camsROBOTICS
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Technical Report
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CAMS Explorer ROV Team

California Academy of Mathematics and Science
1000 E. Victoria Street Carson, CA 90747

2010 MATE International Competition
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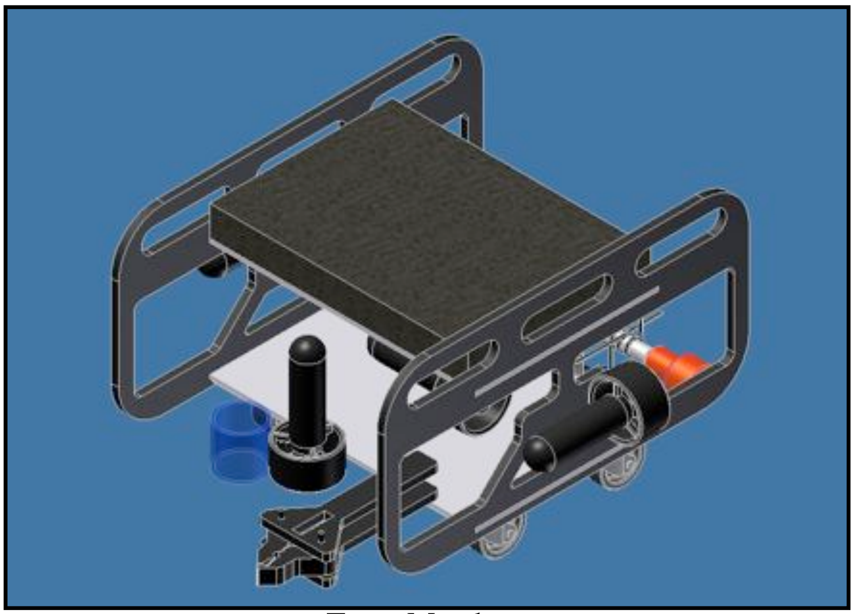

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Abstract

As the California Academy of Math and Science (CAMS) Explorer Remotely Operated Vehicle (ROV) Team prepares for participation in its fourth International MATE ROV Competition, the team has utilized innovation in all aspects of the ROV design, construction, and presentation to meet all monetary, time, and skill constraints. Through the use of Autodesk Inventor Computer Aided Design (CAD) software, the team was able to design and conceptualize every inch of the ROV, minimizing cost and future physical problems. Using our self developed and taught machining and rapid prototyping skills, the team has utilized its creativity to its fullest by manufacturing its own parts to produce a functioning, practical, and efficient ROV. The ROV's sophisticated control system, along with its accompanying software, was completely created and designed from scratch. This allows for maximum compatibility and customizability throughout our ROV system, which include the ROV with a self designed and assembled propulsion system, sensors, float and ballast, and payloads, a tether that sends power and communication data, and a control system that the pilot uses to interface with the ROV. After applying every team member's strengths and weaknesses to the building of the ROV along with good time management, teamwork and leadership, the CAMS Explorer team has constructed a successful and fully functional ROV system for the 2010 International MATE ROV Competition in Honolulu, Hawaii.

Design Rationale

Structure

The structure for the vehicle was designed with simplicity, mass, size, and maneuverability in mind. The vehicle's dimensions are 70cm by 40 cm by 40 cm. The primary structure is made of ½-inch ABS plastic sheets, machined into mounting surfaces for other components of the ROV. ABS was used for its strength and its ability to be easily machined. The structure is held together with ¼-20 machine screws. The ROV uses a simple box frame to maintain simplicity for building and troubleshooting purposes. There are 2-in casters on the base of the ROV to allow easy maneuverability at the bottom of the pool.

Figure 1: Sheet of ABS Stock

Tether

The tether for the 2010 CAMS ROV contains six pairs of 18 gauge speaker wire and three air lines. The speaker wire is used to power the articulation motor as well as the five thrusters. Two of the pneumatic air lines are used to power the pneumatic pistons for the claw, and the other is used to draw a vacuum for the agar payload. The tether was chosen to be 30 meters in order to be short enough to minimize voltage drop along while still being long enough.

