Radical Pi

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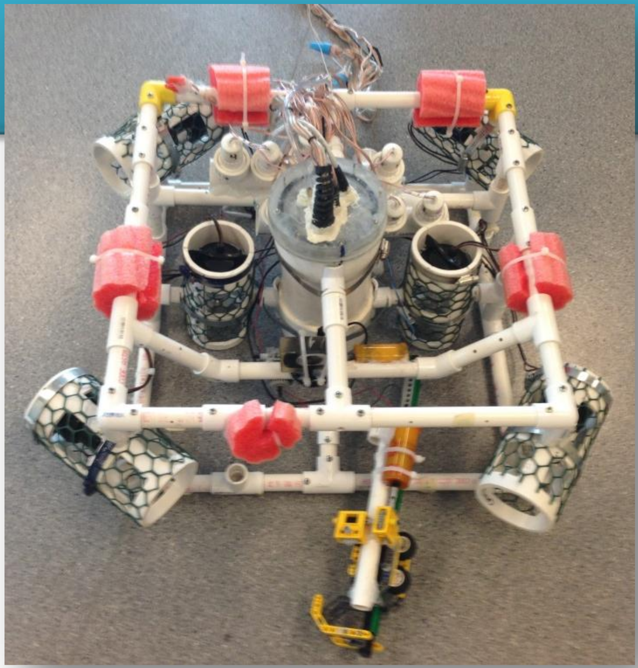
Gahanna Lincoln High School
Gahanna, Ohio



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MATE

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Abstract

The new and improved 2014 Raspberry Pi-based Explorer Division ROV from The Lincoln Group, LLC, "Radical Pi" will provide the user with an effortlessly maneuverable and versatile yet affordable ROV suitable for various underwater operations.

The Radical Pi ROV brings the intuitive and user-friendly advantages of gamer control to the world of underwater robotics with its precise vector-based movement system, allowing the user to direct the ROV in virtually any direction instantly with a simple rotation of the control pad.

In addition, the Radical Pi ROV is extremely flexible and easily repaired or modified due to its totally modular design with each thruster and tool package wired separately using an organized system of interchangeable PVC union joints.

Radical Pi features two interchangeable LEGO based grippers, each specialized for the easy completion of various tasks while on the job. Claw One, built with versatility in mind and boasting on average 10N of force, works to retrieve most objects as well as open and close any containers, while Claw Two has been designed specifically for larger, flat objects.

This new ROV from The Lincoln Group, LLC promises exceptional performance, while maintaining both an affordable and user-friendly design capable of its intended mission and more.

The Mission

Mission Theme

With over 50 shipwrecks discovered in the area, Thunder Bay National Marine Sanctuary in Lake Huron essentially houses a record of Great Lakes cargo vessels that spans hundreds of years. Due to the shipwrecks' historical significance, people at the Thunder Bay National Marine Sanctuary are working to document and conserve the sites of the wrecks through the use of underwater remotely operated vehicles (ROVs). These ROVs can aid historians and scientists in the identification of sunken vessels as well as assist in local conservation efforts such as those involving research of underwater sinkholes or reducing water pollution. Our mission is to design and build an underwater ROV capable of performing documentation of shipwrecks in Thunder Bay National Marine Sanctuary and conduct environmental research, similar to those being used in the real world.

Mission Overview

Task 1

Task 1 includes a number of jobs concerning the documentation and identification of the shipwreck. Our ROV must first take measurements of the shipwreck's dimensions, reporting a value for height, length, and width, accounting for the slope of the pool bottom. Several distinctive features of the ship will also be noted, such as the existence of propeller, paddlewheel, or mast head, which will indicate the type of ship. In addition, our ROV needs to take three (3) "sonar scans" of the shipwreck. In order to do this, the ROV is required to remain stationary in a position such that our camera can maintain the view of a black ring for five (5) seconds for each of the scans. Continuing to document the features of the shipwreck, our ROV will then need to take five (5) successive photographs of the ship's exterior, covering approximately 60cm x 100cm each. Later, our team will use the photos to stitch together a photomosaic of the ship's surface. In addition to documenting the external features of the shipwreck, we must also enter the wreck in order to fully identify the ship. The ROV must begin by removing any debris preventing the ROV from entering through the 75cm x 75cm hole in the side of the wreck, then go inside. Once inside the shipwreck, the ROV will unlock a cargo container, open the container, examine its contents to help identify the ship, then close and re-lock the container. In a further effort to identify the ship, the ROV will find a date printed on a beam within the wreck that indicates when the ship was constructed. Finally, before exiting the shipwreck, the ROV must retrieve a plate, which, when brought to the surface, will indicate the port from which the ship originated. Gathering all information collected during Task 1 will allow our team to determine the identity of the sunken ship.

Task 2

Task 2 involves taking several measurements regarding the surrounding area of the shipwreck. Our ROV is required to take a sample of a microbial mat and return it to the surface as well as take a conductivity reading of nearby groundwater. In addition, our ROV will complete a task assisting future data collection by removing an old sensor string and then replacing the string with a new one. Finally, our team will determine the approximate number of zebra mussels on the shipwreck by placing a quadrat 50cm x 50cm on the ship. Then, the team must count the mussels within the quadrat from a picture taken from our camera. Finally, using this value, along with the surface area of the ship from Task 1, will yield the total number of zebra mussels.

Task 3

Task 3 requires our ROV to contribute to helping keep the environment clean and conserving our resources. While completing the examination of the shipwreck, the ROV will also have to collect both a plastic and glass bottle and bring them to the surface to reduce pollution in the area. In addition, the ROV will perform some cleanup of the shipwreck itself by removing an old anchor as well as the discarded anchor lines surrounding the ship.

Design Rationale

ROV Structure

Frame

When we began our design phase, our team knew that we wanted a simple frame. We came up with the idea of a cube, but later decided that the extra height was unnecessary. We shortened the height of the cube to form a rectangular prism. After the design phase, we built a basic, prototype prism. As the design of our bot became more complex, we added extra joints and PVC in order to connect tool packages, mount motors, and connect the onboard electronics to the frame. After all of the ROV's components were mounted, we had an extra addition. We added a union organizer made out of PVC cut with a Dremel tool in order to better organize the various wires and unions coming from the motors and onboard electronics. After this was mounted, the frame was complete.

