Engineering and Communication: Technical Report

Marine Advanced Technology Education; Remotely Operated Vehicle Competition 2013

"A Century of Success"

Team Members and Roles

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CFO, Mechanical Engineer, Tether Manager	Nathan Morgado
Chief Operational Officer, Pilot, System Engineer	Jordan Vasconcellos
Government and Regulatory Affairs Manager, Electrical Engineer, Technical Writer	Gustin Froias
Funding-Raising, Marketing, and Media Outreach Manager, Design Engineer	Alex Correia
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Angela Basse; Biological and Design Engineer; Engineering Design and Development Instructor

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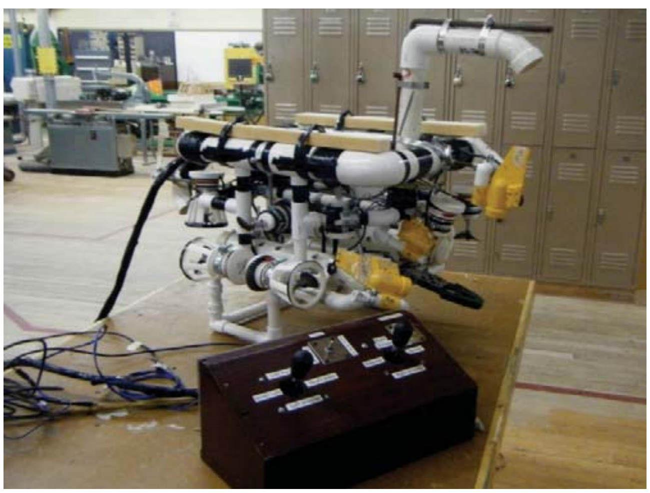
Abstract

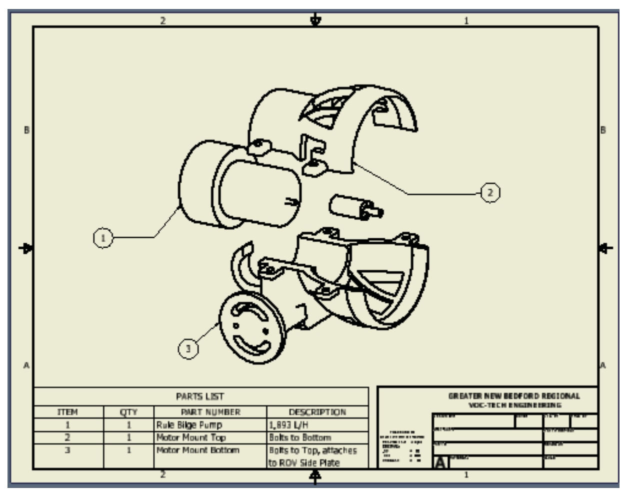
From design to troubleshooting, the 2013 MATE ROV Competition has presented our company, Mariner Engineering, with many challenges, which have tested our abilities as students in a high school engineering technology program. Mariner Engineering is composed of a team of six senior students who have learned and implemented computer aided design, circuit design and construction, computer integrated manufacturing, and manual fabrication. In order to succeed in completing this project, our engineers had to industriously follow the design process. Our team first identified every task of the mission and analyzed the project criteria. We reviewed the rules of the competition as well as the design constraints. We wanted our vehicle to represent the ingenuity of modern engineers who tackle the obstacles of maintaining real cabled ocean observing systems. We designed unique mechanisms and developed specialized approaches to solving the complex challenges posed by the observatory problem set. The tools we incorporated into our ROV, *The Green Bean Machine*, include a bilge pump-driven claw, SIA and ADCP delivery/release mechanisms, and a deployable temperature sensor. They are designed to efficiently complete the tasks presented by the mission. We selected an all-hardware approach, keeping the controls and electronics easy to manage. *The Green Bean Machine* is an ROV which incorporates simplicity, creativity-based design, and high quality workmanship to meet the standards of industry.

Vehicle Photos

ROV Photo: *The Green Bean Machine*



CAD Assembly Drawing: Thruster Mount with Shroud



To the top left is a photo of The *Green Bean Machine*, our remotely operated vehicle. The photo on the top right is an assembly drawing which documents the parts contained in the thruster mount, which is painted with white waterproof paint and can be seen in the ROV photo. The drawing was produced by using the CAD program Autodesk® Inventor® Professional 2013.

