ENKI ROBOTICS

Technical Documentation
MATE ROV Competition
2018

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Lemont, Illinois – The Highwater Foundation
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Abstract

Lipuchka (Russian for "velcro") is an underwater robot that is designed to find and recover lost aircrafts, place and retrieve an ocean bottom seismometer, and locate the optimal location for ocean floor tidal turbines. She comes equipped with four motors for general movement on four planes of motion. The ROV also comes equipped with a claw and lift bag to perform general tasks such as returning eelgrass to its habitat, lifting debris from a crashed plane, and locating and placing tidal turbines in an optimum area. Our robot is well under the size and weight restrictions, allowing for fast movement and the ability to navigate through small spaces in order to complete tasks quickly and safely. Enki Robotics, the team behind Lipuchka's creation, is a group of five determined high school students who will stop at nothing to solve the world's problems (one robot at a time).
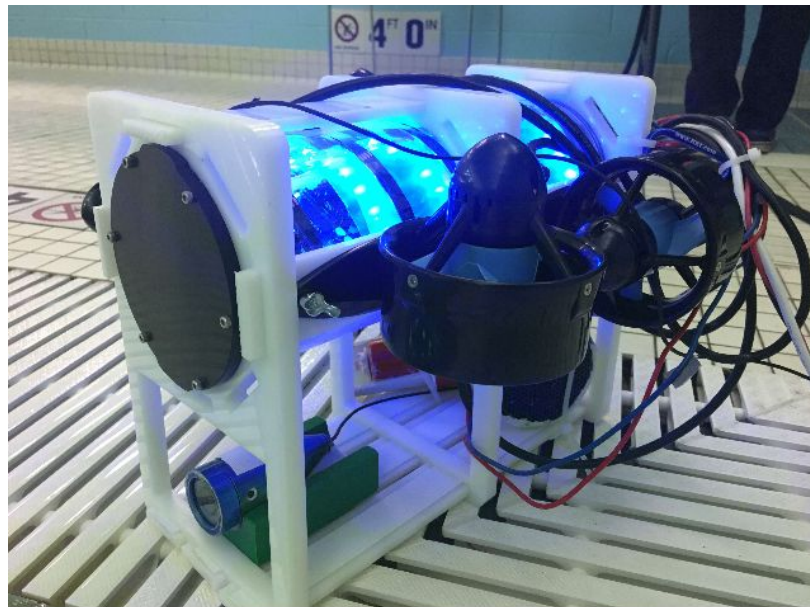
Our completed robot: meet Lipuchka.

Theme Significance

This year, we wanted our theme to be something more than just a witty phrase or a catchy motto. We wanted it to be something significant that reminds us to improve the way we operate as a group. So, our theme this year is simply "teamwork." It may sound cliché, but last year our greatest weakness was dishing out all of the tasks to separate people, and then expecting the whole team to be able to function cohesively. In short, our greatest weakness was a lack of teamwork, which led to several major functional and technical errors. In order to avoid the pitfalls that accompany a lack of cooperation, we chose "teamwork" to be this year's motto.

The entire Enki Robotics team after running Lemont's 9th annual "Frigid 5K."

Company Profile

In order to design and build a cost-efficient robot, Enki Robotics has developed an efficient plan to run their business, using SEA:

Strategize, Engineer, Accomplish.

Prior to the release of the Competition Manual, Enki Robotics had several meetings to divide the team and plan ahead. During these meetings, we used SEA to our advantage by coming up with a plan: each member revealed their hidden obsession, whether it be mathematics, coding, organization, etc., and found their 'bay.' We then assigned each member to two areas: their primary area fits their mastery, for the purpose of utilizing individual talents, while maximizing quality of the work in each crew. The secondary area is a topic that they are unfamiliar with; with this setup, each member will learn something new, while also maximally contributing to the group effort. We also divided each role into one of three categories: Management, Design, and Code.