Motors

The ROV uses five SeaBotix thrusters to move in six degrees of freedom. There is a motor on the left and right side of the ROV to allow forward/backwards translation and yaw control. There are two motors in the center to allow vertical translation and pitch control. There is a single thruster in the center to allow strafing motion. Each thruster is a brushed DC motor with housing. They operate at 80 watts and 19 volts. They use a two blade

Figure 2: SeaBotix Thruster

propeller and weigh 700 grams. In addition, they have a 95 millimeter propeller casing.

Buoyancy/Ballast

The ROV is designed for stability and neutral buoyancy. The ROV is 10 kg and uses high density impact foam for floatation. The floatation was positioned above the structure, with the majority of the mass situated at the base to ensure maximum stability. The vehicle is neutrally buoyant in the first 5 meters of water because the foam does not compress.

Payload Tools

There are three payload tools attached to the ROV to complete the tasks: a claw, a vacuum, and an intake roller. The claw is used in tasks one and three to: remove the pins from the elevator, pick up the HRH, and remove the cap from the HUGO junction Box, retrieving the HRH power communications connector, and take vent spire samples. The claw is made from ABS plastic and two 2-inch pneumatic pistons. To sample the bacterial mat, the ROV uses a simple PVC vacuum. A 2-inch diameter pipe is inserted into the cup and a pump on the surface creates a suction to make sure the bacteria sample does not slip out. The intake roller is used to collect the crustaceans from inside the cave. If needed, the claw can remove the crustaceans from the wall and the intake roller then scoops them into a basket. It is made of a ¼-inch diameter rod, zip ties and a motor. All of the payload tools are located on the front of the vehicle. The intake roller is placed at the base and the others are in the center of the ROV.

Sensors

The ROV has three main environment sensing systems: the camera, the thermister, and the hydrophone. To allow the driver to see the vehicles surroundings and its orientation, cameras are placed around the vehicle. Two cameras are placed pointing directly at the payloads so the driver can easily articulate the vehicle to complete

Figure 3: Hydrophone

the complex tasks. A hydrophone is placed on the front of the ROV to detect the buzzer at the location of the seismic activity, as well as the frequency. A thermister will be used to probe the temperature of the thermal vent at the three different heights.

Electrical

The 2010 CAMS ROV control system is based around the Arduino microcontroller platform. This open-source hardware platform allows for quick and easy development without the need for expensive support hardware. This controller will be connected to the temperature subsystem, as well as the motor controllers. All of the electronics for the ROV are located above water, in a control box. The team decided against putting the electronics on the vehicle because a small leak would render the system completely destroyed.

Figure 4: Arduino

The thermister used for collecting temperature data during the mission is connected to an analog to digital converter (ADC) port on the microcontroller. The raw sensed value in volts is sent back to the PC to be processed and displayed.

To control the SeaBotix motors, Sabertooth 2x25 motor controllers are used. Each motor controller unit supports two individually controlled channels capable of sourcing a continuous current of 25 amps, with spikes up to 50 amps. These motor controllers were chosen because they allow for future expansion to different, more powerful motors without the need to purchase larger controllers.

Figure 5: Motor Controller

The directional thrusters on the ROV are operated by a 19 volt source, the cameras are powered by a 12 volt source, and the electronics require a 5 volt source. The entire system is supplied with a 48 volt source capable of sourcing up to 40 amps. This voltage is regulated down to a 24 volt and 12 volt source. Through the tether, the 24 volt source drops down to 19 volts, the most favorable voltage for the thrusters. The electronics have an onboard 5 volt regulator to drop the 12 volt source down. The power regulators used to bring the voltage down to 24 volts and 12 volts respectively typically run at 90% efficiency, meaning that at max current draw, they would only need to dissipate 48 watts of heat. On the contrary, the 5 volt regulator is only 20% efficient. This is not a problem because the electronics draw such a small amount of current, the power lost to heat is negligible.