Budget/Expense Sheet

	School Name:	Greater New Bedford Voc-Tech			From:	11/30/2012
	Budget Creator:	Adam Weeks			To:	
Date	**Vendor**	**Part Description**	**Qty.**	**Unit Cost**	**Cost**	**Amount**
12/3/2012	All Electronics	3 1/2 digital Multimeter w/ backlight	1	$ 17.95	$ 17.95	$ 71.80
12/8/2012	MSC Direct	Lo-Voc All-Purpose Cement	3	$ 9.71	$ 29.13	$ 47.08
12/8/2012	MSC Direct	PVC Solvent Weld Schedule	5	$ 0.60	$ 3.00	$ 50.08
12/8/2012	MSC Direct	PVC Solvent Weld Schedule	5	$ 0.74	$ 3.70	$ 53.78
12/8/2012	MSC Direct	PVC Solvent Weld Schedule	5	$ 0.43	$ 2.15	$ 55.93
12/11/12	MSC Direct	Duct Tape	1	$ 7.66	$ 7.66	$ 63.59
12/11/12	MSC Direct	Electrical Tape	5	$ 2.01	$ 10.05	$ 73.64
12/11/12	MSC Direct	4 1/2" Hose Clamps	8	$ 7.51	$ 60.08	$ 133.72
12/11/12	MSC Direct	All Purpose Primer/Cleaner	2	$ 5.40	$ 10.80	$ 144.52
12/11/12	MSC Direct	Hex End Key (1/16")	5	$ 7.74	$ 7.74	$ 152.26
12/11/12	MSC Direct	6 1/2" Hose Clamps	8	$ 9.33	$ 74.64	$ 226.90
12/11/12	Vex Robotics	Manipulator	1	$ 19.99	$ 19.99	$ 246.89
12/11/12	Vex Robotics	Gear Box	1	$ 12.99	$ 12.99	$ 259.88
12/11/12	West Marine	Attwood Tsunami T1200 12V Motor	12	$ 39.99	$ 479.88	$ 739.76
12/11/12	All Electronics	Joystick	2	$ 15.00	$ 30.00	$ 769.76
12/11/12	All Electronics	5V Pos Reg 1AMP	1	$ 0.50	$ 0.50	$ 770.26
12/17/12	MSC Direct	3/4" PVC Tee	5	$ 0.73	$ 3.65	$ 773.91
12/17/12	MSC Direct	1" PVC Tee	5	$ 1.28	$ 6.40	$ 780.31
12/17/12	MSC Direct	3/4" Slip x Slip	5	$ 0.47	$ 2.35	$ 782.66
12/17/12	MSC Direct	1" Slip x Slip	5	$ 0.86	$ 4.30	$ 786.96
12/21/12	MSC Direct	Fuse Holder 30 Amp	1	$ 6.28	$ 6.28	$ 793.24
12/21/12	MSC Direct	Ring Terminals	1	$ 12.22	$ 12.22	$ 805.46
12/21/12	MSC Direct	25 AMP Fuses	1	$ 0.73	$ 0.73	$ 806.19
12/21/12	MSC Direct	9" Cable Ties	1	$ 33.42	$ 33.42	$ 839.61
12/21/12	MSC Direct	4" Cable Ties	1	$ 37.19	$ 37.19	$ 876.80
12/21/12	MSC Direct	Disconnect Connectors	1	$ 20.79	$ 20.79	$ 897.59
12/21/12	Jameco	Dome Camera	2	$ 25.95	$ 51.90	$ 949.49
12/22/12	MSC Direct	10.1oz Silicone	2	$ 11.80	$ 23.60	$ 973.09
Total Cost of Production						**$ 973.09**