The management crew oversees the entire team's work--they are the safety sticklers, the social media operators, and the time and money savers. With their calendars, lists, and folders, they drive the organization for the company and manage our resources so we don't go over budget. After consulting the design crew regarding what products need to be bought, the management crew searches for cheaper or more reliable options for the parts. Maintaining a steady but productive schedule is a another priority for management, ensuring that the task of building a robot is executed.

The design crew works with the robot as a whole; designing the frame and assembling the pieces to the robot. An important aspect of this crew is to determine the materials needed throughout the robot building process. Gathering the essentials to create an exemplary robot requires extensive research. Then, the crew assembles the various parts--frame, thrusters, tubing--to create our robot.

Company Profile, continued

Finally, the code crew makes sure the robot has the brains to do all the required tasks. Becoming experts on the missions is vital to the performance of our robot. Using their passion for coding, they brought our robot to life.

After the regional competition, our management crew took a big hit, as one of our team members had to resign due to major schedule conflicts. However, we were able to rebound from this challenge by reorganizing the structure of our team and adjusting the task list, so that each member put in an equal amount of extra effort to compensate for the loss of a valuable teammate.

While each crew has their own individual responsibilities, SEA brings our company together. As a company, we meet and strategize before beginning any processes. Once each crew has a strategy, we proceed with engineering--designing and writing code, while artfully working to bring about a robot. Finally, we accomplish our goals, completing Lipuchka.

The building that brought us all together: Lemont High School.

Project Management & Scheduling

TIMELINE:

August 28, 2017 – September 11

1. Mounted thrusters to tube
2. Assigned roles
3. Created social media accounts

September 12 – 26

1. Worked on electronics
2. Finished CAD design
   a. Ordered frame

September 27 – October 11

1. Everyone created their personal schedules
for the year
2. Worked on controls
3. Overviewed safety regulations

October 12 – 26

1. Put frame together
2. Put electronics in frame housing
3. Created rough outline of technical report
4. Ordered basic claw parts

October 27 – November 9

1. Waterproof cables
2. Connected tether
3. Machined and put together claw parts

November 10 – 24

1. Bought crimp cable
2. Bought motor for claw
3. Club picture day!

November 25 – December 8

1. Tested the underwater camera
2. Got the motors working
3. Finished the claw
4. Started assembling the props

December 9 – 23

1. Finished basic ROV (in time for the water trials)
   a. It can move in the water
   b. It has reliable controls and camera

2. Prepared for water trials

December 24 – January 7, 2018

1. Continued prop construction
2. 3D printed adapter for the underwater speaker using school's 3D printer
3. Continued prop construction

January 8 – 22

1. Brainstormed on fundraising
2. Finished the props

January 23 – February 6

1. Completed the entire ROV
2. Started practicing with props in the water
3. Worked on reports and presentation

February 7 – 21

1. Technical report finished
2. Financial model created
3. Overview of our media presence
4. More underwater practice

February 22 – March 7

1. Begun work on presentation
2. Finalized water plans
   a. Established who, in what order, and which tasks to do

March 8 – 22

1. Overviewed and fixed code
2. Studied presentations and technical reports of other teams

March 23 – April 6

1. Continued studying other teams presentations and altering our own
2. Started adding more depth to our technical report
3. Another underwater prop practice

April 7 – 21

1. More underwater ROV tests
2. Made slight touch ups to buoyancy and propeller speed

April 22 – May 6

1. Practiced presentation
2. Practiced ROV controls
3. Made transport plans

May 7 – May 22

1. Finished the safety presentation
2. Touched up the Tech Report
3. Added new protective propeller netting

In order to maintain a constant rate of progress, the management crew was in charge of ensuring that our team met up at least once every two weeks. On average, however, we got together about two times every week.