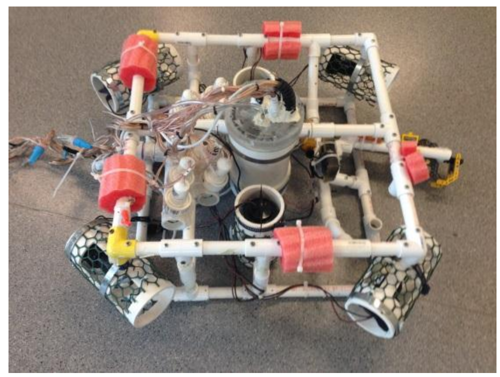


Figure 1: The "Radical Pi" underwater ROV

Vectoring

The bot is driven using what is referred to as a vector-based movement system. This system uses four motors individually and allows us to move in any direction at any desired speed. The ROV's vector-based movement system enables the bot to move in a very specific direction in order to correct a mistake or retrieve an object at an odd angle (not straight or 90 degrees). The system works by employing a simple mathematical equation that generates the amount of force that each motor needs to create in order to move the ROV in a specific direction at a specified speed. The equation is as follows.

U = Left Joystick X-axis
V = Left Joystick Y-axis

$$F_1 = \frac{U+V}{2\sqrt{2}} - \frac{\Omega}{4}, \quad F_3 = \frac{V-U}{2\sqrt{2}} - \frac{\Omega}{4},$$
$$F_2 = \frac{V-U}{2\sqrt{2}} + \frac{\Omega}{4} \quad F_4 = \frac{U+V}{2\sqrt{2}} + \frac{\Omega}{4},$$

Utilizing the input of each joystick, we can calculate the force and direction necessary for each motor to produce in order to move in the same direction as the left joystick is moved with added rotational effect from the right joystick. Our ROV's vector-based movement system included within the bot's programming provides our underwater ROV with superior maneuverability during our mission, enabling us to move in an unlimited number of directions with ease using intuitive joystick control.

Controller/Electronics

The ROV system relies on two individual Raspberry Pi computers communicating instructions from a Ps2 controller and turning those instructions into values that can be used to generate specific amounts of power for a specific motor. The Raspberry Pi above the water does the majority of the work, generating a closed network on which the two Pi's communicate and takes in input from the controller. The input is then converted into a value between 0 and 4096, values that the PWM board can use to control the motors. Those values, as well as a 0 or 1 indicating direction, are then transmitted to the Raspberry Pi onboard the ROV. This Pi takes these values and sends the first one to the PWM board for redistribution and the second straight to the motor controllers. These ordered pairs are the essential backbone of the entire robot. Without this simplified approach to transmitting motor speeds to the onboard Pi, redistribution to the individual motors could get very complicated, causing the Raspberry Pi to slow down and possibly even overheat. See Appendix, *Figure 1* for the complete SID.

Figure 2: The joystick control

Programming

See Appendix, *Figure 2* for an illustration of our program logic.

Floatation

After the construction of the modular rover, we began the initial phase of making our ROV, Radical Pi, neutrally buoyant. Neutral buoyancy is the state in which the average density of an object is equal to the water's density. The frame, tool packages, and central electronics by themselves are denser than water and therefore negatively buoyant, making the addition of flotation, material that is positively buoyant, essential. During the initial prototyping stage, we attached pool noodles as flotation. However, at a later time, throughout the rest of the process, insulation foam replaced pool noodles due to their ability to maintain positive buoyancy under more pressure, at greater depths underwater. When trying to make an ROV neutrally buoyant, two principles that need to be understood are center of mass and center of buoyancy. Center of mass is the point in which the mass of an object is most evenly distributed, while center of buoyancy is the point in which the force applied towards the surface by one or more positively buoyant objects is most evenly distributed. When applying floatation, it is imperative to keep the center of buoyancy above the center of mass to give the ROV stability. In addition, a greater distance between center of buoyancy and center of mass further increases the stability of the ROV. Another concept of which we were aware during the buoyancy testing of our ROV is having an equal distribution of flotation. There needs to be an equal distribution of flotation corresponding to the concentrations of mass on the ROV in order to keep the ROV level at all times. Having done this meticulous process of applying flotation to our ROV, Radical Pi, the resulting product has exceptional maneuverability and stability.

Tool Packages/Attachments

Modularity

Radical Pi was created with modularity in mind. The engineers wished to create an ROV with the ability to exchange individual tool packages without having to completely rewire the tether. Our ROV contains a system of ten PVC unions, each dedicated to a single thruster or tool package, designed such that each electronic component of the bot can be removed individually without disturbing the wiring of any other components. In addition, Radical Pi's modular construction gives users the ability to create new tool packages for use when a new problem not previously considered arises. Waterproof PVC unions containing rubber O-rings enable all motor and tool packages to be disconnected and re-installed with ease, while maintaining a completely waterproof, safe connection. A power and ground wire are secured and waterproofed with epoxy inside each end of the union. The end that is connected directly to the tool packages and thrusters uses a female PVC connector and male wire connectors, whereas the end connected to the central onboard electronics uses a male PVC connector and female wire connectors. This universal configuration on all of Radical Pi's components allows for the interchanging of components at every connection, creating a totally modular and flexible ROV design.

Figure 3: The PVC union system allowing for modular connections between ROV components and the power source

Tether

The tether connects the controller Raspberry Pi to the rover Raspberry Pi and also delivers power and live camera playback. The tether consists of power wires, a camera wire, and a CAT5 network cable. These wires were braided using a simple "outside-to-inside" technique. This braid is used to keep the wires together and out of the ROV's way during the mission.

Figure 4: Radical Pi's braided tether

A PVC union is used to allow the network cable to disconnect from the ROV, making the tether and rover more manageable during transportation and modular in design. PVC end-caps, 1.25" diameter PVC, and a 1.25" PVC union forms a capsule through which the network cable runs. The wires each enter end caps through drilled holes. The wires were stripped just above their entry into the capsule to allow epoxy poured into each capsule to not only seal the wires to the caps, but also to allow the epoxy to enter the wire's coating, preventing water from leaking through the length of the wire itself. The tag ends of the network cable were converted to RJ45 connectors, which were attached via a female to female RJ45 connector using a PVC union connector.