By Nathan Morgado, CFO
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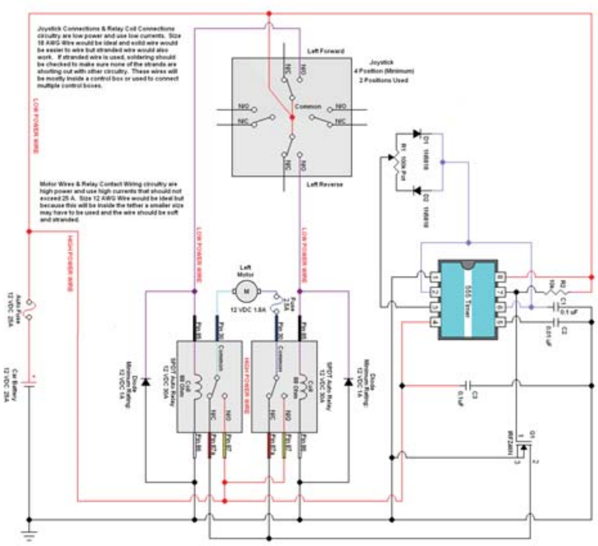
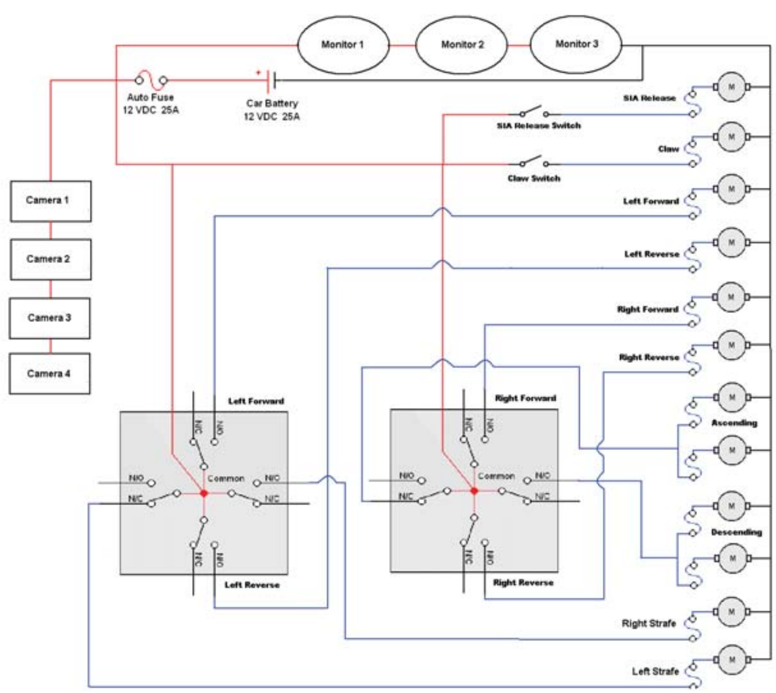
Electrical Schematics

(Created using National Instruments® Multisim Circuit Design and Simulation software)



To the left is one of the early circuit designs discovered by our team during research and development (disregard implementation of the 555 timer and diodes). This circuit uses the switches in a joystick to control the low-power end of a relay circuit. This is then used to alternate positive and negative charges when powering the motor, depending on which of two possible relays is fired. This is what allows the motor to change direction based on the input of the joystick.

The final thruster control circuit was greatly simplified by eliminating the implementation of the relays. Our team concluded that it would be more advantageous to attach additional thrusters to increase mobility, rather than keeping a complicated circuit for multi-directional capability. The 25-amp fuse is integrated into the positive line directly connecting the 12V battery to the control box. This protects the entire circuit from permanent damage and keeps the pilot safe from electrical shock. The circuits are also insulated from the walls of the metal control box by sheets of rubber. Also, two more cameras have been added to the ROV system to increase visibility when submerged.



Design Rationale

The Design Process

Under Project Lead the Way, we learned to follow a twelve-step engineering design process. The following chart will depict this process applied to the MATE ROV Senior Design Project.

1. Define a Problem	Disassemble, redesign, and refine the incomplete 2012 MATE ROV so that it completes the 2013 mission tasks
2. Brainstorm	We discussed possible approaches to redesigning the entire ROV
3. Research and Generate Ideas	Our team did extensive in-depth research on the Internet to study successful ROV designs from previous MATE competitions
4. Identify Criteria and Specify Constraints	We reviewed the rules and broke down each component for both mission tasks, assigning each a level of difficulty
5. Explore Possibilities	We debated which systems would be the best to work on first
6. Select an Approach	We decided to perfect the body before redesigning the tools
7. Develop a Design Proposal	We summarized what we wanted to include in the new design
8. Make a Model or Prototype	The new ROV developed in stages, as we refined the design
9. Test and Evaluate the Design	Throughout the process, we evaluated subsystem designs as well as the entire vehicle by testing them at a local public pool
10. Refine the Design	We continuously made modifications to the ROV, eliminating dysfunctional systems and simplifying complex ones
11. Create or Make Solution	We produced working drawings and finalized the vehicle
12. Communicate Process and Results	We produced a technical report, poster board, and presentation

The frame is made out of ¾” (1.9050cm) and 2” (5.08cm) PVC pipe. When we constructed the frame, we made sure that we primed and glued all of the connections cautiously so that there was no way for the air to escape from inside the piping. This simultaneously prevents water from entering the piping; making the frame watertight. The air trapped inside the frame keeps the ROV buoyant. Our goal was to design the ROV neutrally buoyant. To get there, we provided positive buoyancy by installing a 2” PVC ring around the top of the vehicle and added ballast, as required, to the bottom of the vehicle until neutral buoyancy was realized. Buoyancy is a very delicate state that is easily altered when the weight of the ROV fluctuates with added design components; such as the cameras, manipulator, wiring and motors. Separating the positive (on top) and negative (on bottom) buoyancy mechanisms allowed us to create a vehicle with a low center of gravity; this keeps the ROV stable underwater.

