2012 Mate ROV Competition

CAMS Marine Tech

Technical Report

California Academy of Mathematics and Science

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Martinez, Arnold	12th	CAD designer
Nestor, Paola	11th	Media Strategist
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Abstract

For the past six years, students of the California Academy of Mathematics and Science (CAMS) have successfully completed in the Southern California Fly-Off and have advanced to the International Competition five out of six times. Knowledge from experience has been passed down from the alumni to the current members.

The highly maneuverable Remotely Operated Vehicle (ROV), Pengie~, was designed to withstand underwater conditions and pressures associated with ocean exploration. World War II battle ships, filled with oil and decaying bodies, currently rest at the bottom of the ocean. Now, these shipwrecks pose a threat to the environment as corrosion has allowed the leakage of oil and bacteria into the ocean ecosystem. Pengie~ was created to explore the simulated wreck site and collect various samples, while preserving the delicate nature of the aquatic environment.

The ROV frame is made out of flexible and durable hydrodynamic polyvinyl chloride (PVC), and is powered by four SeaBotix BTD150s and two rule 1100 GPH bilge-pump motors to propel it through the water. The ROV is equipped with 4 payload tools: a two-pronged claw is the main articulation, a double syringe is used to extract an oil sample from the ship, a simple retractable measuring tape gauges the ship's length, and a compass helps determine its orientation.

After various group meetings, brainstorming, and design matrixes, CAMS Marine Tech has come up with an ROV that will successfully complete all of the mission tasks.

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Mission Theme

Throughout World War II, thousands of supply ships were deployed to supply oil to various nations. Both sides, the Allies and Axis Powers, suffered losses as vessels met enemy fire. As a result, thousands of these ships are currently resting at the bottom of the ocean. The ships, worn by time and water corrosion, are now threatening to spill their hazardous cargo.

Aside from war supplies, the ships contained bodies of the fallen men who risked their lives for their country. Many feel that the graveyards of fallen soldiers should not be tampered with in respect to the departed. The United Nations Educational, Scientific and Cultural Organization has recognized that the shipwrecks hold historical significance. The wrecks are time capsules of years before our own—years where the world was at constant battle within its territories—and have preserved the personal time period in its underwater containment.

Although some may see respect for the dead and preservation of national identity as reasons to leave the shipwrecks alone, those aspects remain irrelevant to the current threat of the ships. Oil leakage poses a threat marine life in addition to water cleanliness. The resulting corpses also pose the threat of illness to other marine life by further ingestion. In addition, the corpses may cause disease to the human population as bodies wash ashore and spread hazardous bacteria.

Shipwrecks containing dangerous materials should be contained and cleaned immediately in order to prevent environmental disasters that won't only affect wildlife, but all aspects of human life as well.

Design Rational

STRUCTURE

3D CAD Model of Pengie~

CAMS Marine Tech has chosen a simple yet robust building material: 1/2in PVC piping. The structural strength, easy modularity, and extreme cost efficiency of the material proved more than adequate for the construction of the ROV. Pengie~, being equipped with its holonomic propulsion system, was designed with a square frame which is necessary to ensure equal vector thrust in every direction. The frame was also designed based on the concept that a smaller mass leads to less inertia. With the overall footprints being 35cm x 35cm x 25cm, the frame meets the concept while remaining large enough for our payload tools.

