GEAR

HKUST-ROV TEAM (HONG KONG)

TEAM MEMBERS

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Abstract

This technical report is a description of how the HKUST ROV Team designed and built the ROV "*Gear*" for the 2011 MATE ROV Competition. This year the competition will take place at the Neutral Buoyancy Lab (NBL) at the NASA Johnson Space Center in Houston, Texas. For the competition, the ROV is supposed to complete four tasks themed around the challenges encountered during the 2010 Gulf of Mexico oil spill. The total cost for construction of the ROV is USD 5013. The ROV *"Gear"* contains an electronics tube, which houses all the onboard electronics for the machine. The electronics tube is constructed from PVC (Polyvinyl chloride), capped at both ends with aluminum plates, for heat dissipation into the water. The aluminum plates have water-sealed connectors to pass the tether and motor cabling. The electronics tube houses the MCU, the motor driving unit, the motor drivers, relays, the video driving unit, and the pressure, temperature and humidity sensors. The ROV uses four cameras, eight 48V propulsion motors and five payload control motors. The construction materials for the structural frame include PVC, aluminum and acrylic. The payload tools include a rotary hook to remove the Velcro strip, the well cap for clamping the wellhead, a water piston for collection of water samples and a rotary brush and net to collect the biological samples. The programming language used is C# for the main program and C for the MCU program. For the controller, the ROV uses the Xbox 360 wireless game controller.

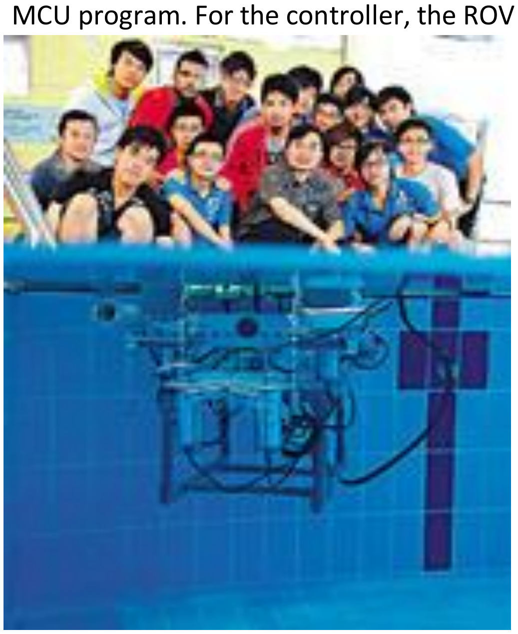


Figure 1: Our team members with the preliminary designed ROV

Figure 2: Team members, Top-left to right, Alex Kwan, Francis Lui, Ka Hou Lok, Ryan Wong, Kam Sing Lee, Sky Yeung, Sau Lak Lau, Leo Kwan, KK Wong, Kin Yeung Leung, Sheshan Aaron, Lok Ping Leung, Prof. Tim Woo, Eric Leung, Ho Sum Lee.