Our frame was designed to have many places to mount subsystems such as motors, cameras and manipulator. Our motors are strategically attached to the frame – some inside, some outside on both horizontal and vertical frame members. With two forward and two reverse motors extending past the left and right sides of the frame, our ROV can tread swiftly through the water. We also have four vertically oriented motors, two for ascending and two for descending to allow for depth versatility. All of our forward and reverse motors are placed in the corners of the ROV frame, far away from the center of the ROV; enabling us to quickly turn by powering one forward motor and the reverse motor from the opposite side.

We designed and fabricated a manipulator for our ROV according to the demands of the MATE ROV mission tasks. Our manipulator was made out of VEX parts and wired directly to a toggle switch. The mount for the manipulator was created using a multitude of nuts and bolts, and some leftover aluminum. This attachment hardware was selected primarily to easily detach and reattach the gripper in case we had to make any changes to the gripper's positioning. We also replaced our initial VEX claw design with newer VEX hardware. This update incorporated a spring-loaded mechanism to close the manipulator as a default position, unless otherwise directed by the operation of the bilge pump. We also added a relay to open and close the manipulator with one toggle switch.

The manipulator gives our ROV the ability to firmly grasp the required competition mission objects. Our manipulator, specifically, needs to disengage biofouling scattered about the competition mission field and place the cable termination assembly (CTA) into the bulkhead connector of the backbone interface assembly (BIA). The manipulator is powered by one bilge pump; allowing it to be easily opened and closed. A toggle switch at the top of the control panel is dedicated to the manipulation of the manipulator. When the switch is turned to the right, the manipulator opens, and when the toggle switch is turned to the left, the claw closes. Additional material and design needs for the manipulator became necessary to tackle the tasks at hand.

We used several plumbing parts to attach the motors to our frame. Two types of plumbing split rings were used with threaded rods between them. The metal-only rings were placed directly onto the PVC. The split rings were then tightened and adjusted to the angle at which we wanted the motors to face. The ring (rubber split ring) hardware is utilized in pairs to safely secure the motors, and then attach the metal-only ring firmly to the ROV frame.

Threaded rod, metal and rubber split rings were used to secure the thruster motors

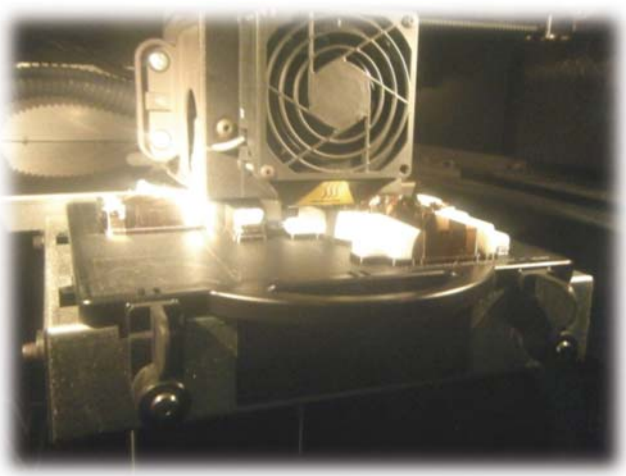
The team added a device on the bottom of the ROV in order to complete Task #1. The challenge with this task is to ensure the steady and timely transport of the SIA to the backbone interface assembly (BIA) located at the bottom of the pool. Testing observations revealed that the initial design of the SIA transport device was unsuccessful as far as keeping the crate balanced. The crate turned in the opposite direction of the ROV which made it difficult to place into the base of the BIA. To counter this, we changed the frame of the ROV to contain a U-shaped PVC crate stabilizing mechanism at its base, which held the crate stable and prevented it from rotating. An aluminum bell was machined and fit to the end of the motor to activate the SIA-release mechanism – comprised of zip-ties. This testing, evaluation, and redesign process made it much easier to complete the steps of Task #1.

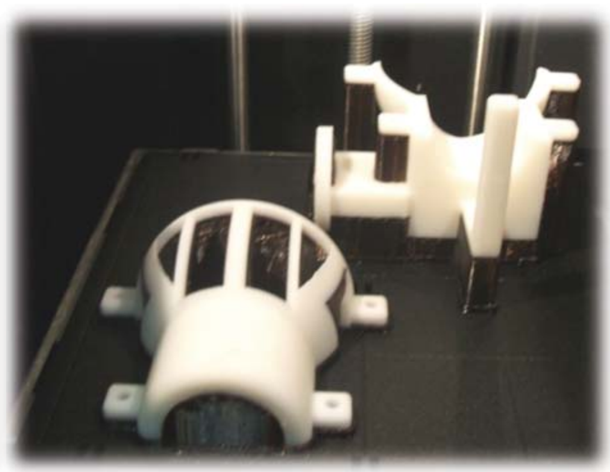
The initial control box was used to initiate immediate testing of the motors and frame buoyancy in the pool. We wanted to test these ROV components as soon as possible to allow time to brainstorm solutions to any difficulties that were likely to follow testing. This also allowed time to design an optimal control system. After testing and redesigning basic ROV functions, we designed a new box and fabricated it. We used wood for most of the fabrication, but incorporated 3/16" Plexiglas into the back of the ROV to reduce the amount of friction so that the tether hole would not fray the wire. The Plexiglas also provided a cool view of the control box wiring and connections and made it easier to access components for adjustments and alterations.