PROPULSION SYSTEM

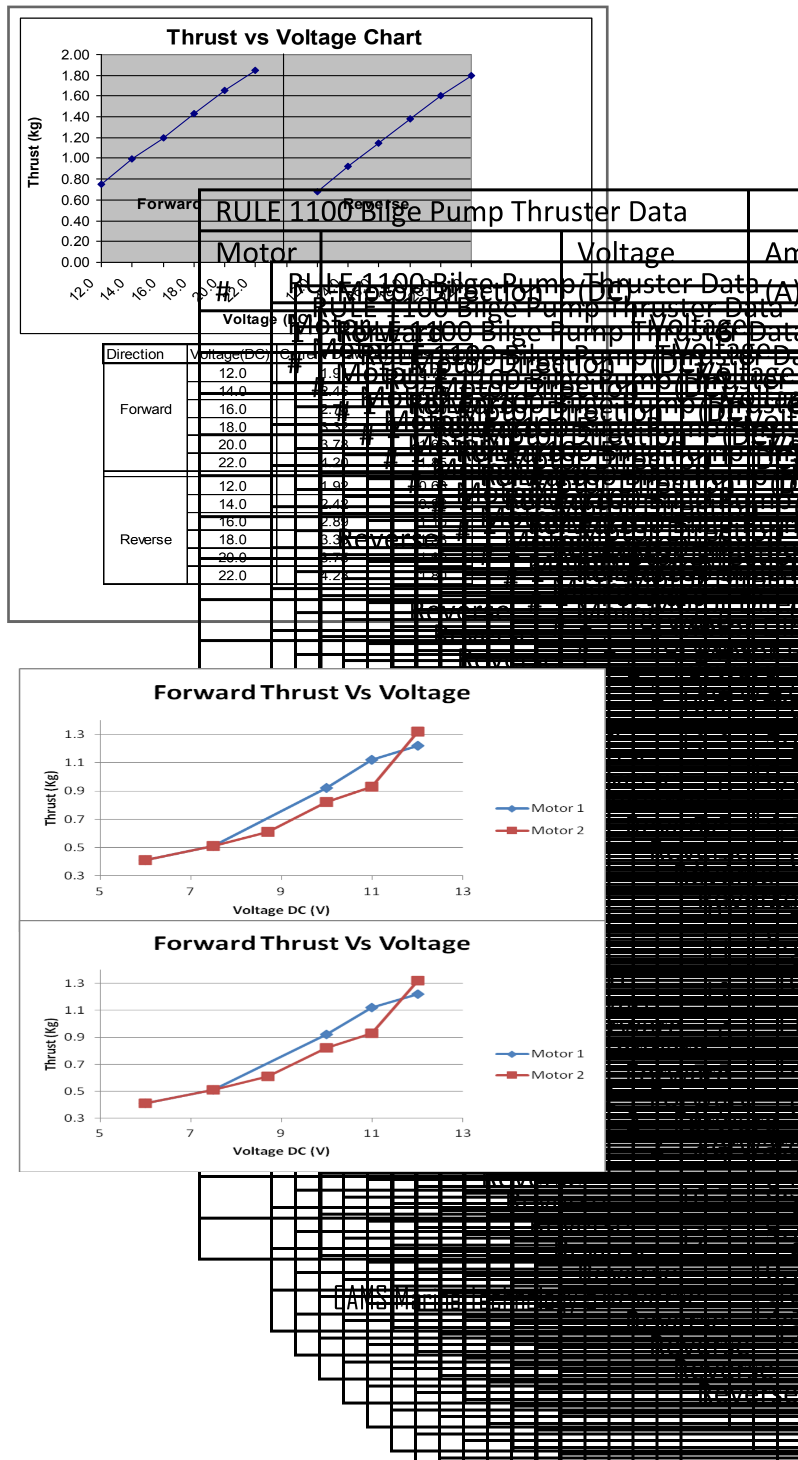
One of the most significant systems of Pengie~ is the propulsion system. The main purpose behind the layout and function of the propulsion system is to allow the ROV to move in all directions along the XY plane of thrust. The various tasks of the mission require precise control and manipulation of all four thrusters. The propulsion system enables the pilot to maneuver effectively during the mission.

The Pengie~ implements a holonomic thrust vector layout as its propulsion along the XY plane. By utilizing four SeaBotix BTD150 thrusters, CAMS Marine Tech now can provide the necessary force in any direction to propel Pengie~ to the pilot's desired location. In order to allow the holonomic control, the BTD150s are mounted at 45 degrees relative to the square angles of the main structure. The thrusters themselves are mounted on small 15.25cm x 4.5cm x 0.625cm clear polycarbonate sheets. The mounting plates attach the thruster to the frame using three bolts.

The XY planar thrust, though important for movement, is not the sole propulsion required for the mission. In order to reach the mission site itself, Pengie~ must be able to descend and ascend. For this, CAMS Marine Tech implemented the use of two Rule 1100 GPH impellors in the front and back of the frame and changed the propellers to increase output. Extensive testing has shown that these thrusters are more than adequate to provide necessary Z axis thrust for Pengie~. The thrusters are mounted using hose clamps around the body of the thruster, fastened onto modified PVC Tee-connectors. The assembly is then connected to the frame structure via another Tee-connector on the main frame. With the thrusters mounted as such, Pengie~ also gains the ability to tilt along the Z-axis, increasing movement capabilities for the pilot during ROV operation.

SeaBotix BTD150 Thruster					
	Motor Direction	Voltage (DC)	Amperage (A)	Thrust (Kg)	Watts (W)
	Forward	12	1.91	0.75	22.92
		14	2.45	1	34.3
		16	2.78	1.2	44.48
		18	3.32	1.43	59.76
		20	3.78	1.65	75.6
		22	4.2	1.85	92.4
	Reverse	12	1.92	0.68	23.04
		14	2.42	0.92	33.88
		16	2.89	1.15	46.24
		18	3.3	1.38	59.4
		20	3.75	1.6	75
		22	4.23	1.8	93.06

Thruster Data and Graphs



Through our testing of the Two thrusters we were able to conclude that the SeaBotix BTD150 thruster is best suited for our mission. Though the Bilge pumps produce significantly more thrust compared to SeaBotix at 12V, SeaBotix at .8Kg-f and Bilge pump at 1.2 Kg-f, the Bilge Pumps require nearly 3.5 times more power. The Bilge Pumps use 77 Watts of power while the SeaBotix use a meager 23 Watts. This huge difference is the main reason why CAMS Marine Tech decided to use them. The benefits gained when using the BTD150s, by not stressing the strict power requirements, allows us to use the power available much more efficiently. This lets us use the other payload tools of the ROV while moving. The Bilge Pumps would blow the fuses before we could even begin to operate the other payload tools, if we were to use them.

With regards to any robotics system, safety is taken into major consideration during design and implementation. All electrical connections to the thrusters are soldered and sealed with three layers of heat shrink and silicon seal. The BTD150s are waterproof and have prop-guards. To protect the Rule 1100s propeller and the fingers of the deck crew, prop-guards were manufactured and installed.