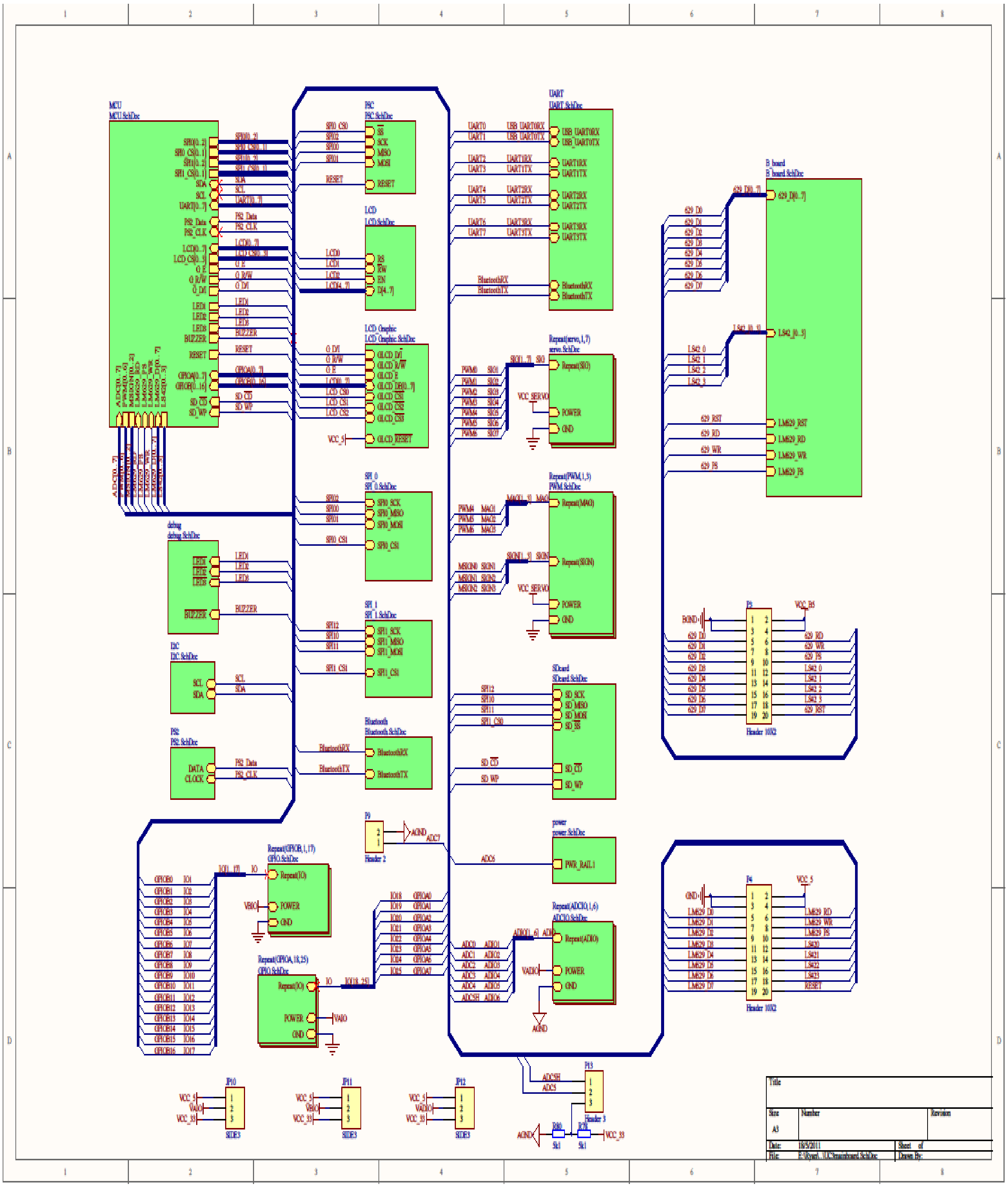
Budget/Expense Sheet

	ITEM	*No.*	*UNIT PRICE*	*TOTAL (USD)*
MECHANICAL	*Thruster PARTS*	*10*	*62.5*	*625*
	Motor	*10*	*50*	*500*
	Electronic Housing Hall	*1*	*625*	*625*
	Laser CUT Plastic PARTS	*NA*	*800*	*800*
	Aluminum PARTS	*NA*	*200*	*200*
	Camera Unit PARTS	*8*	*60*	*480*
	TASK ARM PARTS	*NA*	*50*	*50*
	HIGH TORQUE MOTOR PARTS	*6*	*65*	*390*
	TAUSAKA HIGH TORQUE MOTOR	*6*	*8*	*48*
				3718
ELECTRONICS	*PCB PRINTING*	*NA*	*250*	*250*
	PCB COMPONENTS	*NA*	*200*	*200*
	WIRE	*NA*	*200*	*200*
	Connectors	*NA*	*100*	*100*
	PRESSURE SENSOR	*1*	*100*	*100*
	Temperature Sensor	*5*	*2*	*10*
	Humidity Sensor	*5*	*3*	*15*
	GYRO	*2*	*20*	*40*
	XBOX 360 CONTROLLER	*2*	*40*	*80*
				995
	Miscellaneous	*NA*	*300*	*300*
			Total	*5013*