This PVC union connector is a major component, allowing us to have a modular ROV with a removable and replaceable tether. Within the PVC union connector, there is an O-Ring, and along with the epoxy-filled ends of the connector, it has proven to be extremely effective in keeping the connections inside dry. We have tested this type of connection to a depth of 21 meters, which means it is functional in up to at least three atmospheres of pressure, a depth well beyond sufficient for our mission. Used in both our CAT5 cable network and all of our tool packages, team members can easily and quickly swap out tool packages and/or remove the tether for storage and shipping because of our "quick disconnect" PVC unions.

Camera

The Radical Pi possesses one Logitech HD Webcam C615, a relatively inexpensive but effective option as compared to other underwater cameras available. The cameras were potted in plastic petri dishes with epoxy, effectively waterproofing the entire device. The camera is attached to a USB cable running the length of the tether with inline repeaters. The cord is quite flexible and was easily attached the main tether braid. The major improvement these cameras have over our old cameras from previous years and missions is that these are digital as opposed to analog. Our previous analog cameras had a much lower resolution, which proved to be a disadvantage during missions, producing sometimes unclear images. The higher resolution of this new digital camera as well as the easy output to a computer means that the picture viewed from the camera is clearer and can be easily recorded during missions. Another advantage of the camera, their ability to image in color, allows for easier differentiation between objects and background than black and white cameras, making missions easier to complete.

Figure 5: The HD Webcam potted using epoxy for waterproofing

The rover's potted camera is mounted on a rotatable platform, allowing the pilot to view the mission layout in all directions. This rotating platform is driven by a waterproofed hobby motor connected to power via a "quick disconnect" connected to the tether. Using a flexible U-joint, the hobby motor was run directly into a LEGO gear box, which increases the torque and decreases the rotational speed, giving the pilot greater control over the rotation of the camera. Various gears were used to fix the platform perfectly around its PVC body. The final rotational ratio from hobby motor to camera is 188:1. When fixed to specific parts of the ROV frame, this rotatable camera platform gives the pilot the ability to see multiple tool packages in a matter of seconds.

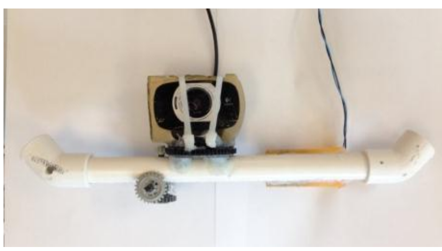


Figure 6: The HD Webcam affixed to its rotatable mount

Grippers

The primary tool packages on the ROV are gripping devices referred to as "The Claws". There are two claws on the bot: one smaller, general purpose claw built to be used for most everything (Claw One) and a second claw built specially for picking up a dinner plate (Claw Two). Although designed for and intended to retrieve the dinner plate during the mission, Claw Two can double as a standard claw in most situations as well. These tools are made from waterproofed hobby motors, which drive the grippers, a series of LEGO gear boxes, and the physical claws themselves constructed primarily of LEGO bricks.

The unique angle from which Claw One grabs objects has proven to be very beneficial. The typical claw is mounted outward from the ROV's frame whereas this design is mounted downward with the motor mounted at a 45 degree angle. The gripping part of the claw has two sections that can work together or separately depending on the pilot's needs. The static portion of the claw is made of two hook-shaped LEGO pieces. The swinging part of the claw, also comprised of two hook-shaped pieces, can swing from 100% open, all the way against the motor, up to 110 degrees past the static claw. Due to the hobby motor's intense rpm, two LEGO gearboxes effectively gear the turn ratio from 576:1.

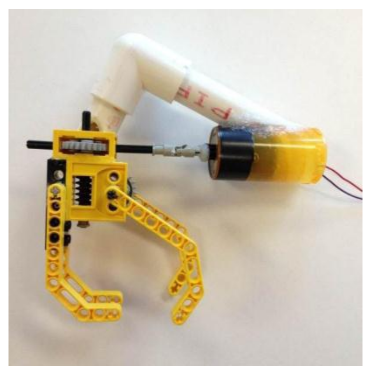


Figure 7: Front view of Claw One, the primary gripper

This claw has a number of desirable features over other designs. First, there are two static pieces which can function as hooks in addition to part of a moving claw. Second, the fingers of the claws are able to interlace with each other, providing better gripping and holding power than a non-interlacing grip. Finally, the angle of the gears has been more reliable and less prone to breakage than other designs after extensive testing and prototyping.

Claw One, our primary claw, was tested with a Vernier force sensor to demonstrate its strength. As per the diagram below, an initial force of approximately 10 Newtons continues to increase over time until a maximum force of approximately 13 Newtons is attained in 18-20 seconds.

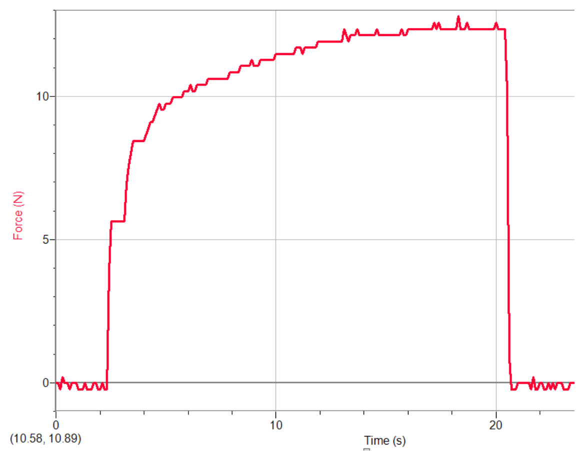


Figure 8: A graph of the results of a grip force test for Claw One

Claw Two was engineered to be able to achieve a firm hold on an object with a wide face, such as the plate in our mission. One half of the claw remains stationary, while the other half is attached a platform that is moved to open and close the claw. The use of LEGO cog plates along the platform, as well as the two LEGO gearboxes provide firm and steady control over the arm whether it is retracting or extending.