BALLAST

One of the most important design features of an ROV is to be neutrally buoyant in water when submerged. To do this, it must have a ballast system which offsets the water displacement the ROV produces. CAMS Marine Tech has created a system of floats positioned in the uppermost regions of the. The floatation system is composed of two 182.5cm^2 x 23cm ABS pipes filled with air. They are sealed with end caps and made water and air tight with PVC glue, silicon seal, and electrical tape. The tubes are then zip tied to the main frame of the ROV and are held down by Polycarbonate plates bolted to the top of the frame. The ABS tubes contain approximately 10,200 cubic cm worth of air able to life 8.25kg, which is just above the amount of lift to compensate for the 7.35kg weight of the ROV. In order to compensate for changes in buoyancy and make it neutrally buoyant, small weights are added to the bottom to help keep the ROV upright.

TETHER

The tether is the most vital component of the ROV. Without the tether the ROV could not move, let alone do any of the tasks. The tether consists of the power cables and any other vital lines to the payload tools, cameras, and other pieces. The tether on "ROV" is composed of 16 wires, three camera wires, architectural foam, and pneumatic tube. The tether is 12 meters long and is bundled tightly to keep the wires neat. A small amount of architectural foam provides a slightly positive buoyant force to keep the tether from dragging down the ROV but maintains a slightly negative buoyancy to control the center of gravity. The foam is equally spaced in order to provide an equal distribution of buoyancy. In addition, it can be used to determine the length of tether that has been deployed.

SURVEIILANCE

Surveillance is a key part of any ROV system. The pilot of the ROV must be able to view the underwater world he is maneuvering in. To do this, CAMS Marine tech has installed 4 Cabela Underwater Cameras in various places on the ROV. These cameras are completely waterproofed, come with a pre-insulated cable, as well as a monitor and power adaptor system that works with our control system. These Camera's have unlimited viewing range in black and white. The Cameras have been mounted to have views of the front at a downward angle, a view of the orientation device, a view of the measuring device, and a final overall drivers view. With these view the pilot can see everything he needs to in order to complete the mission.

ORIENTATION INDICATOR

In order to determine the orientation of the ship relative to magnetic North, CAMS ROV has implemented the use of a ball compass. The compass allows the pilot to denote the orientation of the ship by placing the ROV in direct line parallel with the ship. The ball magnet then aligns itself to Magnetic north and the angel can be then measured off the monitors of the screens on the surface. This method of finding the orientation has been chosen for its simplicity, easy installation, and easy use.

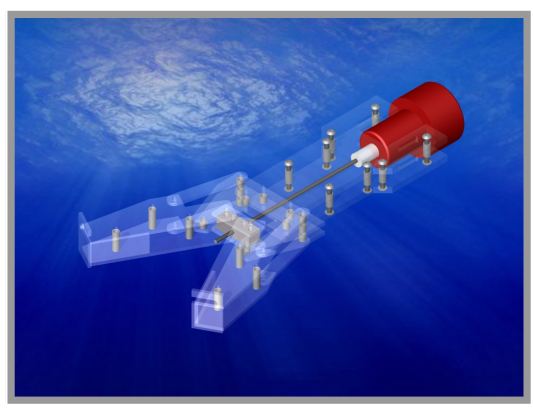
Using a compass created a new challenge of finding a place on the ROV where it would not meet with interference from the rapidly spinning motors. Because the ROV is fairly compact, all the thrusters are in close proximity to one another, and they have a natural magnetic field that interferes with the compass. . In order to function correctly, the compass is placed at the farthest and lowest point of the ROV, near the end of the claw. At this location is can be seen by a camera, is far enough away from motors, and can accurately be lined with the ship. As well as being the main orientation sensor the compass also doubles as a ferromagnetic indicator, detecting whether the desired sample contains any trace of iron.

Payload Tools

OIL EXTRACTOR

A major component of the mission involves the removal of fuel oil from the SS Gardener. In order to complete the task, CAMS Marine Tech has constructed a simple pump method to extract the oil using a probe with two syringes. The pump system provides suction to the probe, which is able to penetrate the hull and remove fuel oil. The pump system operates via a lead screw design to retract and detract the syringe plungers. The pump system converts rotational motion into linear motion using a lead screw attached to a RULE 1100 GPH Bilge Pump with a threaded prop adaptor onto a threaded rod. When the lead screw rotates, the threaded plate moves along a rail, pulling the plungers forward or backward, thus creating suction in the system. The use of two 60cc syringes compacts the size of the pump. The tubing for the system is routed through the pipes of the frame connecting the pump to the probe on the front of the ROV to maximize internal space. The theory behind the pump size is to minimize the volume of contained air, and prevent dilution of the sample. The extractor has been proven to be efficient.