Safety

The Safety Features; Unique Fusions of Operational and Handling Safety

The Green Bean Machine was designed for safe handling and operation. In addition to the mandatory 25-amp fuse to protect the circuits and pilot, we have also integrated rubber sheets to insulate the live electronics from the walls of the control box. This makes it safe to handle for the pilot. The thrusters are encased and attached to the ROV by custom designed mounts, which also function as propeller shrouds. They were designed in CAD and manufactured in a 3D printer, as shown below.





Another one of the *Green Bean's* safety features is its rescue bladder. In the event that the vehicle becomes inoperable underwater or it is burdened with an object that is too heavy to manipulate, the ROV can be salvaged using an internal 25.4cm tire-tube "bladder" that can be inflated via a bicycle pump. Once the bladder is fully inflated, the vehicle floats and can be retrieved. A bleed valve in the control box allows the pilot to easily deflate the tube if necessary.

This system works well and was adapted from a concept in nature. Inside the body of a fish, there is an inflatable swim bladder. When it is expanded, the volume of the fish increases and the proportion of its mass to its volume changes. This causes a decrease in its density. The buoyant force supporting the fish increases as a result, and the fish rises. The ROV's rescue bladder works the same way.

In addition to all of these safety features, which have been extensively tested and refined, caution tape was also applied to the ROV's areas of safety concern for the regional competition, as depicted in the folllowing photos. These methods of warning are currently being refined as we prepare the robot for the International Competition.

Vehicle Systems

Our vehicle, *The Green Bean Machine*, is beautiful from an engineering perspective because of its creativity-based design and fabrication. Though the processes behind its construction were tedious and time-consuming, the vehicle itself and its tools are incredibly simple..

The Buoyancy Compensation/Ballast System: Static and Fully Adjustable

The Green Bean Machine has a static buoyancy compensation system, which allows our team to make incredibly precise adjustments to its buoyancy. There is one floatation chamber and four ballast adjustment points, each at a corner of the vehicle. The floatation chamber, shown below, is a sealed 2-inch PVC rectangle, which keeps the vehicle upright underwater and resists the crushing effects of high water pressure. The adjustment points consist of threaded rods with locking nuts. We adjust the buoyancy (and overall alignment of the vehicle when submerged) by adding or removing washers from these rods. This was a concept we discovered on Homebuiltrovs.org, which we modified for use on *The Green Bean.*

Propulsion: Multidirectional Capability

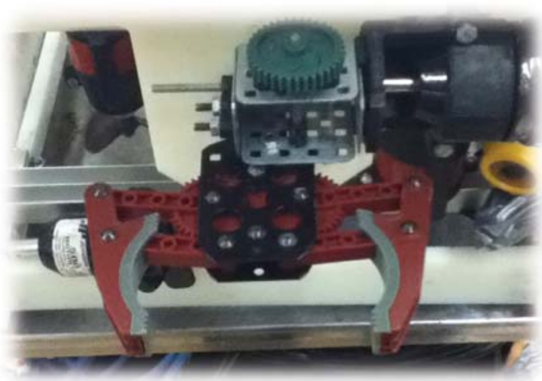
The Green Bean's propulsion system utilizes twelve drive thrusters, which are 4,542 Liter per hour bilge pump motors equipped with 70 mm propellers. The ROV's propulsion system is set up this way because testing consistently revealed that two thrusters would indefinitely propel the vehicle in the desired direction. Therefore, two thrusters are mounted to push in reverse, forward, up (ascending), and down (descending). For turning, one thruster on each opposite corner of the frame is activated. For instance, to turn left, the left reverse-thruster and right forward-thruster would be driven. To turn right, the left forward-thruster and the right reverse-thruster would be driven. In addition, two thrusters are added to each side of the ROV to allow it to travel sideways, or strafe.