Safety

Philosophy:

Here at Enki Robotics, we value safety almost as much as we value teamwork and learning. Before each and every new endeavor that our team embarks on, we run through a meticulous process in order to ensure the safety of all of our members:

- Verbally run through all of the steps that we will go through as a team
- Write down all of the potential risks that we will run into
- Acquire the tools and protective gear necessary in order to deal with the risks
- Be cautious of any unexpected dangers that may present themselves during the entire procedure

Using this process, our team has managed to avoid injury of any variety throughout all of our years working together. Some of the projects in which this process has proven to be the most pertinent were during soldering, propeller adjustments, during the construction of props, and when using chemicals like epoxy. But by taking careful note of the safety hazards and using our simple four step process, we were able to tackle these projects with ease.

Safety, continued

Safety Checklist:

1. **Pre-Construction Checklist**
   - Closed toed shoes, pants and no baggy clothing
   - Workspace is open and has proper air ventilation
   - Crew members using power tools are trained and supervised
   - While soldering and using power tools proper equipment is worn
   - Workspace is clean
   - Long hair is tied back
   - After work is done all materials are returned to their original positions

2. **Pre-Mission Checklist**
   - Safety inspection passed and green flag acquired
   - Closed toed shoes, pants, and no loose clothing
   - 25 amp fuse in place
   - All propellers are shrouded
   - No wires exposed
   - Strain relief couplings in place on the ROV and control box
   - Power has been connected to its correct sign potential
   - All parts of the ROV are hard connected
   - All power to ROV is provided by an external power source (no batteries on ROV)
   - There are 3 to 6 company members on the poolside
   - Tether is properly coiled, not tangled
   - Electronics housing is fully sealed
   - The main power switch is off until all electrical connections are connected
   - Power is turned on once all crew members say they're ready
   - All systems been dry-land tested

3. **Post-Mission Checklist**
   - There is no physical damage to the wiring, frame, and electronic housing
   - The inside of the electronic housing is dry
   - The tether is intact and both strain couplings are still functional

Design Rationale

The design is completely modular!

Each Part of the ROV

The stated industry mission for the Mate Ranger class competition this year was to encourage groups to build a robot that can sort through and retrieve items from underwater plane and engine wreckage. Due to the unpredictable and hazardous environment that our ROV will be operating in, we decided to build our robot to be small, lightweight, and, most importantly, customizable. Lipuchka is the one for the job, because the modular design allows for our robot to be customized for maximum efficacy at the scene of a real life underwater engine crash. All of the additions to our ROV were selected according to strict criteria aimed at minimizing weight and size, while maximizing customizability.

The Claw:

One of the most arduous tasks that we had to undertake during this project, the claw took several months to perfect. We knew that it had to have enough force behind it to pick up objects during the tasks, while not being so forceful that there is too much stress on the motor or the claw itself.

The Electronics:

Wiring the electronics was likely the largest project for the team; we needed this part to be perfect, as one mistake would mean certain failure at Internationals. We decided to store the electronics inside of a cylindrical container, as this is the best way to disperse the water pressure evenly and protect the electronics.

Design Rationale, continued

The Frame:

The frame was relatively simple to construct. We had our CAD expert design the frame based on the propeller sizes, our agreed upon size limitations, and the estimated amount of space that our electronics would take up. After ensuring that our frame was as symmetrical as possible, we ordered the individual pieces to be made out of polyethylene due to the material's low weight and high strength.

The Propellers:

We placed two of our four propellers in such a way that we can accelerate Lipuchka forwards, backwards, left, and right. The other two propellers were placed with a 90 degree rotation so that our ROV can be elevated towards the surface and towards the floor of the pool. The propellers were reused based on their successful performance from the previous year. We chose ducted fans rather than unducted fans based on the significant efficiency difference.

The Cameras:

We fitted two waterproof cameras on to our ROV with the help of 3D printed adapters and some Velcro. One camera was placed on the top, and the other one was placed on the front of the robot, with a downward view. These placements were made so that we have two different perspectives at all times, in order to ensure that we can properly manipulate the props when the time comes to do so.