Table 1: Total expense for the ROV

Electronic schematic

Figure 3: Overall schematic of the UC3 main board



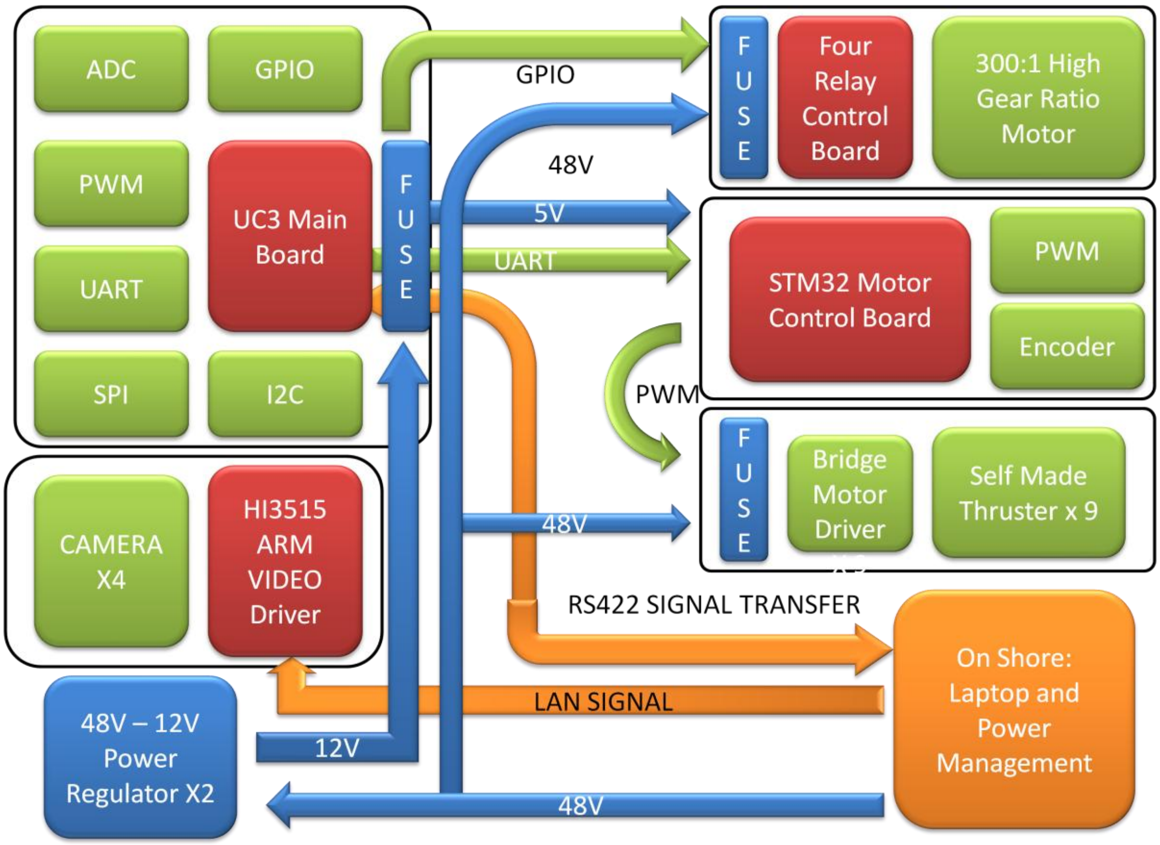


Figure 4: Signal flow diagram of the entire ROV system

Block-diagram or flow-chart of software in the ROV

Figure 5: Flow chart of the overall software running the ROV

Design Rationale for overall System

Since this is our preliminary year in entering the MATE ROV Competition, our primary focus was on stability. The other important aspect we needed to consider was speed. The ROV needed to complete specific tasks in the shortest amount of time possible. Since most of our member had competed previously in other robotics competition we were quite familiar with task specific operations. Hence, we designed the ROV based on a modular design philosophy. Each module performs a specific task. This, in effect provides for a simplistic design. We could summarize our overall design principles as follows:

- Stability
- Simplicity
- Speed
- Modularity

Based on these principles, we looked into how to accomplish each of the mission tasks. We realized that each of the mission tasks can be accomplished using a reference guider system. Therefore, our ROV incorporates a reference guider system to accomplish the mission tasks. The reference guider for the different tasks are as follows:

- Tasks 1 and 2: The reference guide for Task 1 is the oil pipe. Once the ROV reaches the pipe, it docks onto the pipe and accomplishes Tasks 1 and 2.
- Task 3 and 4: Task 3 will not need any reference. The reference guide for Task 4 is the sea floor. Once the ROV is in position it can easily sweep up the biological samples onto the net.

In designing the ROV, we have also given special attention to add acceleration and deceleration features. From our previous experience in robotics competitions, we have understood that these features are vital for precise and smooth control of a manually operated robot.

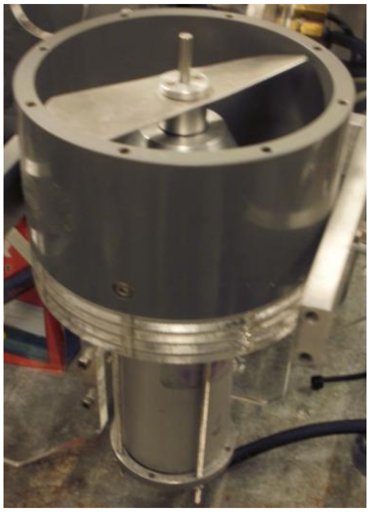
Table 2: Gantt chart for the ROV project.

	1 /2 - 15/2	16/2 – 28/2	1/3 – 15/3	16/3 – 31/3	1/4 – 15/3	16/4 – 30/4	1/5– 15/5	16/5 – 31/5	1/6 – 15/6
Mechanical									
Preliminary Design	PRELIMINARY DESIGN					FINALIZED DESIGN			
Solidworks		CAD DRAWING				CAD DRAWING			
Manufacture			MANUFACTURE				PARTS		SPARE
Hardware									
PCB DESIGN	MAIN SYSTEM DESIGN								
Manufacture			MANUFACTURE				SPARE	PARTS	
Programming			MAIN			SENSOR			
Testing					PRELIMINARY DESIGN TEST			FINALIZED DESIGN TEST	

Design Rationale for Mechanical System

Buoyancy and Propulsion System

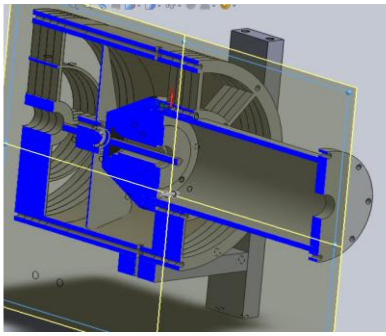
Following preliminary research, we found out that most systems use neutral buoyancy. However, since we have experience in control and we believe control is one of our strengths, after consultation with the hardware and software members, we decided to use positive buoyancy instead. In essence, we use the power of the motors to control the depth of the ROV.