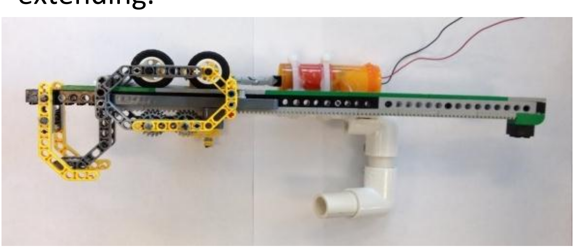


Figure 9: Front view of Claw Two, the plate claw

Safety

The Lincoln Group, LLC makes the safety of its members and others a priority. The company has a basic protocol that is used when setting up the ROV in any area for the first time:

- Bot is unpacked from any casing, and the components are checked and prepared to be powered up. At this time it is also checked that all components are dry.
- Hands-Free check is called for the first time. Everyone steps back from the bot as the control system, cameras, and monitors are connected to the power supply.
- All above components are inspected for functionality.
- Hands-Free check is called for the second time as the bot itself is connected to the power supply.
- Wait for 30 seconds before attempting to use the controller, in order to allow the two Raspberry Pi boards to connect. Once the LED lights on the network switch turn green, the connection is complete.
- Hands-Free check is called for the third time, and the controller is activated. All six thrusters are individually tested for functionality.
- Once functionality is confirmed, the bot is lowered into the water and rolled to ensure that all air has left the frame.
- Hands-Free check is called for the last time. Hands holding the ROV release, and the pilot proceeds to test the ROV for functionality in-water.

- Once functioning, the pilot uses the controller and proceeds with the mission.

Safety is an extremely important aspect of working with any sort of robotics or mechanics. The Lincoln Group, LLC kept in mind the safety of its members and the bot's users when designing, constructing, and operating Radical Pi. We re-used an innovative motor shroud design from a previous year that prevents loose debris and unwanted appendages from coming near the propellers of the thrusters. In order to prevent injury as a result of human error, we also wrote "Caution" around each motor shroud. During the construction of Radical Pi, safety equipment, such as goggles, was always used when using any equipment that could burn, create flying pieces of PVC, or in any other way injure the operator.

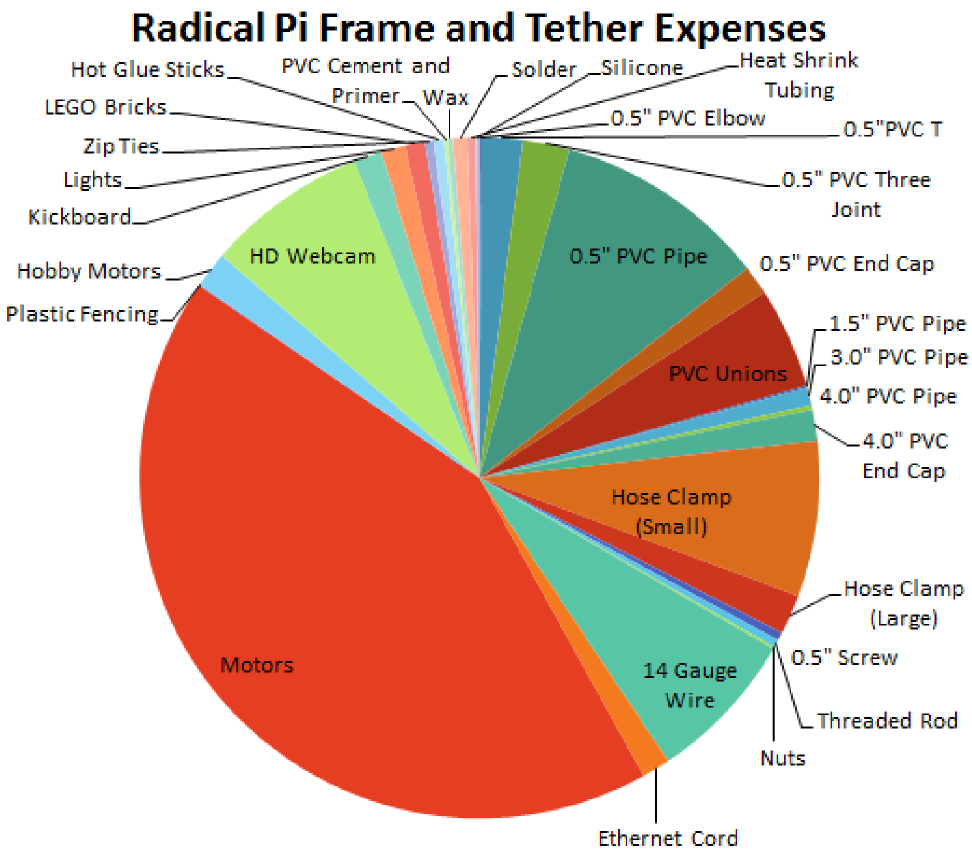
Figure10: Radical Pi's motor shroud design

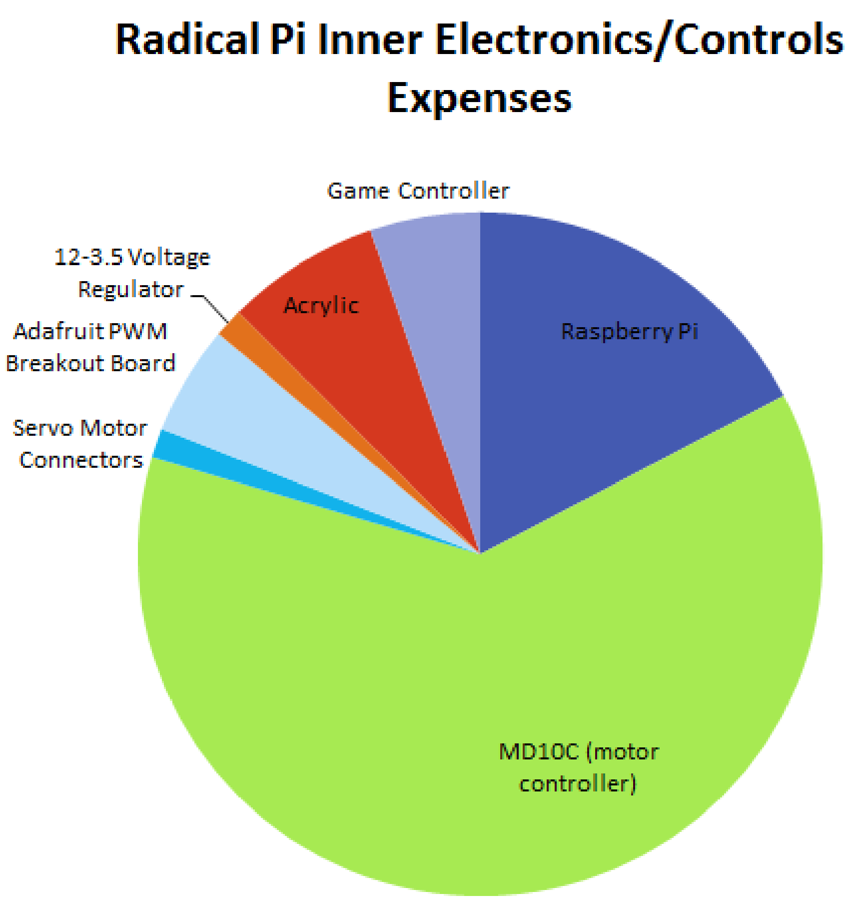
Simple safety principles were also followed during all aspects of creation of Radical Pi. During all phases, common sense was often followed. PVC cutters were always purposefully closed, hot glue guns and soldering irons were always placed on tables and never left unattended, and any sort of cutting tool was always used with caution. We also took care to always unplug power supplies after use, especially when located near any water.