Testing

The Claw:

This took quite a bit of testing and revisions to get right. Our main problem was getting the claw to apply enough force to hold on to objects without damaging the motor or the claw. It took a lot of hard work, but we were able to calibrate the claw motor to apply more force while still maintaining the structural integrity of the claw. We ran through several iterations and designs for claws, and tested the amount of force each one can grip. Once we determined a design, we calibrated the control box so that it stays within its range of motion. Now our final model is finished, and it works like a charm.

The Electronics:

Several Arduinos, multiple Raspberry Pis, a few overnighters, some advanced code academy courses, and a couple hundred thousand "error" signals later, our electronics have finally been perfected. We tested our electronics communications with the ROV for extended periods of time to replicate the product demonstration at the competition. We calculated the amount of I/O errors per minute and progressively worked on decreasing it. By testing after each change, we were able to determine the impact of our additions.

The Propellers:

With two controllers that make it feel like we are piloting an F-15E Strike Eagle military jet, testing our propellers was probably the funnest part of Lipuchka's construction. In order to determine how many amps are pulled at max thrust, we used an ammeter and adjusted the speed accordingly.

The ROV:

After the completion of all of the basic components of the robot, we made several appointments with our local park district so that we could test our ROV in a pool. We brought our homemade props and were able to successfully manipulate most of them. We also managed to get to the root of our waterproofing problem during these testing days so that we could fix it.

Finances

Budget:

The Enki team was operating under an assigned budget of $3000. Not only did we spend significantly less, we undercut our own original expectations in terms of how much we would spend by several hundred dollars. We thank Jeremie Bacon for setting up the Chicago Tech Rocks fundraiser, as that is how we were able to fund much of the construction of Lipuchka.

Reasons for Buying and Building Specific Parts:

Nothing that we bought was without purpose. We decided to use purchased propellers, because we wanted a high quality, reliable product that produced minimal turbulence underwater. However, we decided to build the claw, because the slight increase in quality that accompanies a pre-built claw is not worth the hundreds of dollars that it costs to buy it. Our team applied this same cost-benefit analysis in order to determine which parts to buy, and which parts to build.

New and Reused Parts:

The propellers were reused from last year. We custom ordered the entire frame new, after designing it on CAD. We bought the two underwater cameras new and hooked them up to our electronics. We also made use of our school's 3D printer to print several objects, such as an adapter for our underwater cameras, as this was cheaper than buying new.

Cost Projections:

Our original cost projections, after tallying up everything that we expected to buy, was hovering around $2,800. However, we noticed that we could cut costs by building certain parts of our ROV, rather than buying them online. For example, our homemade claw was extremely cheap to construct, while a quality waterproof claw can cost hundreds of dollars online.

Project Costs:

All in all, our total costs added up to about $2,500, not including travel expenses. The entirety of this expense was covered from the money raised during the Chicago Tech Rocks fundraiser and from our fundraiser from last year's competition, and the excess will be used for transportation costs and any last minute expenses during our stay in Seattle.

Travel Expenses:

All in all, we have estimated our travel expenses to the international competition in Seattle, including the flight tickets and hotel reservations of all team members and mentors, to be approximately $6,000. We were able to raise this money by using the website gofundme.com and accepting donations from various other generous individuals.

Reflections

Lessons Learned/Challenges

One of the biggest challenges that we faced during the construction of our ROV was the task of waterproofing the central electronics tube. This also happened to be the most important job, because all of our proverbial eggs were in one basket: nearly all of our electronics were placed in the central tubing, and so if there is even a slight leak, we may be out of the competition for good. We were able to overcome this technical challenge by researching a variety of waterproofing techniques, such as using wax, O-rings, aquarium sealant, silicone, etc. We ended up choosing a reliable O-ring method, which we tested extensively as we neared the competition deadline. In addition, Alex sharpened his CAD skills and helped in the revision of documents. Nathan learned the most efficient methods of ensuring that everyone is obeying safety protocol. Jordan learned how to manage financial information, minimize costs, and keep track of purchases through spreadsheets such as Microsoft Excel. Finally, Martin and Dominik went from newbies to pros at managing and writing documents in the Python programming language.