We required the ROV to be maneuverable in all directions. Therefore, we decided to use four propellers in the up-down direction. It allowed the ROV to turn at an angle.

In total, we have eight propellers, four propellers for up-down motion and four propellers for the forward-backwards motion.

Figure 6: Picture of a propeller with blades showing



The propellers are 0.115 m in diameter and 0.2 m in length. We experimented with some off-the shelf propeller blades, however we found out that these propeller blades did not produce a satisfactory thrust, so we decided to custom build our own propeller blade. Following initial testing of our blade, we found that the thrust generated using our custom-built blades were better than the off-the shelf blades. Therefore, we decided to employ our custom-built blades in the final design.

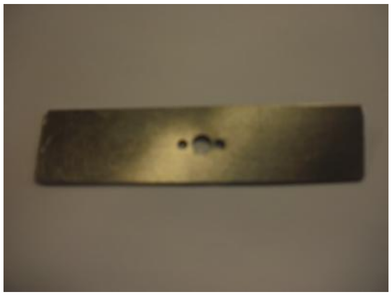


Figure 7: Top, Solidworks diagram of the propeller, bottom left, the off-the shelf propeller blade used in generation one of the ROV, bottom center, front view of our custom designed propeller blade, bottom right, side view of our custom designed propeller blade.

Structural Frame

The structural frame of the ROV consists of two acrylic plates on the sides, ½-inch PVC tubes at the center, and aluminum blocks that hold the propellers.

Figure 8: Picture of the ROV showing only the structural frame.

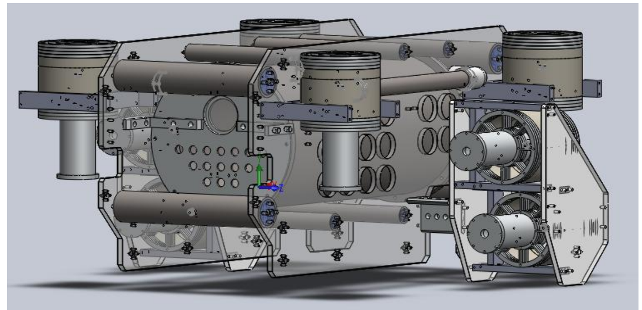


Figure 9: Solidworks diagram of the structural frame of the ROV, with propellers included.

The ROV structural frame measures 0.7 meters in height and 0.8 meters in width and length.

Electronics Tube

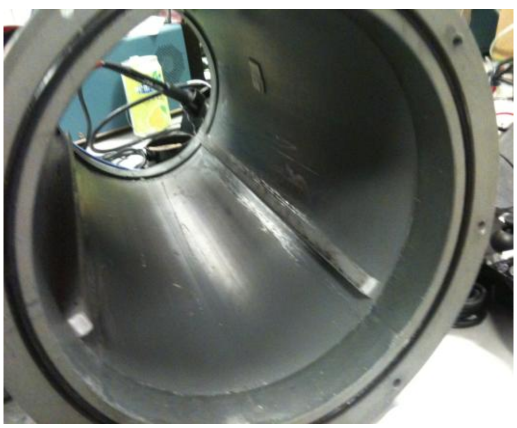
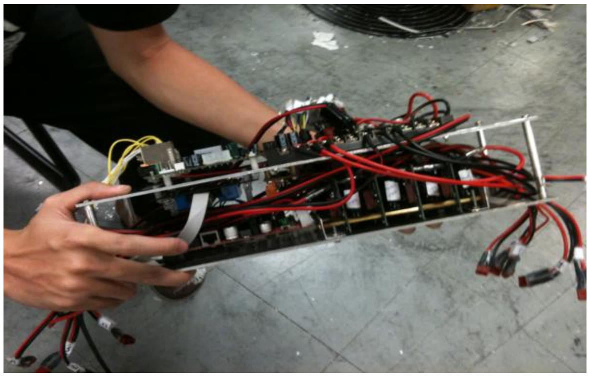


Figure 10: The electronics tube casing. It houses the onboard electronics.

Once the on board electronics had been decided and the size for each of the electronics boards obtained from the electronic engineers, the mechanical engineers decided on the sizing for the electronics tube.

We decided to use a tube shape because it allows for easy waterproof using o-rings. Another reason we chose the tube shape is because, even though we cram the tube with electronic boards, there will still be enough air trapped inside the tube that would add to the buoyancy of the tube and offset the weight of the electronic boards.

We also had to design a heat transfer system in the electronics tube to remove the excess heat generated from the on board electronics.