Thruster and Tool Control Circuits: Precise and Simple

The Green Bean's controls are basic analog circuits; using switches, relays, and twelve bilge-pump motors. The circuits are fully electromechanical. This means they do not need any software or programming to drive their functions. The reason for this decision was simple; we did not yet have sufficient knowledge of software programming or microcontrollers at the time to begin designing a computer-based control system. Furthermore, we have had more experience with designing and testing analog and digital logic circuits using hardware components. Therefore, an all-hardware approach was more logical to select. Additionally, all the circuits are contained at the surface, within the control box. This way, we eliminate the risk of water penetrating our circuits, because they are not onboard the vehicle. We contained the terminal blocks that connect the tether to the thrusters and tools, inside special housings onboard *The Green Bean Machine*. We then waterproofed the housings by filling them with construction silicone. Refer to the photos below.

The Mission Tasks

So far, we have explained how *The Green Bean Machine* was designed to meet the standards of industry. Here, we will elaborate on our strategies for accomplishing the MATE 2013 mission tasks.



<u>Task One: Complete a Primary Node and Install a Scientific Instrument on the Seafloor</u>

The Green Bean is equipped with a Vex Robotics® Vexplorer® claw, which we use to accomplish several components of the mission tasks. For instance, in task one, the manipulator is designed to tightly grasp the Cable Termination Assembly (CTA) and deliver it to the Backbone Interface Assembly (BIA). A camera placed directly above the claw will be used to observe the work envelope of the manipulator.

The SIA deployment mechanism is described under **Payload Description** on **page 12**, under **"The SIA".**

<u>Task Two: Design, Construct, and Install a Sensor for Measuring Temperature as a Function of Time</u>

Refer to pages 11-12, Ongoing Challenges

Task Three: Replace an Acoustic Doppler Current Profiler (ADCP) on a Mooring Platform

In order to complete this task, we decided on a very simple design. The best way to approach this problem was to allow the ROV to handle both ADCPs at separate points on its frame. We developed a system that keeps the ROV buoyant and level at all times, because it will have at least one ADCP on board while travelling underwater and completing tasks. For a detailed explanation on the ADCP deployment mechanism, see **Payload Description** on **page 12, "The ADCP".**

The manipulator is used as a simple protrusion for locking and unlocking the hatch on the mooring platform, as well as changing the position of the hatch itself. This is achieved by skillfully maneuvering the ROV such that the "protrusion" does most of the work. The manipulator is also used to grip the power connection to the mooring platform.

Task Four: Locate and Remove Biofouling from Observatory Structures and Instruments

It is our intention to use the Vexplorer® manipulator to handle and remove biofouling from the observatory. Methods of adapting the claw to the biofouling mission props are still under development, as noted on **pages 11-12,** under **Ongoing Challenges**.

Challenges

Technical Challenge

The Green Bean Machine is a very intricate system. Needless to say, we encountered many problems while engineering its systems. One problem we faced was that the bilge pump motor we planned to use was too weak to rotate the axle connected to our Vexplorer® manipulator. We were puzzled as to how to solve this problem, but we discovered the perfect solution. Shown on the left is a Vex Robotics worm gearbox. It is a type of gear that greatly decreases output speed and increases output torque by a factor of 25. If we connect the worm gears to the drive axle connected to the bilge pump, and connect the worm wheel to the driven axle inside the manipulator, the pump will make 25 rotations while the manipulator makes one. This decreases the speed of the turning, and increases the strength with which the motor can close the manipulator. Also, this type of drive train physically resists motion in the opposite driving direction, meaning it is impossible for the driven axle to turn the drive axle. Shown on the right is a photo which depicts the integration of the gearbox with the manipulator.

Nontechnical Challenge

While attempting to overcome the technical challenges, we often experienced internal conflicts within our team as a result of mental fatigue. At times of persistent stress, we often argued with each other during the project, bringing down the group morale. However, we combated the effects of this stress by separating, taking breaks, and meeting again to tackle the issues at hand with cool minds. Using this technique, we were able to overcome our project's tense moments.

Ongoing Challenges

As of May 23, 2013, Mariner Engineering has not yet completely developed a reliable system for measuring the temperature over the hydrothermal vent in Task Two of the 2013 Mission. We are currently working through short-circuiting and temperature reading accuracy problems. Also, the team is finalizing some ideas for specialized removable tools for the manipulator, which would adapt its fingers more appropriately to the unique, varying geometries of several of the mission props, including the CTAs and biofouling samples.

Troubleshooting Techniques

Method of Evaluation

During a recent pool test, we discovered that one of the forward thrusters was not functioning. When we returned to the lab, we removed the leads for that thruster from the circuit and tested them for continuity. This was done to rule out any problems with the tether or thruster. Since neither was causing the problem, we analyzed the circuit and discovered that a faulty connection had dislodged power to that thruster. We repaired the connection by soldering it completely into place.