When designing how the tool packages would connect to the ROV, the female plug was always placed on the power side of the circuit. This precaution was taken in order to reduce the chance of accidental shock. In house outlets, the same precaution is taken. The female connection is on the wall, while the male connection is connected to the appliance being used. Since the male connection has no power without the female connection, and the female connection prevents anyone from touching a live wire, it is hard to accidentally shock oneself. Many more accidents would ensue if this were not the case. Since this sort of safety is demanded in our homes, the Lincoln Group, LLC believes it should also be demanded in the work place. The Lincoln Group, LLC, by following these and other important safety principles in placing fuses and using proper grounding procedures, is setting the bar for other Explorer Class vehicles.

Budget

ROV Budget			
Quantity	*Item*	*Unit Cost*	*Total*
	Frame and Tether		
2	0.5" PVC Elbow	$ 0.28	$ 0.56
22	0.5"PVC T	$ 0.46	$ 10.12
8	0.5" PVC Three Joint	$ 1.44	$ 11.52
408.6	0.5" PVC Pipe (per cm)	$ 0.13	$ 53.12
20	0.5" PVC End Cap	$ 0.36	$ 7.20
10	PVC Unions	$ 2.50	$ 25.00
52	1.5" PVC Pipe (per cm)	$ 0.01	$ 0.52
73.9	3.0" PVC Pipe (per cm)	$ 0.06	$ 4.43
19	4.0" PVC Pipe (per cm)	$ 0.06	$ 1.14
1	4.0" PVC End Cap	$ 7.71	$ 7.71
8	Hose Clamp (Small)	$ 4.80	$ 38.40
2	Hose Clamp (Large)	$ 4.90	$ 9.80
51	0.5" Screw	$ 0.04	$ 2.04
1	Threaded Rod	$ 1.87	$ 1.87
8	Nuts	$ 0.07	$ 0.56
140	14 Gauge Wire (per foot)	$ 0.27	$ 37.80
70	Ethernet Cord (per foot)	$ 0.10	$ 7.00
6	Motors	$ 36.99	$221.94
2.03	Plastic Fencing (per sq. foot)	$ 0.13	$ 0.26
3	Hobby Motors	$ 2.97	$ 8.91
1	HD Webcam	$ 40.00	$ 40.00
1	Kickboard (floatation)	$ 7.00	$ 7.00
1	Lights	$ 5.99	$ 5.99
1	LEGO Bricks	$ 5.00	$ 5.00
100	Zip Ties	$ 0.02	$ 2.00
1	Hot Glue Sticks (Pack of 24)	$ 2.54	$ 2.54
0.1	PVC Cement and Primer Twin Pack	$ 9.69	$ 0.97
0.25	Wax	$ 5.47	$ 1.37
1	Solder	$ 3.47	$ 3.47
1	Heat Shrink Tubing	$ 1.99	$ 1.99
0.25	Silicone (per tube)	$ 3.98	$ 1.00
			$521.23
	Inner Electronics/Controls		
2	Raspberry Pi	$ 25.00	$ 50.00
11	MD10C (motor controller)	$ 16.33	$179.63
10	Servo Motor Connectors	$ 0.40	$ 4.00
1	Adafruit PWM Breakout Board	$ 14.95	$ 14.95
1	12-3.5 Voltage Regulator	$ 3.95	$ 3.95
3	Acrylic (per sq. foot)	$ 7.00	$ 21.00
1	Game Controller	$ 15.00	$ 15.00
			$288.53
	GRAND TOTAL	**$**	**809.76**


Radical Pi Frame and Tether Expenses
Hot Glue Sticks
PVC Cement and Primer
Wax
Solder
Silicone
Heat Shrink Tubing
LEGO Bricks
0.5" PVC Elbow
0.5"PVC T
Zip Ties
Lights
0.5" PVC Three Joint
Kickboard
HD Webcam
0.5" PVC Pipe
Hobby Motors
0.5" PVC End Cap
Plastic Fencing
1.5" PVC Pipe
PVC Unions
3.0" PVC Pipe
4.0" PVC Pipe
4.0" PVC End Cap
Hose Clamp (Small)
Hose Clamp (Large)
0.5" Screw
Motors
14 Gauge Wire
Threaded Rod
Nuts
Ethernet Cord


Radical Pi Inner Electronics/Controls Expenses
Game Controller
12-3.5 Voltage Regulator
Acrylic
Raspberry Pi
Adafruit PWM Breakout Board
Servo Motor Connectors
MD10C (motor controller)

Barckhoff's Principles

In order to reduce wasted time and money, the Lincoln Group, LLC quality assurance applied a set of principles to the manufacturing of our ROV. These principles were developed by J.R. Barckhoff in *Total Welding Management.* Barckhoff has worked for forty years in the welding industry, and his experience helped him create a system of evaluating any process for efficiency. This system improves production while decreases the cost of what is being produced, as well as the labor and time required to develop and fabricate the final product. He calls this system the "Barckhoff Welding Management System"; however, for the sake of being concise, the Lincoln Group, LLC refers to this system as "Barckhoff's Principles". Barckhoff simply looked at production in an area such as manufacturing and asked the question, "How can we reduce cost and wasted time in this area?" Barckhoff examined all aspects of production and posed this same question. He looked at design, manufacturing, and quality control of a product. Many companies across America have adopted his system of quality assurance due to its ability to increase efficiency in production.