The entire system is protected with a 40 amp in-line fuse. Each subsystem (electronics, cameras, motors, etc.) is fused with a 2 - 15 amp fuse, depending on current draw needs.

Software

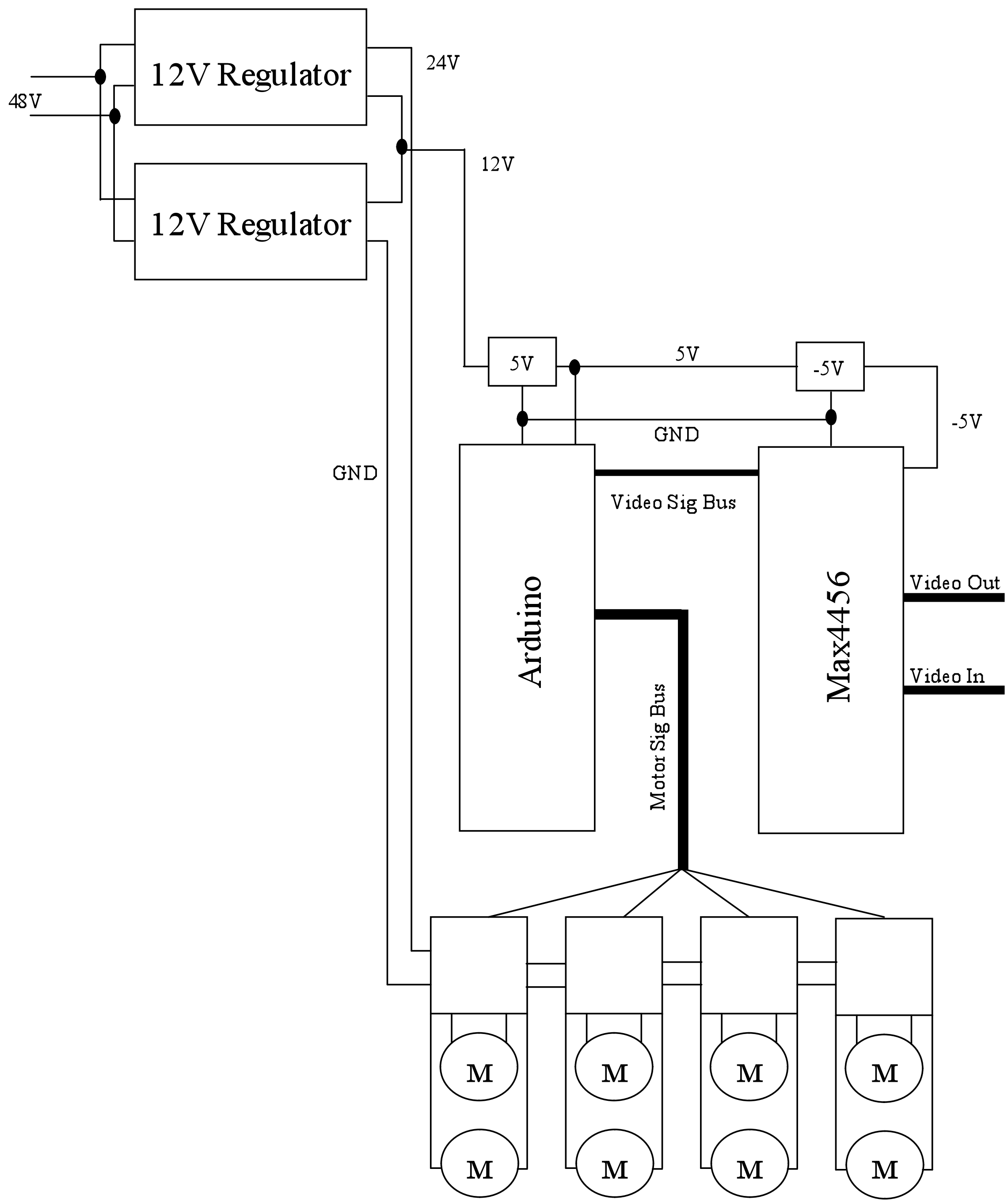
The 2010 control system has two main parts, the PC and embedded. The PC side runs a custom Java program written to maximize user functionality. A simple 12 button gamepad is used to get driver input. The controls are modeled after that of modern first person video games, which allows virtually anybody to control the ROV with ease.