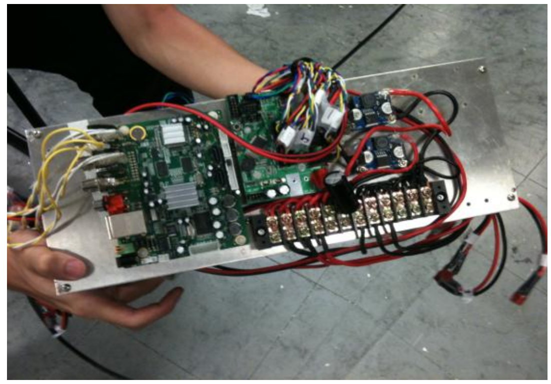


Figure 11: Left, a side view of the onboard electronics. Right, a top view of the onboard electronics.

Wellhead Cap

Inspiration for the design of the wellhead cap was drawn from the in-ear earphones. Following preliminary research into this design, we found that this design worked satisfactorily. Therefore, we employed it for the final wellhead cap.

Figure 12: The wellhead cap.

Figure 13: Inspiration for the wellhead cap was drawn from in-ear earphones.

Design Rationale for Electrical System

We decided to use an onboard microcontroller because it would be easier for us to get the signals from the sensors using the MCU and then pass it on to the PC. Due to our experience in PID control and motion control algorithms in the Robotics competition using the Atmel 32-bit AVR UC3 microcontroller, we decided to employ it as our microcontroller of choice. The 32-bit AVR UC3 microcontroller gives us the flexibility to put as many sensors as we want without worrying about the number of sensor ports, since the 32-bit AVR UC3 microcontroller provides the ability to add over 50 sensors.

The sensors we used in the ROV are as follows:

- Temperature Sensors
- Pressure Sensors
- Humidity Sensors

Temperature Sensor

We have adapted to use the DS18B20 temperature Sensors to monitor the ROV's internal and external temperature. Temperature management is an important factor for stability and control. With our custom design, the DS18B20 can be easily plugged into the UC3 main board, providing real-time temperature feedback to the surface computer.

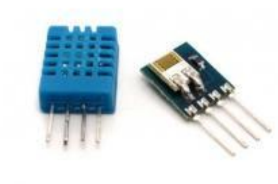
Figure 14: The DS18B20 is used as our temperature sensor.

Pressure Sensor

For the pressure sensor, we have chosen to use the SSI Technology P51 series pressure sensor. It gives out absolute pressure values, which greatly helps in the determination of depth, thus giving us a higher accuracy for our depth calculation. The P51-50 series can measure up to 345 kPa (50 psi).

Figure 15: The SSI Technology P51 series pressure is used in the ROV for depth calculation.

Humidity Sensor



For the Humidity Sensor, we have chosen to use DHT11. This sensor acts as an alarm and monitors the ROV's internal humidity. If there is a leakage in the electronics tube, the DHT11 will relay back an increase in humidity to the surface. The DHT11 communicates with the surface computer via the UC3 main board. The pilot will be notified of possible water leakage, he could then take necessary measures to ensure safety of the ROV.

Figure 16: DHT11 acts as the humidity sensor, detecting water leakages in the electronics tube.

Camera

The camera system uses four 640x480 VGA cameras with s-video output and integrated night vision. The cameras are housed in aluminum waterproof casings, designed and built by us. The cameras are placed in critical locations (two on the sides overlooking the Velcro strip remover, one overlooking the organism collector, and one looking straight ahead) , providing important visual information. The cameras relay data to an onboard video driver board that then relays the data through a LAN cable to the surface computer.

Figure 17: A picture of the left side camera.

Tether

The tether of the ROV is custom built by us. The tether consists of two power cables that transfer 48V and ground to the ROV, one cable for RS 422 data transfer, and one LAN cable for video data transfer.

Figure 18: A picture of our custom made tether. The black cables connect to 48V and ground rails. One of the grey cables in the LAN cable and the other cable is the RS 422 data transfer cable.

Design Rationale for Software System

Controller and GUI

In generation one of our ROV, we used the PC Keyboard to control the ROV. We soon found out that this method of controlling the ROV was quite tedious and imprecise. Therefore, in the next generation of our ROV we used the Xbox 360 wireless controller. The Xbox 360 wireless controller is more intuitive and easier to handle than the keyboard control. The program for the controller was programmed in C# using the XNA framework. C# was also used in the entire GUI development for the surface computer.

Figure 19: Screenshots of the controller's GUI.

Figure 19.1: Controller state display.