The Lincoln Group, LLC evaluated all aspects of the company according to Barckhoff's principles. We evaluated our production capabilities in the design, manufacturing, and quality assurance as Barckhoff describes in order to aid our own system of production. Each individual component of our ROV, including all of our tool packages, hardware, and the frame itself was inspected using the same method. In addition, our use of Barckhoff's principles during all phases of production ensured that we did not waste valuable materials and money.

In the design area, we were able to reduce the materials needed to build a waterproof case for the onboard electronics as well as reduce the size of the onboard electronics themselves. In previous years, the casing and electronics board have been unnecessarily large, and previous members remarked that it was difficult to attach the casing to the frame. However, this year, the team decided we needed to design and manufacture the onboard electronics differently so that the casing could be smaller. The new design secures the casing to the frame with hose clamps and PVC and is roughly one half of the size of last year's casing. It is also able to be vertically mounted to the frame, whereas last year's casing, due to its size, had to be horizontally mounted to the frame. The electronics board itself is also about half the size of last years'. The individual circuit boards were placed on a board horizontally, and the board only had one layer. This year, we mounted the boards vertically (when looking at the electronics capsule lying on its side), and we layered the boards on top of each other to save space. This years' onboard electronics and casing best illustrate our use of Barckhoff's principles during the design phase of production.

In the manufacturing area, we were able to reduce work time by creating a work station for the building of our onboard electronics. We compiled all of the materials needed to build our newly designed electronics board in one place and organized them by type. This allowed our specialists to have all needed materials in front of them even before they started constructing, which saved many hours of traveling to and from hardware stores or tool benches to fetch materials. With regards to reducing motion-delay time, we utilized assembly-line techniques. Each specialist would manufacture a specific piece of the electronics, and then pass it on to the other, who would manufacture another specific piece. This enabled each specialist to master the manufacturing of a specific part so that it was made with the same quality, but also allowed for evaluation by a second set of eyes that could spot mistakes as easily as the original builder. By incorporating these two manufacturing methods, we were able to reduce scraps of the needed materials to make an efficient and smaller circuit system.

For the quality assurance area of our ROV, the specialists checked each other's work. As they assembled the pieces of central electronics, they would pass their work on to another specialist, who would then evaluate the construction of piece. After the pieces had been evaluated by those in the manufacturing department, we had someone outside of the manufacturing department evaluate the construction. We also often had this person watch the manufacturing process in order to possibly give insight on how to further improve the process. Our process of quality assurance helped us see any mistakes in the pieces of onboard electronics before assembling the entire capsule, preventing hours of reworking and several additional evaluations. This also prevented the waste of valuable materials if the piece were flawed. The Lincoln Group, LLC took special care to ensure that our team did not waste valuable time, resources and money by strictly following the manufacturing efficiency principles developed by J.R. Barckhoff during the design and construction of our ROV, Radical Pi.

Challenges/Troubleshooting

We faced many challenges while developing this year's ROV. For example, numerous issues existed with the initially prototyped waterproof casing for the onboard electronics. The capsule had significant issues with leaking at depth below 3 meters. The casing leaked at least 50 ml of water every time we dropped it in higher depths. In order to determine where the water was leaking, we attached the lid to the casing and pumped air into the container while it was submerged and watched for bubbles. We quickly discovered where the leaks were and sealed them successfully using additional silicone and epoxy. Since we sealed the leaks in the casing, we have not had any further issues with leakage.

Future Improvements

The Radical Pi is the second of what we hope to be a series of several Raspberry Pi-powered ROVs from The Lincoln Group, LLC in the Explorer class in years to come. The first improvement we expect to make concerns allowing the camera to have two different axes of rotation, not just one. This adaptation could also be applied to our grippers, which would make them more versatile. A second possible change we are considering in the future is upgrading the quality of our current thrusters to provide greater vertical power. Current vertical force could be improved in order to more easily lift heavy objects to the surface. A third improvement would be to send the video footage through the cable connecting the two Raspberry Pis. This would require a great sum of work on the software, but would eliminate the USB extender cable in our tether we currently use to communicate the data from the camera to the surface.

Skills Gained

Throughout the entire process of the production of Radical Pi, all members of The Lincoln Group, LLC, especially those new to the program, expanded their knowledge of engineering design, electronics, and waterproofing. Numerous skills including those involving programming the Raspberry Pi and creating a truly modular design were refined, learning from the previous years of The Lincoln Group, LLC's operation. Certainly many technical skills were acquired by our team, but another set of skills that are just important to our success were also developed through the production of our ROV: problem-solving and troubleshooting skills. Our team had to identify specific issues and gained practice brainstorming solutions to these obstacles. Our experience this year building an underwater ROV has taught all of us something valuable in the field of engineering and design.

Team Biographies/Reflections

Aaron Grgurich

Engineer / Builder

I am a junior and a second year member of the Gahanna Lincoln High School Underwater Robotics Team. I joined the team because I enjoy engineering, and I love working with my hands. While being a part of this team, I learned a lot about waterproofing, electronics, and robotics. Outside of robotics, I am a car enthusiast, and I enjoy video games and nature. At school, I am a part of the DECA Marketing Program, National Honor Society, Science Academy, Varsity Lacrosse Team, and The GLHS Investment Society.

Anthony Condo

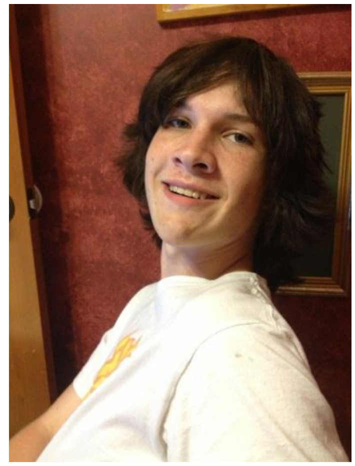
Engineer / Builder / Planner

I am currently a junior at Gahanna Lincoln High School, and this will be my first year in the Explorer division and my second at a MATE overall. I have a great interest in robotics overall, like solving puzzles, and enjoy building things with my hands. I am an avid music connoisseur, love reading, camping, and playing videogames in my spare time. Through this program, I have learned many different things and have been pushed to expand my knowledge in multiple directions. I have enjoyed the chance to build and design various parts of the robot these past two years and look forward to next year.