Future Improvements

In hindsight, the waterproofing task should have been the first one that we started working on, so that we could have had the peace of mind of knowing that our electronics were protected. However, this is not what happened, and we ended up being just a mere month away from the competition when we found out that our waterproofing was not sufficient for keeping out 100% of the water. In the future, we will be sure to secure a solid storage compartment to keep our electronics dry early on in the construction process, so that we will have free time to focus on the more trivial tasks as the competition date grows closer.

Acknowledgements

References

The following sources have been incredibly useful for the purpose of gaining insight into various engineering principles and coding techniques:

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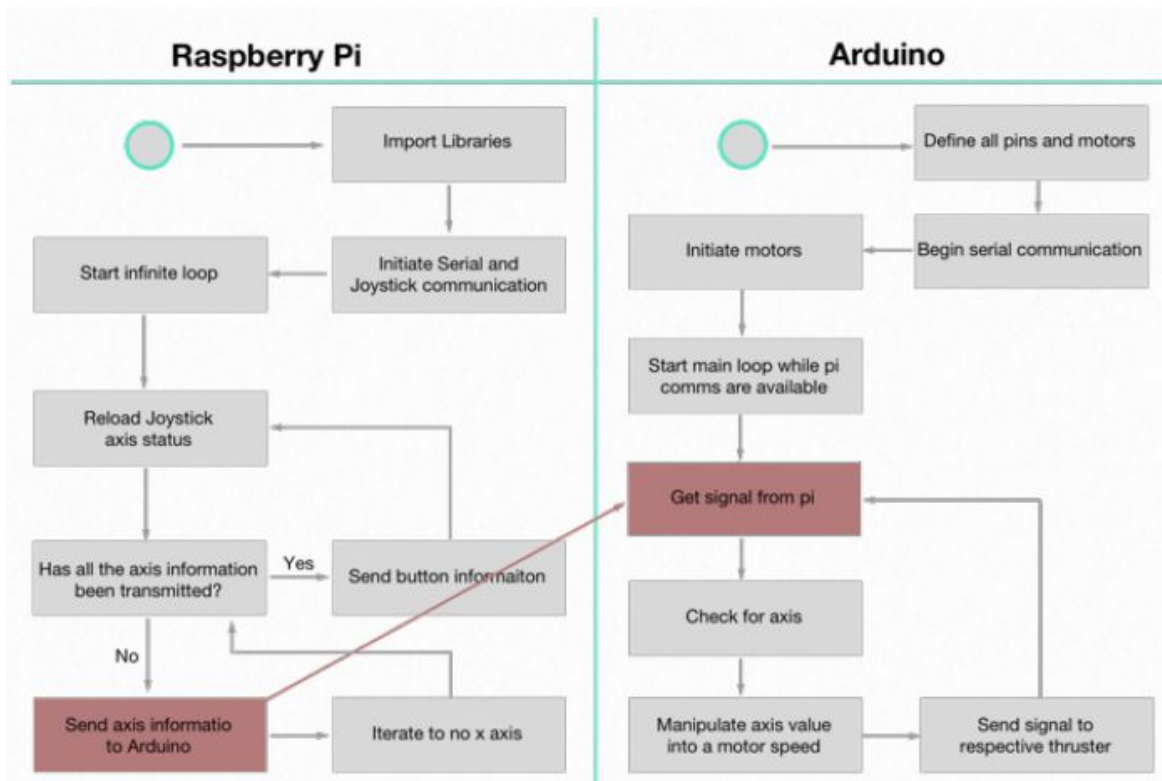