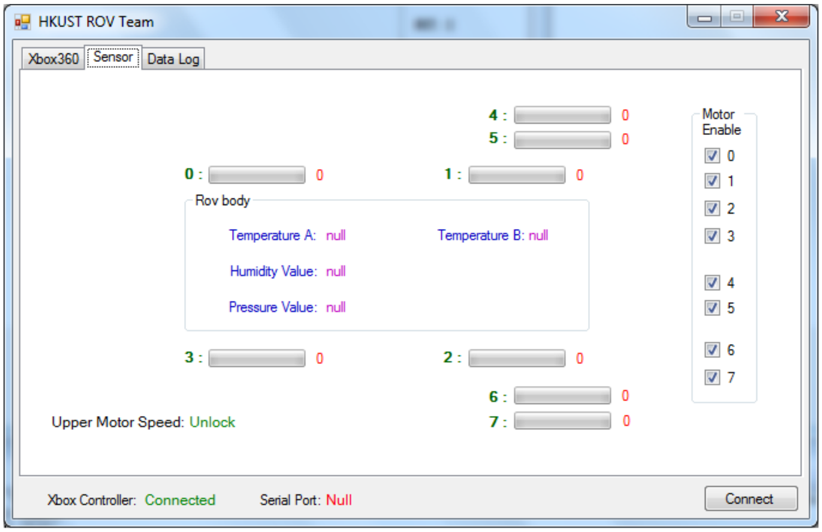


Figure 19.2: Motor speed setting. Feedback from onboard sensor. Enable and disabling of motors.

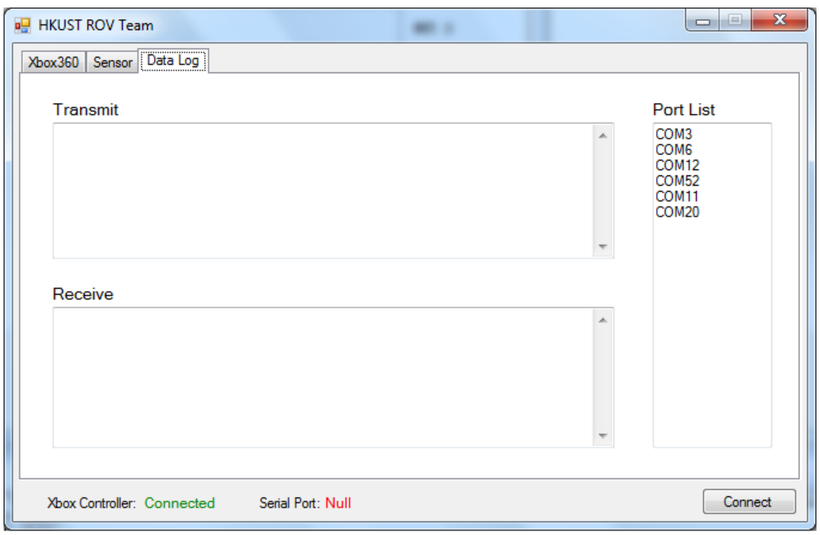


Figure 19.2: Data log of the transmitted and received signals. The screen also displays all the available COMM ports.

Communications

Communication between the PC and the MCU is done through our custom-built communication protocol. The communication protocol uses a checksum to check the received data packets. Since time critical data is being transferred, if an invalid data packet is received then the packet is discarded. On the PC side, the communication protocol is implemented in C#. On the MCU side, the communication is implemented in C. An auto-search feature is implemented in the PC program to search for available COM ports for communication with the ROV. Communication between the PC and MCU is achieved using the USB port. The serial data is sent from the USB port through a RS 232 cable. Since RS 232 is not suitable for long distance communication, the RS 232 cable is connected to an off-the shelf RS 232 to RS 422 adapter. The data is then sent through a RS

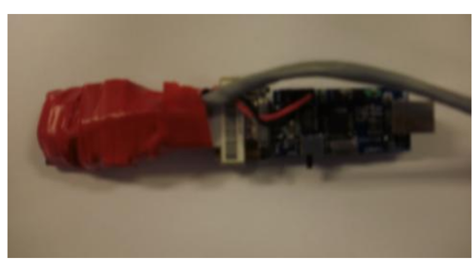


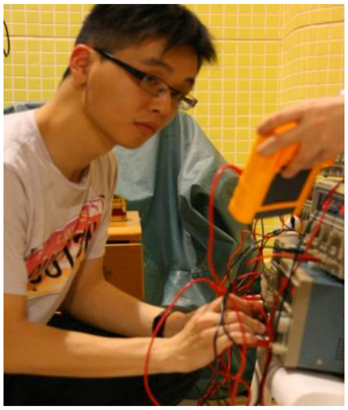
Figure 20: The RS 232 to RS 422 adapter.

422 cable. Since the UC3 microcontroller can directly communicate using the RS 232 cable, we have placed an off the shelf RS 422 to RS 232 adapter between the RS 422 cable and the MCU.

MCU

Programming for the MCU is done in C. The programs in the MCU are responsible for MCU side communication, and sensor data gathering. The data from the sensors is updated every second and passed onto the surface computer. Since real-time, accurate depth information is required, the MCU is used to implement the depth calculation using data from the pressure sensor.

Safety features and Precautions



As safety precautions, we have included fuses in each of the electronics boards. Additionally, the power supply is installed with fuses and circuit breaker for electrical protection. We have also undertaken to label all dangerous zones and parts on the ROV, such as moving parts, high voltage cables, and bright lights. Our team has also compiled a safety checklist. Before placing the ROV in the water, our team members run through this checklist to ensure the safety of equipment and personnel in the area.