Vehicle and Component Testing

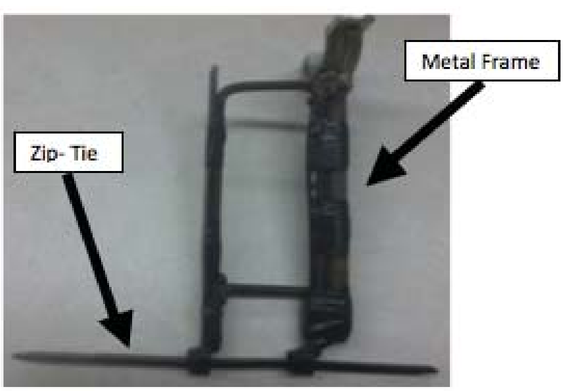
Throughout the course of the project, we ceased development of the vehicle in order to evaluate our progress by testing it. We periodically visited the local YMCA to use their pool and drive the vehicle. We used these opportunities to collect and analyze as much information as possible about its behavior when submerged, so we could develop approaches for modifications when we returned to the engineering laboratory. As it currently stands, *The Green Bean* has seen over 50 hours of pool time, and has been altered in its entirety several times. All of its tools and payloads have also been evaluated.

Payload Description

The Green Bean Machine possesses interchangeable payloads that are designed to complete the mission tasks. Besides the video cameras, thrusters, buoyancy/ballast system, and manipulator, the ROV also carries the following as part of its payload:

The ADCP

The Acoustic Doppler Current Profiler is a required payload of this year's ROV. The vehicle uses a modified hook that is fixed to the frame to catch the damaged ADCP, while a special release mechanism (SIA release, refer to the following) deploys the replacement ADCP reliably and quickly.



The SIA

The Science Interface Assembly (SIA) is a significantly large object, and would otherwise be difficult to handle if the ROV's frame were not designed to house, transport, and deploy it. Shown here is the release mechanism, which operates exactly as the ADCP release does; a bilge pump motor connected to a zip tie via a small string rotates quickly, pulling the tie away from the metal frame which supports the hook. This instantly releases the SIA.

The Temperature Probe is a payload tool, but is still under development, as noted on the previous page, Ongoing Challenges.

Future Improvement

Our Company agrees that if we could participate in the MATE ROV Competition again with *The Green Bean Machine*, we would use 18-gauge cable in the tether instead of 16. This modification would allow the ROV increased mobility, as it would drive much faster and turn more easily. We have found that as we have added thrusters and tools, the ROV's tether has greatly increased in weight. The thick, heavy tether often gets twisted and can restrict the vehicle's motion.
Also, we suspect that pulse-width modulation would greatly improve the handling of the manipulator, as the speed with which it is closed on an object would be more easily controlled. We believe that if we improved in these areas, *The Green Bean Machine* would be an even better competition machine.

Lessons Learned

Technical Skill Acquired

While participating in this project, our company learned how to develop efficient manual fabrication procedures for the aluminum propeller drive dogs, the PVC frame, the manipulator, and the PVC buoyancy chamber. We also learned how to tweak the buoyancy of a submerged system, and how to operate our Dimension® 3D Printer.

Interpersonal Lesson Learned

An interpersonal lesson we have all learned is how to work as a team. This project has taught us a great deal about the importance of communication and collaboration among individuals working on an engineering design project. Minor communications issues on working drawings and CAD programs for our 3D printer and CNC machines, lead to inconsistent practices when it came time to mill, print, and fabricate the various components of our vehicle.