The PC side control system program displays data on motor speed, joystick input, competition time, schedule, and sensor input. The competition timer allows the pilots to see how much time they have left. The task scheduler uses previous completion times from practice runs and amount of time remaining to prioritize the tasks needed to be done. It tries to pick the tasks with the largest point gain that are able to be done in the time remaining. The sensor graphing function allows the pilots to quickly produce a digital chart of the temperature readings from the different heights on the vent for the competition judges.

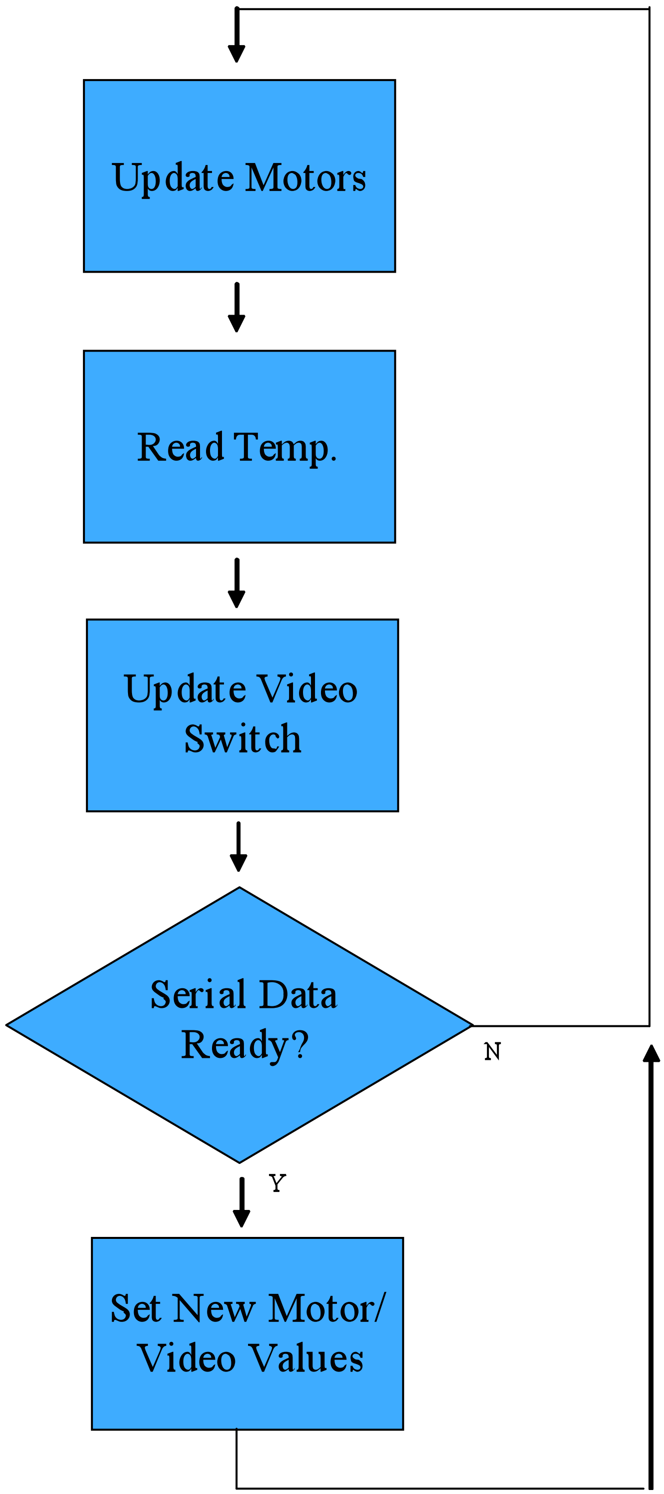
Figure 6: Java

The embedded side software takes incoming data from the PC via a RS-232 serial connection, and takes the appropriate action. The two main tasks that the embedded system will be tasked with its setting motor values and reading the temperature sensor input.