Figure 21: Lak running through the safety checklist by checking the voltage of the power source.

Payload Description

Task 1: Remove the damaged riser pipe

This task involves the ROV to transport and attach a line to the U-bolt on the damaged riser pipe. The ROV should then simulate cutting the riser pipe by removing the Velcro strip. Finally, the cut-off portion must be removed from the work area.

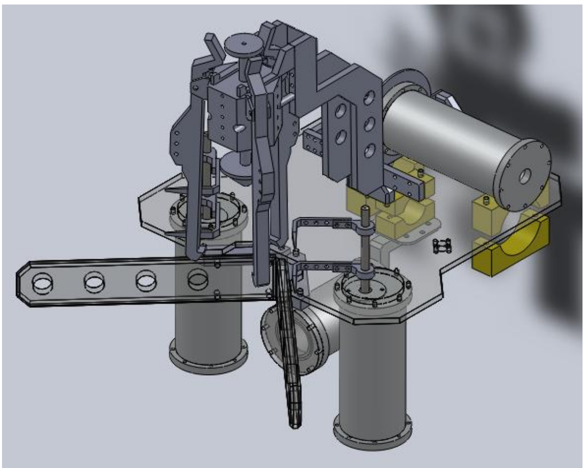


Figure22.1: Solidworks diagram of the revolving hook with wellhead cap.

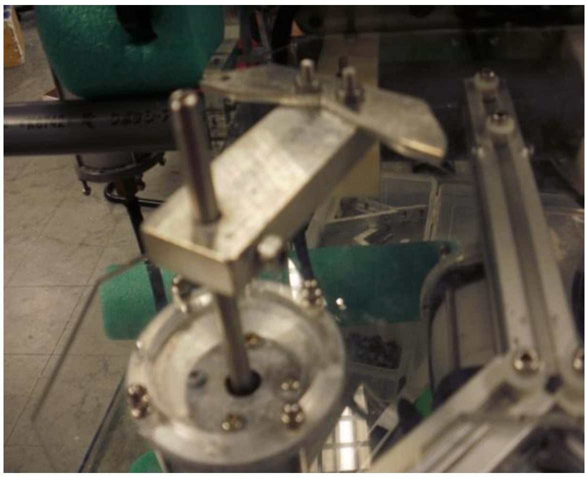


Figure22.2: Photograph of the revolving hook.

Figure 22.3: Photograph of the gripper that attaches to the U-bolt.

To attach the line to the U-bolt, we created a gripper that which will be attached to the line. The gripper would lock onto the U-bolt. A revolving hook attached to a motor is used to remove the Velcro strip. The hook would slip into the ring attached to the Velcro strip and thus remove it. Once this is done, the damaged riser pipe would be removed manually via the line.

Task 2: Cap the oil well

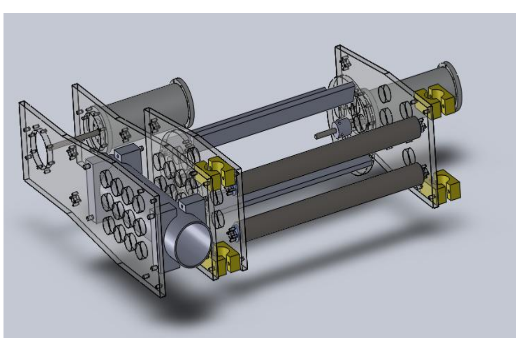
For this task, we have to design a cap that would cover the wellhead and stop the oil flow. At the competition, the ROV is supposed to transport the cap to the oil well and install it onto the wellhead. Since we have used the reference coordinate system, the motor arm for the cap would already be in line with the wellhead to place the cap once the damaged riser pipe is removed.

Figure 23: Photograph of the wellhead cap.

The wellhead cap's design is based on the design of in-ear earphones. The oil cap is constructed from 0.03 meter PVC, rubber lining and a screw is attached to the top. The screw is then attached to a metal strip.

Task 3: Collect water samples and measure depth

This task requires the ROV to collect water samples from a specific depth to test for the presence or absence of oil. The mission tasks involve interpreting a graph to gauge the depth at which to sample, measuring the depth at sample site, collecting the water sample and returning the water sample to the surface.



To collect the water samples, we use a simple water piston to suck the water. The piston can collect 0.0003 cubic meters of water, we can control the piston to suck in and eject the water out.

Figure 24: Solidworks diagram of the water sample collector.

Task 4: Collect biological samples

This task involves the collection of one sample of sea cucumber, glass sponge, and Chaceon crab, and returning these samples to the surface.

The collection unit consists of a rotary brush that will sweep through the seabed and transfer the organisms from the seabed to a net.