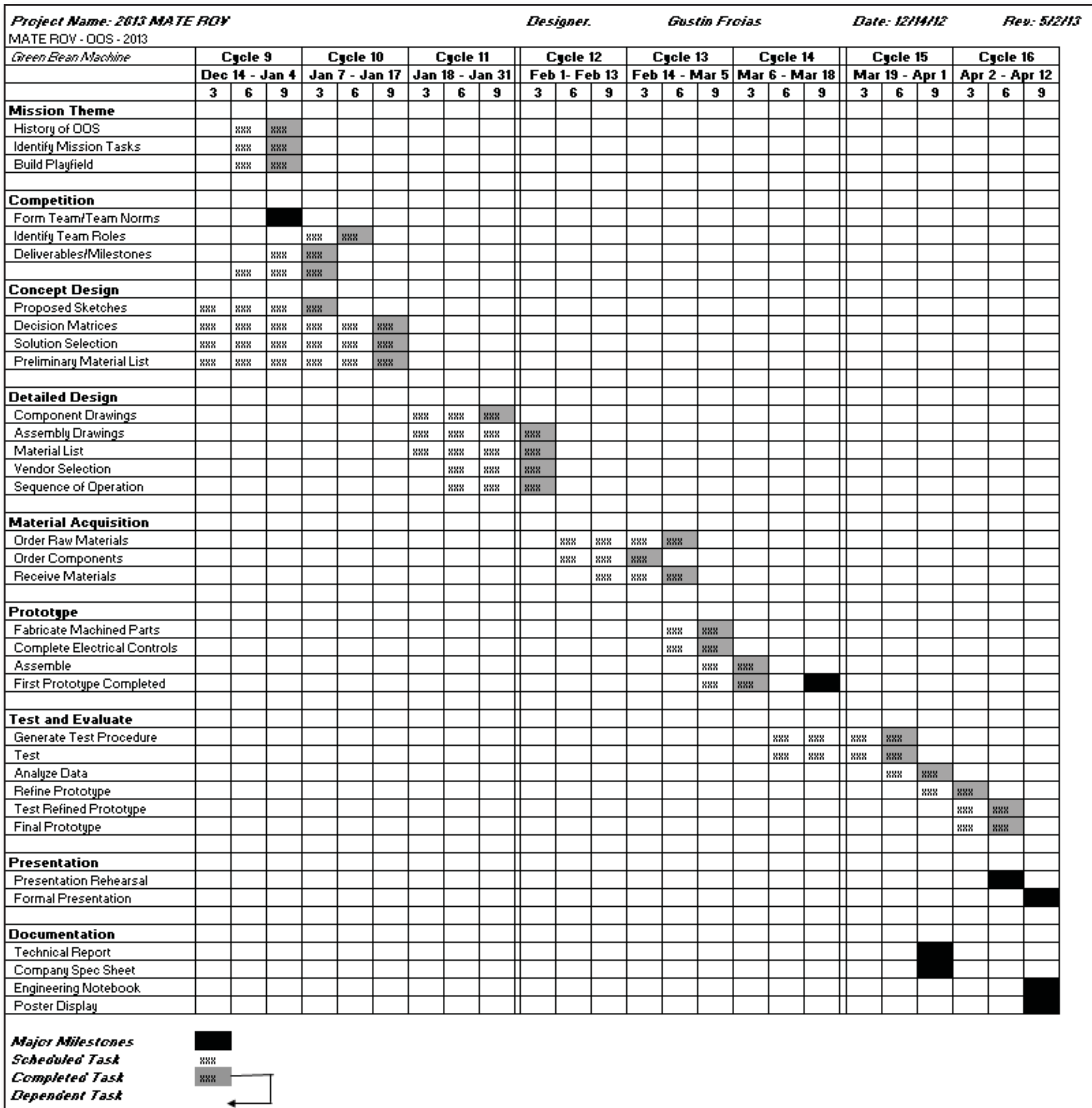
Reflections

When we started this project, it was a little overwhelming to think of how we were going to redesign and reconstruct last year's ROV. The project was extremely stressful at times and there were days where we questioned whether we were going to succeed in our endeavors. However, as seasoned students in an Engineering Technology career program, we faced the challenges and tackled them to the best of our ability. We used every concept we learned from our instructors concerning digital and analog electronics, engineering design, communication and documentation, problem solving, and manufacturing, to deal with this great challenge as any engineer would. We are glad and very fortunate to have gained such a unique educational experience by participating in this competition.

Teamwork

Throughout the construction of the ROV, we worked together to exemplify the meaning of teamwork. We originally formed two teams of three students each, but then combined the design successes of each team's products to construct *The Green Bean Machine*. We communicated the components that we thought worked well between the teams and took said components and meshed them together. We concluded that the frame of ROV 1 (group 1's preliminary design and prototype) was neutrally buoyant and had a simple, yet successful, design. We also concluded that the control box and controls themselves were easier to operate and simpler on ROV 2 (group 2's design and prototype). Each individual had a role with several responsibilities and deadlines. The end products of both the ROV and the technical report were truly the result of a great deal of patience, perseverance and cooperation, which is the formula for successful teamwork.

MATE ROV Senior Design Project Gantt Chart



Acknowledgements

The Greater New Bedford Regional Vocational Technical High School 2012 ROV team members would like to thank the MATE Center for giving us the opportunity to showcase our abilities in both the New England Regional and International Competitions. We would also like to thank all of the Engineering Technology staff at GNBVT for all of their support, including our Cluster Coordinator, Mr. Stephen Walker. Our team also extends our gratitude to the New Bedford YMCA, for allowing us to use their pool as our principal testing site.

We would like to personally thank our instructor Mr. Bernardo for providing technical advice and moral support throughout the course of our project. Without Mr. Bernardo's guidance, we may have

lost our focus while trying to overcome the many technical issues we encountered.
We would also like to thank our instructor Mrs. Basse, who has greatly assisted us through both years we have participated in the MATE ROV Competition. Our vehicle *The Green Bean Machine* is a tribute to their support as instructors and we thank them for all they have done for our team.

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