Electrical Schematic



Control System Program Flow Diagram



Expenses

	Part Description	Unit Price	Quantity	Total Cost	Reused Cost
1	ABS Sheet 1/4" Thick, 24" X 48", Black	$89.02	4	$356.08	$0.00
2	Corrosion-Resistant Aluminum (Alloy 5086) .125" Thick, 24" X 48"	$75.22	1	$75.22	$0.00
3	Super-Tough Ionomer Foam 4 lbs/cu ft Density, 1/4" Thick, 48" X 76", Black	$33.70	1	$33.70	$0.00
4	Joystick	$15.26	1	$0.00	$15.26
5	Camera/ Montitor	$179.99	4	$719.96	$0.00
6	SeaBotix Thruster	$499.95	6	$2,999.70	$0.00
7	Voltage Regulator	$324.89	2	$324.89	$324.89
8	Nutrient Agar 500mL Bottle	$19.25	6	$115.50	$0.00
9	PVC Tee Connectors (10 Pack)	$2.61	3	$7.83	$0.00
10	PVC 90 Degree Elbow (10 Pack)	$1.98	2	$3.96	$0.00
11	Self Drilling Screww (100 Pack)	$9.95	1	$9.95	$0.00
12	Sabertooth Motor Controller	$124.99	4	$499.96	$0.00
13	18 Gauge Paired Speaker Wire (250')	$99.95	2	$0.00	$199.90
14	Pneumatic Tubing	$18.75	2	$37.50	$0.00
15	Pnuematic Piston	$27.00	3	$81.00	$0.00
16	Control System PCB Printing	$125.00	1	$0.00	$125.00
17	Control System Components	$50.00	1	$0.00	$50.00
18	Misc. Electronic Components	$30.00	1	$30.00	$0.00
19	Misc. Hardware	$100.00	1	$100.00	0
TOTAL				**$5,395.25**	**$715.05**

Challenges

Compared to the more experienced and funded university teams, the CAMS Explorer ROV team, which is composed of less than ten high school students of all grade levels, lacks significant resources, in depth technical skills, space, time, funding, and sophisticated machinery. However, with innovation and a working team dynamic, the team was overcome to overcome all constraints to build the best ROV possible.

CAMS ROV recognized the time challenge, and made the decision early on that the ROV would have two frames: one cheap and simple PVC pipe frame for the regional competition, and one more complicated and expensive ABS plastic frame for use at the international competition. The motors used on the ROV, although they are easy to mount on ABS, cannot be directly attached to PVC. Immediately, CAMS ROV understood that the motors each needed a small rectangular ABS mount and proceeded to construct them, but the mounts also cannot be directly attached to the PVC frame.

After the problem was fully identified, CAMS ROV utilized intense brainstorming sessions where a multitude of ideas were gathered and evaluated based on their pros and cons. Because of many team members' intense scrutiny, many ideas were deemed unrealistic: for example, it was suggested that CAMS ROV should try to screw motor mounts directly into the PVC, but this idea was rejected due to inability to effectively hold the motor in place. U-bolts were also suggested; however, the motors and mounts were not long enough to facilitate the use of U-bolts.

Finally, it was proposed that CAMS ROV use extra ABS rectangles on each motor mount to create plastic "clamps." These clamps, consisting of the motor/mount, another piece of ABS, two washers and two bolt-nut pairs, were fastened around pairs of PVC pipes about 7.5 cm apart. By tightening the bolts on the "clamps" CAMS ROV is able to hold the motors in place on the frame, but the bolts make the clamp very versatile and easy to adjust.