ALL PURPOSE UTILITY GRIPPER



3D CAD Model of Gripper

Many of the tasks involved in the mission require the use of a manipulator. A manipulator is a key element in transporting debris/wildlife/sonar devices and making repairs. It needs to be versatile enough to complete all these tasks and more, as well as be durable and reliable enough to function when it needs to. To do this, CAMS Marine Tech has decided to utilize the same lead screw motion conversion system to actuate the opening and closing of a claw. The linear motion, in this case, pushes an aluminum block which forces the grippers attached to the plate to rotate about their separate pins. The entire assembly is held on a plate of polycarbonate which is mounted to the frame. The claw is aligned with the front of the vehicle, protruding out the frame a full 6 inches with the rest of the claw safely inside the frame. The gripper is supported at the bottom of the ROV in order to allow easy access to mission objects and to provide overall camera angles.

The claw serves many different purposes, hence its name. One of these purposes is its role as the Neutron Back

Scatter sensor. This sensor is imbedded into the right gripper of the claw and is in the perfect position to allow the sensor to easily reach the testing location on the ship. With this extra add-on the manipulator is a very versatile and important part of the Pengie~.

MEASURING DEVICE

The measuring device for the ROV is used to figure the length of the S.S. Gardener at the bottom of the sea. CAMS Marine Tech has decided to use a 9 meter long length of fabric measuring tape to be wound about a spool. The spool is spring powered and naturally rests in the retracted position. At the end of the measuring tape is a small "lasso" made of a PVC ring, which the pilot uses to hook around the protrusions of the ship. The spool is located along the front, left-hand side of the ROV, with the PVC ring outside of the main frame. The pilot then maneuvers to position the ring over the protrusions and then thrusts backwards extending the tape measure. A camera mounted over the spool watches as the tape is extended and as the pilot moves pass the other end of the ship, the pilot can visibly see the measured distance from end to end. Once the distance has been noted and verified the pilot returns to the front of the ship to remove the PVC ring. With the spool being self-retracting, there is no worry of having the tape be a hazard. The device is simplistic in design using very few parts and has proven to be effective in testing.

Control System

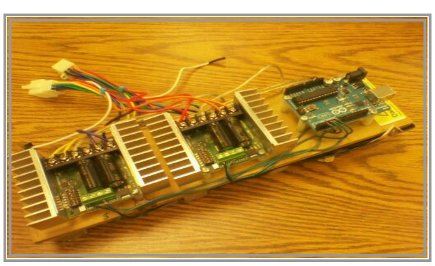
CONTROL SYSTEM

Pengie~'s main control system is made of the following items: the mission control computer, the processor Arduino Uno, six LMD18200 thruster control switches, and 2 H-bridge switches to control the payload tools. They were challenged by their mentorto manufacture and utilize their very own electronic speed control system.

The most important part of the control system is the computing processor CAMS Marine Tech used, an Arduino Uno, because it was easy to use, had many extra accessories for programming, and proved to be quite durable.

Normally, the electronic speed controller is the component of the control system that costs significantly more than the rest of the components. To cut down costs, CAMS reverse engineered many other speed controllers such as the Sabertooth, Jaguar, and Victors controllers. Due to 2010 MATE Summer Insti- tute's extensive database, CAMS Marine Tech was provided with schematics that made the research much easier.

LMD18200 is an H-bridge driver chip with many safety features that can change the direction of current and voltage in the thruster depending on the PWM signal provided from the control system. It cuts the price of the control system board by half. Unfortunately, with an unprotected 12V input, LMD18200 cannot provide enough consistent power for lengthy periods without a significant increase in heat, damaging the chip permanently. In order to solve this a fuse system had to be implement which prevented the chip from using so much power. By doing this the chip will never reach critical temperatures so long as the fuses are intact.



Back Up Control System

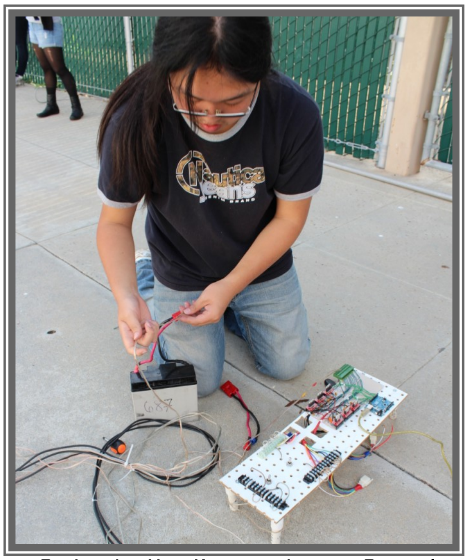
Pengie~'s back-up control system consists of the mission control computer, another Arduino Uno, four Sabertooth 2X25, and a USB Xbox 360 controller. All of the items used to create the backup control system are off-the-shelf products. This was to minimize the possibility of failure at the time of the construction. It also lessened the concern of failure in the CAMS created system.

For any ROV, it is crucial to be able to control the speed of the thrusters in order to precisely control movement of the ROV. In order to do this, the Sabertooth

2X25 was chosen. The Sabertooth 2X25 is an extremely flexible platform, being able to use PWM, simple serial, or serial packets. Along with this, it also provides a constant 5 amps per channel, which can increase to 10 amps per channel when necessary. It's voltage ranges from 6V to 24V which is perfect for competition standards. The control aspect enters by varying the voltage that the Sabertooth applies to the thrusters. By varying this voltage, the thruster speed changes, and the overall speed of the ROV changes as well.