Sarah Ryan

CFO / Engineer / Communications

I am currently a junior at Gahanna Lincoln High School, and this is my first year as a part of the underwater robotics team with The Lincoln Group, LLC. With this year being my first experience on the underwater robotics team, I have certainly acquired a great deal of new skills involving the construction and testing of underwater ROVs these past few months. While working with the team this year, I got the chance to learn about the entire process from designing an ROV to actually building the ROV as well as the troubleshooting and problem solving techniques used when encountering an issue during the ROV's development. I thoroughly enjoyed my experience on the team this year and look forward to doing it all again next year.



Nathan Alden

CEO / Pilot / Programmer / Electronics

This is my third year on the underwater robotics team here at Gahanna Lincoln High School. I am a recent graduate from GLHS. I spent the previous two years on the team developing and improving upon the design that I originally came up with for an underwater robot utilizing a Raspberry Pi. This year was no different. I spent most of the year decreasing the size of the container that houses the onboard electronics and developing a new vector-based movement system. I do not currently plan on pursuing a career in engineering, nor do I plan on attending college for such. I have enjoyed my time here at GLHS as well as my time spent with the underwater robotics team.

Nelson Okeke

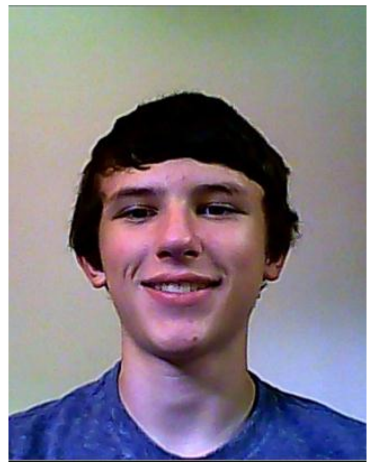
Engineer / Builder

I am a graduated senior from Gahanna Lincoln High School. This is my second year in the Underwater Robotics Team. I am going to attend the University of Akron, where I will major in mechanical engineering. I enjoy creating things, helping others, and using as few words as possible.

Kaleigh Alden

Safety / Engineer / Builder

This is my first year as a part of the Lincoln Group, LLC, and I am a current junior at GLHS. Since it is my first year as part of the underwater robotics team, I have had lots of room to learn. Over the course of the year, I have learned a great deal of engineering skills as well as effective teamwork skills. My year in underwater robotics has thoroughly inspired me to continue next year in the Explorer division of underwater robotics. I also plan to pursue mechanical engineering at OSU following my senior year of high school.



Aaron Glanville

Engineer / Builder / Photographer

I am a sophomore at Gahanna Lincoln High School. This is also my first year participating on the school's underwater robotics team, The Lincoln Group, LLC. Though at the beginning of the year I lacked experience pertaining to this kind of work, throughout the process I was able to gain the skills needed to design and build an ROV. After having a great time working for The Lincoln Group, LLC, I plan on using my acquired skills for my junior and senior year to further construct underwater robots.

Acknowledgements

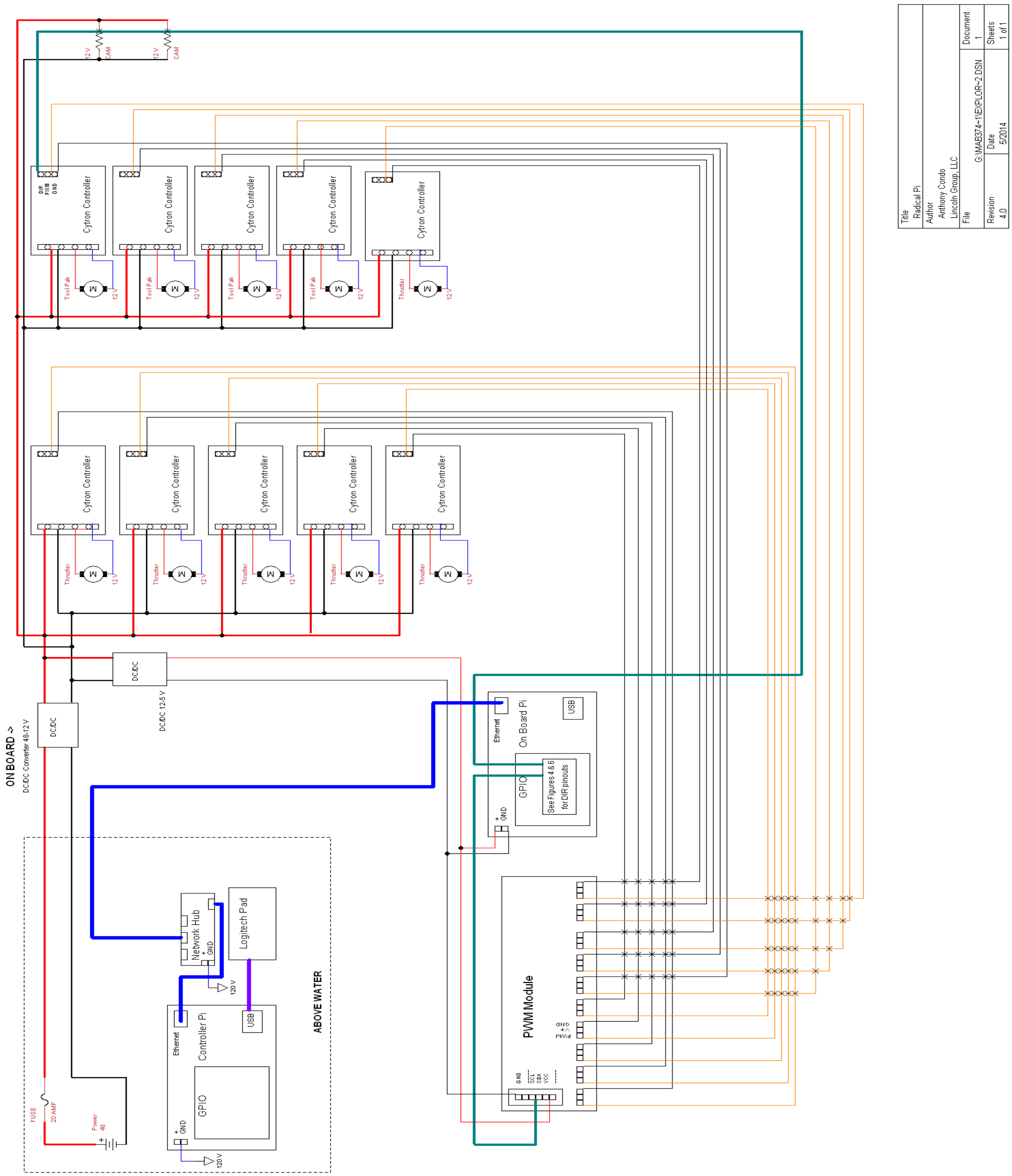
The Lincoln Group, LLC would like to thank all of the people that helped to make this trip to the M.A.T.E. International Competition possible. First, we would like to extend our greatest thanks to Mr. Fred Donelson, who offered up his classroom and pool for designing, testing, troubleshooting and practice. He also provided us with some of our funding for materials for the ROV and shared his extensive knowledge of underwater vehicles with us. We would also like to thank Mr. Ralph Alden for all the time he spent providing us with invaluable guidance while designing and waterproofing the ROV's main circuit board. Mr. Dave Alden also provided us with some of our funding for materials as well as instrumental help in programming the movements for our tool packages. We extend our thanks to Mr. J.R. Barckhoff, whose principles of quality assurance helped us to design an ROV that reduced costs from last year and still allowed us to build a quality ROV. Finally, we would like to thank our families and friends for all of their funding and support, and for inspiring us to reach new heights.