Trouble Shooting Techniques

CAMS ROV has such a two-part troubleshooting system in place. The primary component of the system is the method CAMS ROV uses to diagnose and treat small mechanical failures that can occur during construction of, transport of, or competition with the ROV. This process begins with a simple checking system: CAMS ROV members check for obvious, superficial errors in the drive motors, in the frame, and in each articulation system of the ROV by touching the ROV and asking the pilot to operate all the different components. Checks are completed quickly several times, including after transport, before and after competition, and intermittently during construction; problems with the ROV are thus discovered soon after they arise.

Next, rapid action is taken on the part of CAMS ROV to fix the problem. Simple mechanical failures, such as broken cable ties or loose or missing bolts, can easily be fixed using spare parts CAMS ROV keeps on hand. Structural problems such as frame cracks or broken articulations are more of a problem. Because CAMS ROV does not have the resources to keep spare frames or copies of articulation systems on hand in a competition setting, the team convenes and discusses how to use materials it has to fix the problem. Rapid structural fixes are meant to be practical only in the short run, so CAMS ROV makes permanent fixes or replacements once they have access to the materials and tools required. Design problems, unlike ROV part failures, are more difficult to fix.

Instead of encompassing specific part failures, design problems include the long-term performance detriments brought about by poorly designed systems or parts. Although design problems are not immediately dangerous to the structural integrity of the ROV, the problems can lead to repeating mechanical failure or inefficiency and poor performance during normal ROV operation. CAMS ROV identifies design problems during practice sessions with the ROV.

After one or more problems have been identified, CAMS ROV discusses how to improve or completely replace existing systems on the ROV. Design problems are most common amongst the articulation systems, and are often identified in designs that haven't even been implemented yet. Once CAMS ROV synthesizes a solution to a design problem, it assigns one or more members to finalize and implement the solution. By only dispatching part of the team to implement a solution, CAMS ROV creates maximum time efficiency for the team as a whole.

The distinct sub-processes of the CAMS ROV troubleshooting method allows CAMS ROV to address problems quickly and efficiently. In addition, because the method covers three different types of problems, CAMS ROV is safer from performance loss than it would be otherwise.

Lessons Learned

The most prominent lesson learned during the months spent on the ROV is the importance of strong adherence to the design process. Spending ample time in the brainstorming, designing, building, and refining steps of the design process is essential to creating a stable, reliable robot capable of accomplishing tasks. Although prior robot and ROV knowledge from some team members is helpful, the level of perfection required in ROV design forces the team to think outside the box, spot critical errors (no matter how small), and compromise and agree to one single design.

The brainstorming stage is perhaps the most important when creating an ROV. Due to the large amount of time required to create an operational ROV, ideas must be finalized early on, and are difficult to change later on in the season. This year's set of challenges required quick, decisive discussions of possible solutions, a far cry from the relaxed planning stage of other robotics competitions.

The designing stage had a similar need for efficiency. Materials must be ordered as soon as possible in order to maximize time spent building, so formalized designs had to be set up very quickly. Heavy emphasis was placed upon the creation of Computer Aided Designs, which would both provide clear blueprints for handmade parts and allow for the machining of more precise parts.

During the actual construction of the ROV, mistakes and imprecise measurements could not be tolerated. Every cut and seal had to be carefully measured in order to avoid wasting precious material and time. Because most of the building was done by the newer members of the team, such waste was inevitable in the beginning, but as they gained experience, the amount of wasted material significantly decreased.

Due to the diligence observed in the three prior steps to the design process, testing and fixing was kept at a minimum. In the future, we would set a more rigorous schedule and allocate a lot of time for pool testing. However, we, like all teams, are constantly learning and improving on our work, and will apply this knowledge to all fields of engineering, not only ROV.