The software used in the control system is Arduino and Processing. These programs are free, and are open source. Due to the nature of the open source software, there is an abundance of library files available. This enables the Arduino to integrate with most of the sensors and electronic items commonly available. This is how we are able to integrate the control computer with the Xbox 360 controller's software and have it all interface with the Arduino code. Together these systems combine to produce our control system.

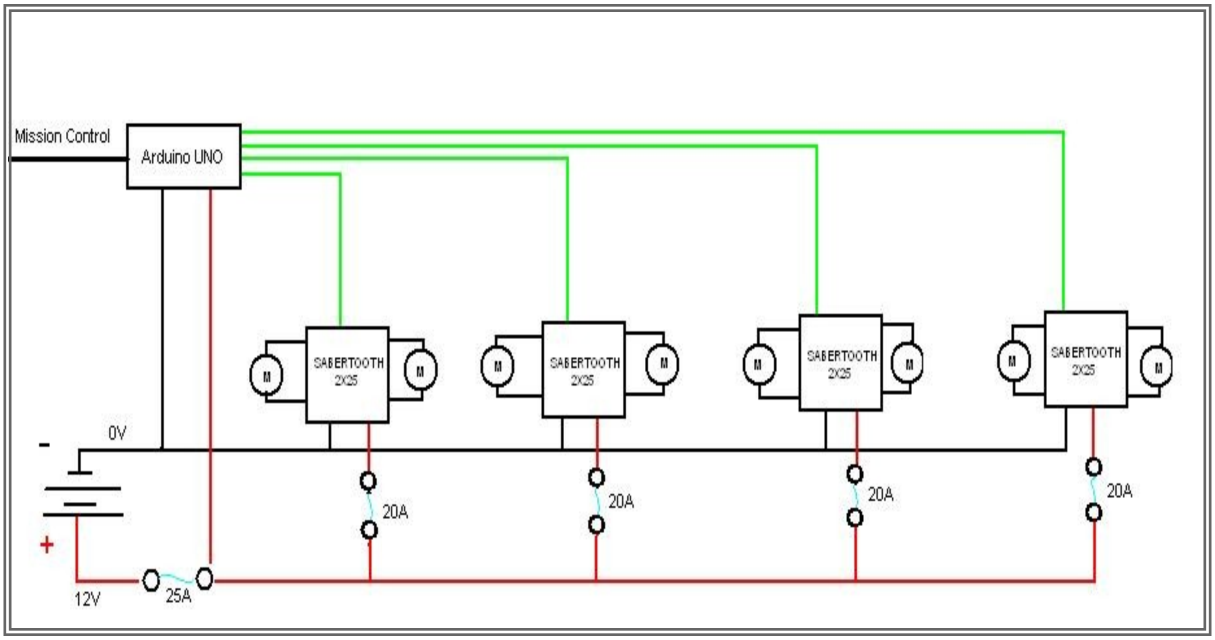
The flow of the programming involved is very simple. It was constructed in this way to anticipate the prevention of errors. It also allows the programming to be easily fixable should errors occur during testing and operation. The progression begins when the pilot sends a digital signal to the mission computer via the Xbox 360 controller during operation of the ROV. When the mission computer receives the data signal, it computes the serial packet via program processing. Depending on the analog stick's digital value or the signal from the buttons, the program computes the serial packets to send to the Arduino. When the packet is complete, the code is sent to the Arduino.



Co-Leader You-Keun working on Control System

When the Arduino receives the serial packet, it determines which command line goes to which electronic speed controller. There are multiple electronic speed controllers on the ROV, thus the Arduino must be able to read and distribute the signals correctly to be able compute which command line is intended for which electronic speed controller. When the computation is done the serial packet is sent to each speed controller. Depending on the serial values, the electronic speed controller varies the resistance values causing the voltage value to increase or decrease, which turns the thrusters on or off.

After sending the serial value, the Arduino sends an echo data packet back to the mission control. If the mission control computer doesn't receive the echo data, it signals an error to the driver and alerts him that the system needs to reboot. If there is no error, the mission control computer waits for the next signal from the controller as the cycle continues until the mission ends. This loop is done every 2 milliseconds, so the reaction time of the program is instantaneous by human standards. This allows the movement of the ROV to be fluid and controllable to the finest detailed movement..



ELECTRICAL SCHEMATICS

CONSTRAINTS

Safety

- Nothing hazardous
- No sharp edges
- Propeller guards
- Burnt zip-ties
- No batteries onboard
- Sealed electronics

Human Resources

- Experience
  - Mr. Harder – Robotics Mentor
  - Ed Hofmann – Machinist
  - Mr. Matheus - Engineer
  - Matthew Francis-Landou - Programmer

Physics

- Pressure of 2 ATM
- Expected temperature changes
  - Lowest: 12 C
  - Highest: 36 C
- Chlorine Water
- Possible wave currents
- Buoyancy

Availability of workspace and tools

- Machining Lab
  - Mills
  - Lathes
  - Band saw
  - Horizontal band saw
  - CNC Router
  - Drill Press
  - Precision measuring tools
  - Hand tools
  - Rapid prototype machine
  - Laser cutter

Availability of components and materials

- McMaster
  - Various Materials
  - Structural components
  - Electrical components
  - Tools
- Online Metals
  - Various Metals
- Home Depot
  - PVC
  - Tools
- Harbor Freight & Tool
- Plastics Depot
- Lowes
- Walmart
- Torrance Electronics
- Radioshack
- Frys
- Tommy's house

Safety and Challenges

Safety

Several safety precautions were implemented throughout the design and building process in consideration of our company. A checklist of detailed procedures was compiled and rigorously followed to ensure the protection of the equipment and safety of personnel. Team members are required to run through the checklist before submerging the ROV. Several safety features have been installed for user protection:

All thrusters are protected by prop guards to prevent debris from damaging the motors and to provide a safety shield around the spinning propellers.

