In addition to these components the motors and props will be housed in PVC pipes to reduce the chances of debris damaging the drivetrain and allow for various mounting points. The pressure vessels are planned to be clear PVC with caps to allow for easier manufacturing, monitoring for flooding and to serve as a lens for the camera that will provide feedback.

Item	Quantity	Price
Brushless Motors	4	50
Electronic Speed Controller	4	40
Arduino Mega	1	16
Arduino Sensor Shield	1	5
Webcam	1	
Pressure Sensor	1	7
Moisture Sensor	1	3
Compass	1	2
Gripper Assembly	1	12
Voltage Regulators	2	
Servo Motor	1	20
Composite Sheet (2’x1’)	2	
Aluminum Rods (1/2”x1’)	6	
Cat5 (100-200ft)	1	45
Power Cable (100-200ft)	1	40
PVC 3”	4ft	10
Clear 3” SCH40 PVC	2ft	20
PVC caps	2	
Waterproof Connectors	2	
Lights for camera	2	5
Total		$276

Table 2: Component Cost

3.2 Prototype Cost:

Since manufacturing and design is planned to be handled within the team, the actual prototype cost is going to be approximately the cost of materials and miscellaneous items such as fasteners and various adapters. Because of the current analysis of components it is expected that the overall prototype will cost under $1000 and is expected to be over $500.

3.3 Product Development:

The prototype for this project will be essentially the same as the design with minor variances due to supply or manufacturing issues since its design is based on fitting competition guidelines. This is due to attempting to get the ROV operational in a timely manner to help guarantee success at the MATE ROV competition. Future goals are developing the system to be highly modular that will enable accessories to be added for performing additional tasks. Some changes that may occur on the final design are some autonomy, better sized motor/prop configurations, and on-board power. These changes are being considered to allow for ease of use, increase the potential applications this ROV can be utilized and to help increase maneuverability by reducing issues that may occur from the tether's drag and the amount of cables that would have to be managed from land. The manufacturing of the ROV will be conducted at FIU with assistance of the equipment in the manufacturing lab. As Figure 2 (Appendix) shows our components are primarily connected through an Arduino Mega which allows for multiple channels of component interfacing which will allow for easily being able to add more features to the ROV depending on the applications it will be facing.

3.4 Cost Analysis:

Based on a labor rate of approximately $30/Hr for each member of our team as seen in the table below the prototype development cost is currently at approximately $1500. This cost if the design would move to a higher production volume would however be broken down through the sale of each unit. The materials costs are still being calculated as research is conducted to help determine the final items in the design. Currently full prototype development cost including labor is expected to be around $3500 for a single unit, which would account for paying for design, all manufacturing and towards the higher price range for the components that are still undecided.

Time Log per Team Member			
Task	Member	Time (Hr)	Total Time
Preliminary Research	Daniel & Ryan	4	8
Design Configurations	All	3	9
Drag Calculations	Ryan	2	2
Validating Drag	Daniel	1	1
Presentations	Edgar	2	2
Report	All	5	15
Control systems	Daniel	3	3
Modeling Design	Daniel	2	2
Component Research	All	2	6
			49

Table 3: Team Time Log

3.5 Planned Testing:

Testing for the ROV will consist of testing individual components for function within limits that will be established based on analysis and keeping conservative values to help safeguard the design from failure. This will reduce the chances of a catastrophic failure that will cause significant financial loss of the team. In addition to these tests trials will be conducted in a pool to make adjustments to the ROV configuration and tune its performance potential. Finally testing regarding the velocity of the ROV and capabilities of the thruster configuration and control system will be assessed.

4 Status

4.1 Timeline:

	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14
Project Formulation											
Initial Design											
Evaluate Initial Design											
Design Improvement											
Control System Selection											
Hardware Selection											
Construction											
Testing and Refinement											

Table 4: Timeline For Project

4.2 Conclusions:

In conclusion, the project is going as planned and is on track to produce a small, modular ROV platform suitable for the MATE competition and beyond. From initial design research and simulations, the planned operational speed will be likely reduced to 2 m/s as opposed to 3 m/s. This reduces the drag force from 130N to approximately 50N and will allow for smaller thruster motors; reducing the cost, weight, and power requirements. Maximum operational depth will be determined with additional calculations and simulation, but at this time we see no problem in meeting the MATE requirement of 30 feet with the current design. In the future, material selection and testing of the pressure vessels will have to be performed to further validate the design concept. With testing the pressure vessel, the design may be able to be refined further or reconfigured to allow a further operating depth. In addition, control system options are being explored to ensure an easy to develop and easy to use system to make this system as naturally intuitive as possible.

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5) Ballard, Robert. "The JASON Remotely Operated Vehicle System" Woods Hole, MA 1993
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Appendix:

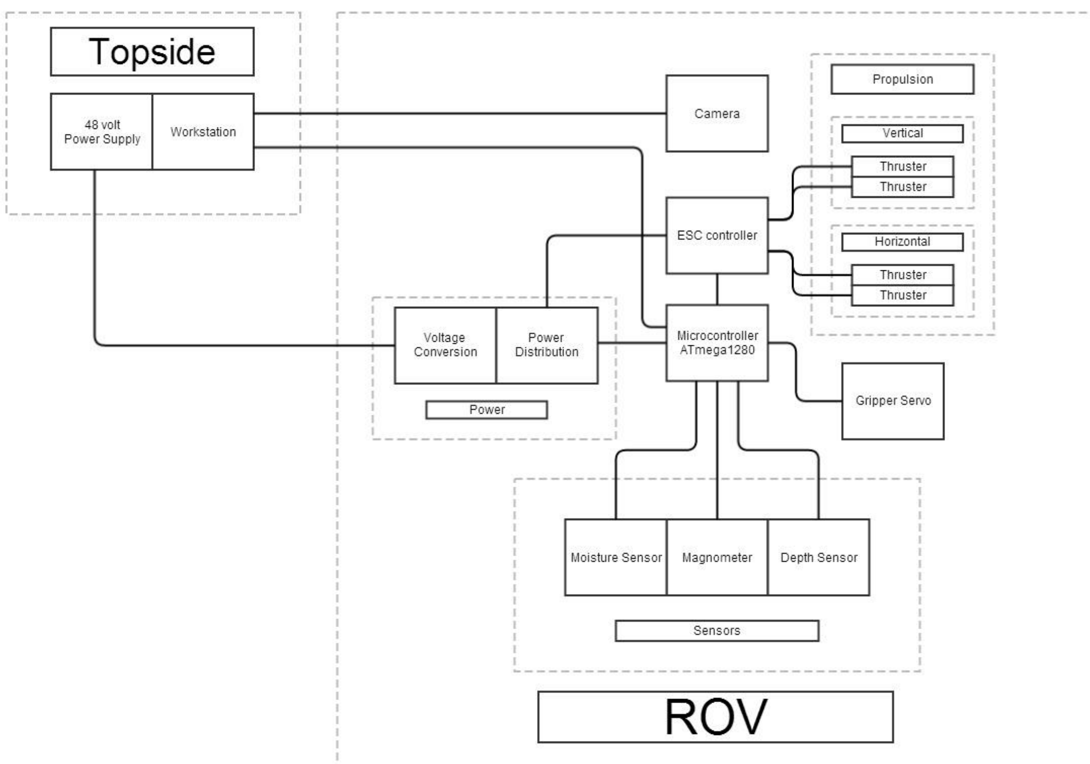

Figure 2: Functional Block Diagram