Reflections

For many of us, ROV has been our first foray into the field of professional engineering. Having worked without mentor support, we are continually amazed by what a small group of high school students can accomplish. The 2010 MATE ROV challenges have been a great way to explore ideas and experience the engineering world.

MATE exposed us to the formalities that are associated with engineering, if only a little. Through our presentations and performance, we were able to see firsthand what a professional engineer is expected to do. The qualification process at Long Beach City College was very methodical, allowing the team to successfully demonstrate the full capabilities of our ROV in a simulated environment. Being a participant in the MATE competitions has opened doors of opportunity to the CAMS ROV team as we learn and perfect engineering and technical skills as well as presentation, writing, teamwork, and other essential life skills.

Figure 7: Team Photo

Future Improvements

Made using a rapid prototyping machine available at the school, our custom claw still leaves room for improvement. Being the team's first time including an articulate claw into an ROV design, the first prototype had many errors, including: not enough accounting for offsets due to the additive manufacturing process, too much excess material, and not enough claw grip. In order to improve upon the initial design, the original CAD file needs to be modified and the claw needs to be rapid prototyped once again. Aside from taking offsets into account, the claw's grippers will be serrated in order to create a rougher gripping surface, preventing slipping. In addition, grooves will be added to the design in order to cut down on the amount of material used. At about 10 dollars per cubic inch, not only is the material expensive, but not all of it is required for a structurally sound piece. Thus, to cut back on costs while still maintaining functionality, grooves need to be strategically incorporated into the claw's design. Furthermore, more planning for the pneumatic operation needs to be done. The claw's base/attachment has already been modified to make space for the two pneumatic pistons, but positioning could be modified in order to improve the compactness of the design.

Loihi Seamount

Hawaii sits within the region known to geologists as the "Ring of Fire" a 40,000 km wide horseshoe shape region that houses 75% of the worlds active and dormant volcanoes. Hawaii is located on a "hotspot" of the "Ring of Fire" a area that is volcanically and seismically active, that is away from the principal areas of volcanism within the "Ring of Fire." Loihi seamount is located 35 km off of the southeast coast of the island of Hawaii; situated on the southern flanks of the shield volcano Mauna Loa. At approximately 400,000 years old, Loihi is the youngest of the volcanoes within the Hawaiian-Emperor seamount chain. Rising 3000 meters above the bottom of the seafloor, Loihi is taller than Mount St. Helens prior to its explosive destruction.

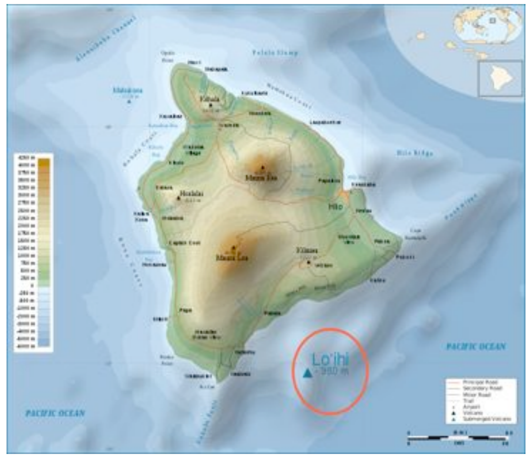


Figure 8: Loihi Seamount

As Hawaii sits upon a volcanic hotspot within the "Ring of Fire" frequent eruptions of magma are released from the depths of the mantle to build layer upon layer of basaltic rock on the bottom of the seafloor. Loihi was created when the slow movement of the tectonic plate over the "hot spot" resulted in a narrow stream of the mantle to convect upwards and release basaltic magma. This process has occurred for the last 400,000 years to present day, building the Loihi seamount to what we know it as today. Loihi is currently within the Submarine pre-shield Stage of Volcanic development for volcanoes that are "born" within the Hawaiian "hotspot", Loihi's current stage of development is characterized by infrequent, low volume eruptions. Due to the eruptions occurring underwater, because the eruptions occur underwater the lava is called "Pillow Lava" due to the shape that the