Cautionary labels are placed near all moving parts to provide a warning of potential danger.

Handles are provided on each side of the frame to allow for safe launch and easy retrieval.

An emergency shut-off switch is included in the control system to cut off power in case of a system failure.

Challenges

During the construction of the ROV, CAMS Marine Tech encountered several issues regarding the frame design, and considered various methods for measuring the length of the ship. The initial design consisted of a large rectangular frame to house all the required sub-systems. The measuring device was a measuring tape with a hook attached to the end.

While competing in the So-Cal Fly-off Regional, we found that the frame was "too bulky" and caused excess drag due to its large profile. The extreme water resistance caused a decrease in the output of the drive system which proved to be problematic as it hindered the ROV's movement and overall speed. The measuring tape proved to be successful in its function, but once tested underwater, the metal coil acting as the retractor was prone to rust.

Our final design consists of a much smaller frame which just barely contains all the sub-systems. The smaller frame reduces surface area thus reducing water resistance and significantly amplifying motor output. The measurement of the ship length now utilizes a cloth measuring tape which is wound up by an 1100 Rules GPH Bilge Pump. A hook connected to the end of the tape allows easy attachment to the ship.

Troubleshooting Techniques

Just like any other project, troubleshooting techniques are essential. Troubleshooting is the process of solving problems by tracing and correcting faults in a mechanical or electrical system.

During the testing stage in our design process, we used troubleshooting when correcting our buoyancy. The initial buoyancy was very negative so we had to calculate the amount of air needed to obtain neutral buoyancy. However, calculations are in an absolute reality, so when we tested buoyancy again, we were still slightly negative. We then proceeded to correct this using architectural foam.

Another example of applying troubleshooting techniques was our measuring device. Originally, we had a normal measuring tape duct taped to the side of our ROV. After successfully testing it in the water, the measuring tape no longer functioned. We reverse engineered the measuring tape and found the problem to be the metal coil. We unfortunately didn't think about the metal coil inside and what effects the water might have on it, thus resulting in a rusted metal coil. We decided that instead of a metal coil as the retractor, a bilge pump motor would be more effective.

Future Improvements

CAMS Marine Tech has been able to design, manufacture and create a working ROV system to complete the tasks presented in this challenge. As a company we strive for the very best that the company can produce. But as with all thing there is always room for improvement.

With all our difficult challenges, and limited resources for completing the MATE task we found that there is much room for improvement. Considering the ROV itself many different things can be improved upon. Due to our limitations we could not implement underwater electronics. Our limited budget, despite the contributions from previous years and donations, could not support underwater electronics. For planned future improvements, the ROV would implement underwater electronics as well as a brand new control system at the surface. This would require a new level of design and programming which we could have supported, but could not implement. If we were to implement an underwater control system, we would need to improve upon our knowledge of waterproofing much more. Our simple methods of heat shrink and silicon seal would not suffice for waterproofing an entire control system. We would also improve our current waterproofing by investing in off the counter waterproofed pin connectors for the tether.

Other improvements could be made to the Structure and payload tools themselves. Our solution to the fuel oil problem was unique, and was successful, but had its drawbacks. The pump was able to leak out fluid as it was left open to the pool space. For future improvements a one way valve could be utilized to prevent the outward flow of fuel oil. Another place for improvement would be in the structural materials used for the frame. Though PVC is an outstanding building material, it can be hard to work with as there are certain limitations to building with all round surfaces. An improvement to this could be the use of sheet metal or polycarbonate as the main structural material. Aluminum sheeting provides the same, if not more, structural strength as PVC does while being able to be manufactured into whatever shape needed for the frame. It is also relatively lightweight for metals and has plenty of mounting space. Polycarbonate is nearly the same as aluminum in these regards other than it is clear and can be used for waterproofing things that must be seen. When used in conjunction, these materials can be used to construct a frame which is both structurally sound while also being aesthetically pleasing. The would be the next step up from using PVC piping.

Not all the improvements to be made are those pertaining to the ROV. One of the biggest problems faced throughout the year was communication amongst the team members as well as with the mentors. When it came to being able to all meet together at a common place and time the team experienced difficulties due to the many obligations that the team members had. There was also problems with conflicting ideas and long winded arguments amongst the members. Planned improvements would be for better organization and planning for all the members. A more detailed schedule should be created and adhered to other than the previous one in place now.

Lessons Learned

Each member is expected to learn the basics of manufacturing an ROV. To accomplish this, we follow the KISS principle (Keep it Simple Scientist).