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Appendix A
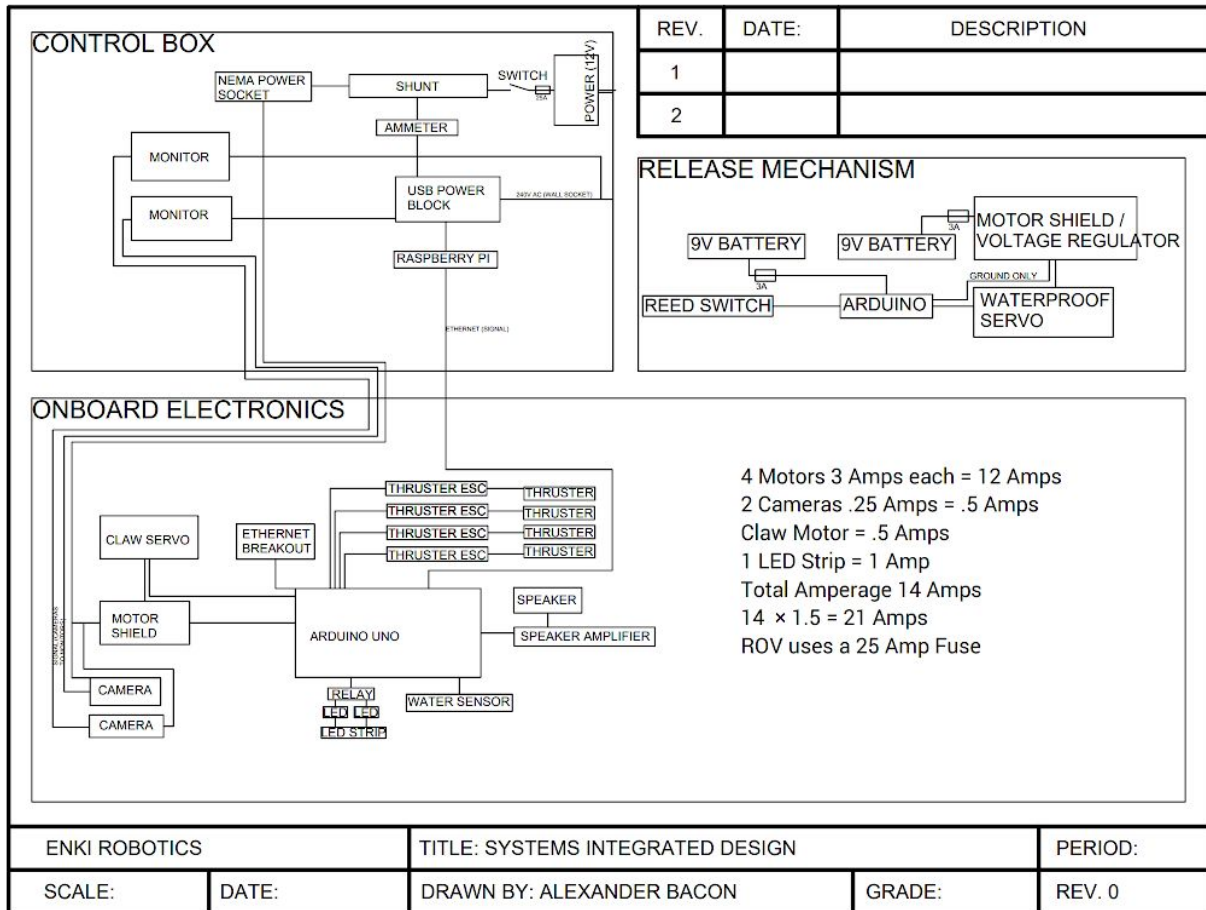
CAD drawing of ROV electronics, by Alexander Bacon

Appendix B

Flowchart of the controlbox and ROV programming, by Dominik Chraca

Appendix C

Finances:

As a group, we were operating under the monetary constraints of spending no more than $3000. By putting our heads together and cutting costs, we were able to defeat this budget with about $500 remaining (for travel expenses, see the page titled "Finances").

Budget Overview:

In the end, our total costs for this year hovered around $2,500 and change. This number beat both the monetary constraints that we were operating under, and the total costs that we estimated we would spend at the beginning of the year. All purchases listed in the budget were made in the past 12 months, and we received no donated parts. The only reused parts are the propellers, which are indicated as "reused" in the budget below.