References

Barckhoff, J.R. *Total Welding Management.* Miami, Florida: American Welding Society, 2005.

"2014 MATE ROV Competition Manual: Explorer Class." *Marine Advanced Technology Education*. MATE, 2014. Web. n.d.

Figure 1


12 V
CAM
Cytron Controller
DIR
PWM
GND
Tool Pak
Thruster
M
ON BOARD ->
DC/DC Converter 48-12 V
DC/DC
DC/DC 12-5 V
Ethernet
On Board Pi
USB
GPIO
See Figures 4 & 6 for DIR pinouts
GND
PWM Module
Network Hub
Logitech Pad
120 V
Controller Pi
ABOVE WATER
FUSE
20 AMP
Power 48
Title
Radical Pi
Author
Anthony Condo
Lincoln Group, LLC
File
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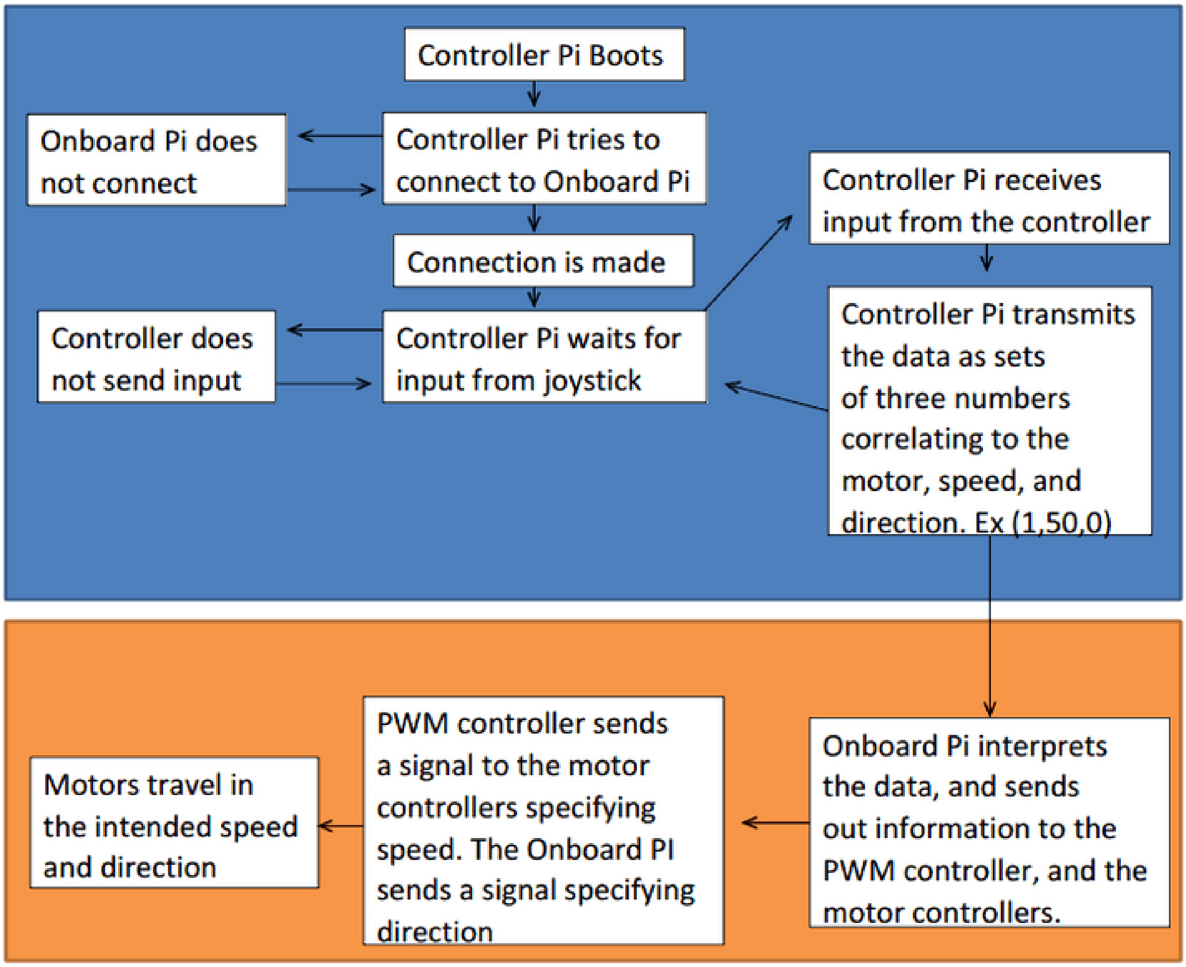
Document
1
Revision
4.0
Date
5/2014
Sheets
1 of 1

Figure 2



Controller Pi Boots
Onboard Pi does not connect
Controller Pi tries to connect to Onboard Pi
Controller Pi receives input from the controller
Connection is made
Controller does not send input
Controller Pi waits for input from joystick
Controller Pi transmits the data as sets of three numbers correlating to the motor, speed, and direction. Ex (1,50,0)
PWM controller sends a signal to the motor controllers specifying speed. The Onboard PI sends a signal specifying direction
Motors travel in the intended speed and direction
Onboard Pi interprets the data, and sends out information to the PWM controller, and the motor controllers.