Technical

- Organization is good
- Safety
- Follow the Gantt chart
- Utilizing the different tools at our disposal
- Keep things short, simple and to the point
- How to create motor controllers from scratch
- Learned how to waterproof electrical devices
- Application of the Design Process

Interpersonal

- Arguments do not get anywhere
- Listen to Mentor advice because most often it is correct
- Decide and move on
- Communication is key, without it there is no team

Reflection

The MATE ROV competition has been a highly influential program on CAMS Marine Tech. After competing in the So-Cal Fly Off regional competition, our motivation to become number one has been significantly increased. During preparation for the regional competition, our team encountered several technical difficulties such as malfunctioning payload tools, miscalculations, and miscommunication between team members and mentors. As regional quickly approached its date; however our team pulled together to overcome such difficulties. We brainstormed for possible methods to replace our malfunctioning ROV components, recalculated and redesigned, and collaborated together to complete Pengie~. After overcoming the complications from build season, we are proud by the fact that our hard work and dedication has qualified us for international competition.

Acknowledgements

The CAMS Marine Technology ROV Team would like to thank all the support from our school and all the parents that helped get all way up here. We would like to thank our mentors, Ted Harder and Mitch Amos, for all the help and dedicated time they spent on the team. We wouldn't be where we are without your help.

Thank You!

Resources

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Appendix A : Budget

Structure						
Item	Mfg P/N	Source	Unit Price	Quantity	Subtotal	Paid
½in. x ½in. x 10’ PVC Pipe	67447	Home Depot	$ 1.35	2	$2.70	$2.70
½in. x ½in. PVC Tee Connector (10 Pack)	401-005P10	Home Depot	$ 1.98	3	$5.94	$5.94
½in. PVC Plus Connector	420-005HC	Home Depot	$ 0.80	1	$0.80	$0.80
½in. x ½in. 90° PVC Elbow Connector (10 Pack)	CP406-005	Home Depot	$ 1.70	1	$1.70	$1.70
½in. PVC Male Adaptor Connector	436-005HC	Home Depot	$ 0.25	8	$2.00	$2.00
½in. PVC 90˚ Side Outlet Elbow Con-nector	413005RMC	Lowes	$ 1.18	8	$9.44	$9.44
½in. PVC Cap	447-005HC	Home Depot	$ 0.25	1	$0.25	$0.25
#8-32 x 1-¾in. Machine Screws (50 Pack)	29012	Home Depot	$ 5.24	1	$5.24	Previous Year
#8-32 x 1in. Machine Screws (100 Pack)	33472	Home Depot	$ 18.77	1	$18.77	Previous Year

Propulsion System						
Item	Mfg P/N	Source	Unit Price	Quantity	Subtotal	Paid
SeaBotix Thrusters	BTD150	SeaBotix	$ 1,000.00	4	$4,000.00	Previous Year
Rule 1100 GPH Bilge Pump	27D	Amazon	$ 37.29	2	$74.58	Previous Year
12 in. x 12in. x ¼in. Sheet Polycarbon-ate	33-GE-XL-1	Home Depot	$ 12.98	1	$12.98	Donated
7/8in. x ¼in. Saddle Spacers (50 pack)	92842A200	McMaster	$ 7.15	1	$7.15	$7.15

Payload Tools						
Item	Mfg P/N	Source	Unit Price	Quantity	Subtotal	Paid
1100 GPH Bilge Pump Motor	27D	Amazon	$ 37.29	2	$74.58	Previous Year
60 cc Syringe		Amazon	$ 0.47	2	$0.93	$0.93
¼in. x ¼in. x 36in. Aluminum Sheet	8975K563	McMaster	$ 13.32	1	$13.32	Donated
VEX Linear Motion Kit	276-1926	VEX Robotics	$ 24.99	1	$24.99	Donated
1/8in. x 20in x 36in Threaded Rod	17320	Home Depot	$ 1.97	1	$1.97	Donated
12in. x 12in. x ¼in. Sheet Polycarbonate	33-GE-XL-1	Home Depot	$ 12.98	1	$12.98	$12.98
Navigation Compass Ball Vehicle RV	B005GJKZ5K	Amazon	$ 3.99	1	$3.99	$3.99

Tether

Item	Mfg P/N	Source	Unit Price	Quantity	Subtotal	Paid
Cerrowire 100 ft. 14 Gauge 19 Stranded THHN White Wire	112-3472C	Home Depot	$ 23.97	3	$71.91	Previous Year
Lincoln Electric 60/40 1/16 in x 8 oz Leaded Rosin Core Solder	60R31/2POP	Home Depot	$ 10.48	1	$10.48	$10.48
¼ in. White Polyolefin Heat Shrink Tubing (5 Pack)	HST-250W	Home Depot	$ 1.99	4	$7.96	$7.96
Gardner Bender 3/16 in. Heat Shrink Tubing (8 Pack)	HST-187	Home Depot	$ 1.95	3	$5.85	$5.85
Gardner Bender 4 fl oz. Liquid Tape	LTB-400	Home Depot	$ 5.99	1	$5.99	$5.99
8 in. Double-Locking UV Resistant Zipties (100-Pack)	295813	Home Depot	$ 5.99	1	$5.99	$5.99
Architectural Foam	N/A	Donation by LBCC	$ -		$0.00	Donated