Funding and Income:

Money raised from Chicago Tech Rocks fundraiser: $1,018.82
Money reinvested from last year's fundraiser: $1,486.34
Total amount used for budget costs from fundraisers: $2,505.16 (full amount covered)

Details and Significance

Our original estimation in regards to how much we would spend on our ROV this year was about $2,800. However, by constructing the electronics ourselves (as opposed to buying them pre-made), and by spending slightly more time online looking for less expensive alternatives, we were able to undercut this original estimation by approximately $300.

Budget Details	Quantity	Total Cost
Thruster		
T200 Thrusters (reused)	4	$808.00
Thruster Cable (3 Conductors, 18 AWG)	1	$7.00
Total Thruster		$815.00
Structure		
Frame	1	$230.00
Closed Cell Foam	1	$12.98
Electronics Tube Dome	1	$35.00
O-Ring Flange	1	$27.00
Dome End Cap	1	$59.00
Total Structure		$363.98
Connections		

100 Feet 14 Gauge Wire	5	$75.35
Network Modular Connector	1	$10.13
25 Amp AGC Fuses	25	$4.99
Crimp Connectors Plugs	8	$5.60
Ethernet Connector Breakout Board	1	$2.58
10 Piece Reed Switches	1	$8.88
Dupont Wire Kit	1	$7.49
Socket Adapter Connectors	100	$10.99
Total Connections		**$126.01**

Camera

RCA to HDMI Video Audi Converter Adapter	1	$14.59
Underwater Fish Camera	2	$217.74
USB Camera for Arduino	1	$11.77
Electronics Tray (4"Series)	1	$79.00
Total Camera		**$323.10**

Control Box

Inland USB Basic Keyboard	1	$3.99
Elemen14 7" Touchscreen LCD	1	$69.99
SRA Aluminum Case	1	$36.03
12V 25A Racing Power Supply *	1	$91.98
RCA to HDMI box	1	$14.99
ASUS USB Portable Monitor	1	$187.69
Microlab USB Clip-on Speaker	1	$12.99
Anker 40W USB Wall Charger	1	$25.99
Total Control Box		**$417.66**

Control System

Wickedd Motor Shield, 4 Motors	1	$49.99
Raspberry Pi 3 (Donated)	1	$0.00
Arduino Mega	1	$0.00
Arduino Uno	3	$0.00
Arduino Uno	1	$7.49
Screw Terminal Breakout Board	1	$12.00
Audio Amplifier	1	$7.96
Total Control System		**$77.44**

Claw

Makeblock Robot Gripper-Black	1	$29.99
Van Steel Nitrile 12CT	1	$3.99
Submersible Bilge Pump	2	$29.98
Servo Motor	1	$18.10
C12-Ounce Aerosol	1	$18.96
Total Claw		**$101.02**

Waterproofing

Aluminum End Cap	1	$16.00
O-Ring Set	2	$6.00
Marine Adhesive Sealant	1	$10.97
Total Waterproofing		**$32.97**

Miscellaneous

5-pack 9v Battery Clip	1	$5.99
Micro Digital Amp Meter	1	$5.88
8-pack of 9v Batteries	1	$9.99
Computer AV Adapter Cable	1	$5.85
Watertight Dry Case	1	$13.67
Vinyl Gloves	100	$6.24
Double Sided Tape	1	$10.99
Velcro White Tape	1	$10.33
Network Installation Kit	1	$59.99
Ad-Tech Multi Temp Glue Stick	50	$8.69
Hex Socket Head Cap Machine Screw Bolt	100	$6.18
Shipping		$16.00
Armatron	1	$29.41
USB Well Charger	1	$11.99
Lift Bag	1	$39.98
PVC Cap	1	$1.62
Uxcell Ohm Through Hole Carbon Resistors	1	$5.18
Total Miscellaneous		**$247.98**

Total Research & Development	**$2,505.16**