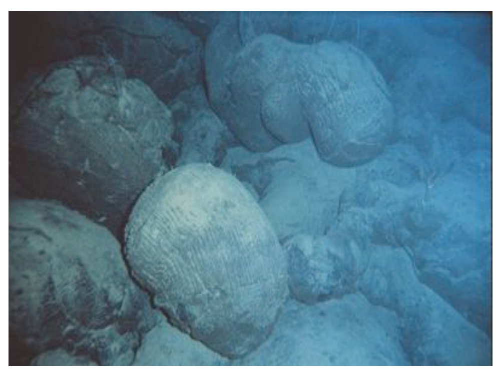


Figure 9: Pillow Lava

lava takes upon being simultaneously cooled by the water, and the pressure from the water to form the "pillow" like balls of hardened lava.

With the nature of all undersea volcanoes, hydrothermal vents exist across the dikes, and summit of the Loihi Seamount. These vents are located 1,100 meters to 1.325 meters below the surface of the water on Loihi, the vents range from temperatures of 10 degree Celsius to 167 degree Celsius. The vents spew forth fluids that are characterized by high concentrations of carbon-dioxide, and Fe(II); but there is on average a greater amount of sulfuric acid(H2S) that is produced.

It has always been postulated that life could exist in extreme environments such as high heat, extreme cold, anaerobic, poisonous gases, extreme altitudes or extreme depths. Research is continuously being conducted to search for existence of life forms in extreme conditions. At the Loihi Seamount it was found that around the hydrothermal vents, mats of bacterial growth survived and grew expanding meters away from the vent. These bacteria are use iron that spews forth from the vent to balance the mineral content of the water for the surrounding marine life. Research was done at the hydrothermal vents through the use of ROVs to collect samples from the bacterial mats, and surrounding environment.

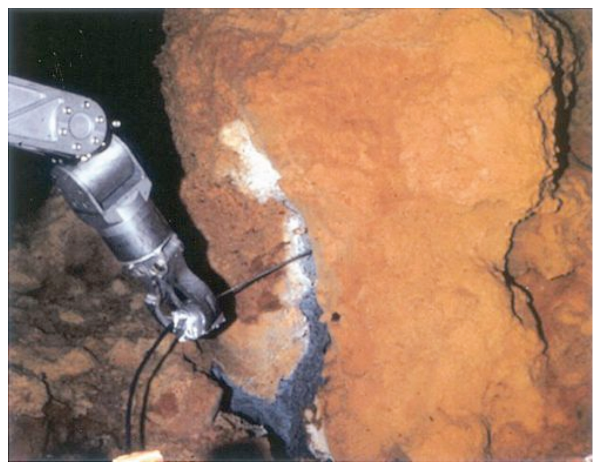


Figure 10: ROV Collecting Bacteria

The current research and this year's MATE competition have many parallels. The use of a ROV to collect a sample of agar represents current uses of ROVs in scientific research, collecting samples of microbes, particulate matter and other research samples. The task of nearing a "vent" and taking water temperature readings is another industry parallel in the use of ROV's doing more scientific research.

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Acknowledgements

The CAMS ROV team has performed amiably in the past months, beginning with the announcement of the mission in (insert date), the qualification match in (insert date), and culminating with the International Competition (insert formal name). Of course, all of our accomplishments would not have been possible without a little assistance. As a token of our gratitude, we would like to thank the following:

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- The CAMS Parent Teacher Student Organization (PTSO) for giving the team funds to build and complete the ROV
- Paul & Joanne Vawter for donating items necessary to complete the construction of the tasks
- John & Lil Petti for allowing us to use their residence and pool for ROV construction and testing
- Boi Duong & Nguyen Lam for allowing us to use their residence and resources for ROV construction
- And lastly, all of the parents of the ROV team members for their support and investment