Real Electrical System

Item	Mfg P/N	Source	Unit Price	Quantity	Subtotal	Paid
Arduino Uno	0-A000046	Arduino	$ 29.99	1	$29.99	$29.99
Power Divider/Fuse Box				2	$0.00	Previous Year
LMD18200 Motor Driver	LMD18200T/NOPB	National Semiconductor	$ 17.80	6	$106.80	$106.80
LMD18200 Breakout Board	BOB-00747	SparkFun	$ 1.95	6	$ 11.70	$11.70
25 Amp Fuses	CAT# FS-25	Any Electronic Company	$ 1.00	1	$ 1.00	$1.00
5 Amp Blade Fuses	CAT# FSA-5	Any Electronic Company	$ 0.25	8	$ 2.00	$2.00
Ceramic .01µF 100v Capacitor	SR201C104KAR	Donated by CAMS	$ 0.20	12	$2.40	Donated
Resistors		Donated by CAMS	$ 0.20	18	$3.60	Donated
15x45 (pins) Veroboard	N/A	Donated by CAMS	$ 29.99	1	$29.99	Donated
9 Pin Quick Disconnect 18 AWG	CES-32-3009	Donated by CAMS	$ 0.63	2	$1.26	Donated
6 Circuit Double Row Terminal Block	IDEAL 89-406	Gordon Electric Supply	$ 7.54	3	$22.62	$22.62
Double Pole/Single Throw Switch	GSW-14	Torrance Electronics	$ 4.00	2	$8.00	$8.00
#8-32 x 1-¾in. Machine Screws (50 Pack)	29012	Home Depot	$ 5.24	1	$5.24	Donated
#8-32 x 1in. Machine Screws (100 Pack)	33472	Home Depot	$ 18.77	1	$18.77	Donated
½in. x ½in. 90° PVC Elbow Connector (10 Pack)	CP406-005	Home Depot	$ 1.70	1	$1.70	$1.70

Backup Electrical System						
Item	Mfg P/N	Source	Unit Price	Quantity	Subtotal	Paid
Arduino Uno	0-A000046	Robot Marketplace	$ 29.99	1	$29.99	Previous Year
Sabertooth 25 Dual 25A Motor Driver	0-SABER2X25-RC	Robot Marketplace	$ 124.99	4	$499.96	Previous Year
25A Blade-Type Automotive Fuse (3-Pack)	270-10814	Radioshack	$ 2.19	1	$2.19	Previous Year
20A Mini-Blade Automotive Fuse	270-1095	Radioshack	$ 2.19	6	$13.14	Previous Year
Fuse Holder 6POS Panel MNT ATC	15600-06-21	Radioshack	$ 11.52	1	$11.52	Previous Year
10A Blade-Type Automotive Fuse (3-Pack)	270-1081	Radioshack	$ 2.19	3	$6.57	Previous Year
3A Mini-Blade Automotive Fuse (3-Pack)	270-1089	Radioshack	$ 2.19	3	$6.57	Previous Year

Claw						
Item	Mfg P/N	Source	Unit Price	Quantity	Subtotal	Paid
Black PVC Tubing, 3/16" ID, 1/4" OD, 1/32" Wall Thk	5231K35	Mcmaster	$.20 ft.	50 ft	$10.00	10
Multipurpose Aluminum (Alloy 6061) 1/4" Diameter X 6' Length	8974K31	Mcmaster	$6.08 each	1	$6.08	6.08
Impact-Resistant Polycarbonate Sheet 1/4" Thick, 12" X 12", Clear	8574K28	Mcmaster	$14.01 each	1	$14.01	14.01
Impact-Resistant Polycarbonate Sheet 1/8" Thick, 12" X 24", Clear	8574K41	Mcmaster	$12.52 each	1	$12.52	12.52
Type 316 SS Pan Head Phillips Machine Screw 8-32 Thread, 1/2" Length, packs of 50	91735A194	Mcmaster	$6.83 pack	1	$6.83	6.83
100 Grade 2 Steel Nylon-Insert Thin Hex Locknut Zinc-Plated, 8-32 11/32" x 11/64"	90633A009	Mcmaster	$2.30 pack	1	$2.30	2.3
2 m 1/2" square aluminium stock	6ALR9	Mcmaster	$13.10	1	$13.10	Donated
12" x 24" x 1/16" Thick Neoprene	NP60S-0062-F	Mcmaster	$15.42	1	$15.42	Donated
#8-32 x 1in. Machine Screws (100 Pack)	33472	Home Depot	$ 18.77	1	$18.77	Donated
1100 GPH Bilge Pump Motor	27D	Amazon	$ 37.29	1	$37.29	Previous Year

https://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/protection/ significance-of-uch/

Travel Expenses			
Item	Unit Price	Quantity	Subtotal
Airflight	$545.00	10	$5,450.00
ROV Shipping	$50.00	1	$50.00
Hotel	$125.00	7	$875.00
Car	$500.00	1	$500.00
Food	$150.00	10	$1,500.00