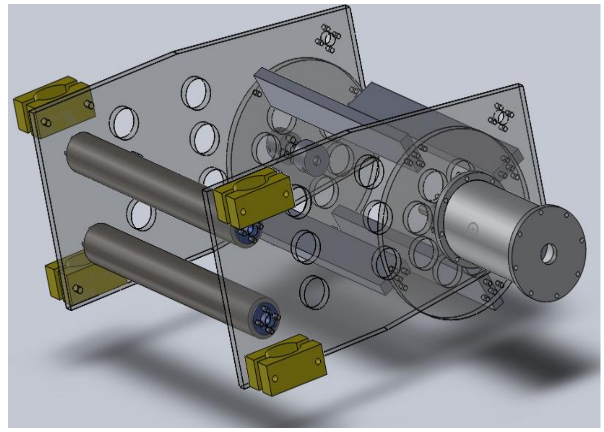


Figure 25: Solidworks diagram of the biological sample collector.

Description of at least one challenge

During the construction of the ROV, we encountered excessive heat being generated by the onboard electronics in the electronics tube. Our initial design involved placing the circuit boards on two boards of acrylic. However, due to the excessive heat generated we had to design a method of cooling the system. Our team members came up with various methods of cooling inside the electronics tube.

Our final design involved placing heat sinks on the circuit boards and then mounting all the boards onto aluminum sheets. The aluminum sheets were then connected to the aluminum plates on the sides of the electronics tube. The heat sinks would dissipate the heat from the circuits onto the aluminum sheets. The aluminum sheets would absorb some of the heat and then dissipate the rest onto the aluminum plates on the sides of the electronics tube. These aluminum plates face the water on the outside and would then dissipate the heat to the water.

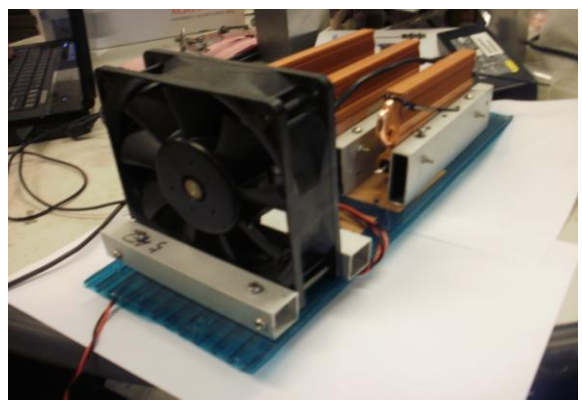
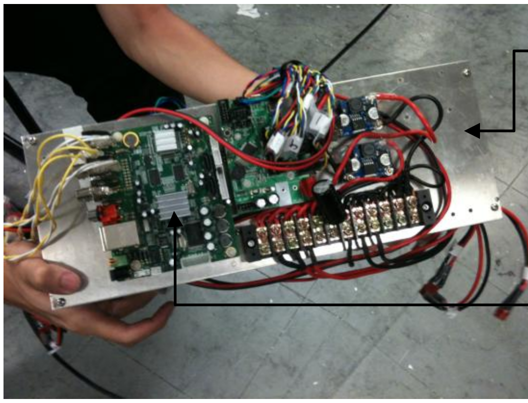


Figure 26: The heat pipe we constructed during our research into cooling methods for the electronics tube.

Figure 27: Our final cooling system.



Aluminum mounting plate, attached to heat sink to absorb the heat

Heat sink used to transfer heat away from the electronic board.

Explanation of troubleshooting techniques

Another problem we faced was propeller malfunction. During our initial tests of the Generation 1 ROV, some of the propellers stopped working while the ROV was operating. We applied a systematic approach to troubleshoot this problem. The entire propeller system can be broken down into sub-parts such as the:

1. Motors
2. Motor casing
3. Propeller
4. Program Code
5. Electrical supply
6. Electronic control system

We tested each of the parts to determine the location of the problem. We found out that the load was too high for the motors; the motors drew in too much current, causing the onboard electronics to malfunction and the motors to overheat and finally burnout. We decided to replace the motors with a different set of motors and use the water as a cooling agent for the motors. However, this method did not prove suitable; the carbon brushes once exposed to the water started to wear out. We finally designed our own propeller blade, replacing the off-the shelf propeller blades used in the first generation. By studying the pitch and diameter of the propeller, we were able to adjust the load and torque of the motor bearing. Using this data, we were able to estimate the load and torque of the motor unit. This technique of modular testing was used in the software, electronic and mechanical systems as well, whenever we encountered a technical problem. Please refer to Figure 7 for photographs of the off-the shelf propeller blade and our custom designed blade.

Description of at least one lesson learned or skill gained

This year is the first year we are taking part in the MATE ROV competition. However, most of our members have taken part in the Robotics competition in previous year. Nevertheless, the MATE ROV competition gave our members a unique learning opportunity. One of the unique skills we learned was the technique of waterproofing. Even though the skill can be easily mastered, the technique required some detail study before implementation. Another aspect was the detail mathematics that went into designing our custom propeller. Since underwater, was a new frontier for us, we had to learn about underwater mechanics and how they could be applied to the ROV.

We decided to use the Xbox 360 wireless controller and so, our members had to learn about the signals generated from the Xbox360 controller in order to integrate it with our control program. Another new skill we learnt was in the area of long distance cable communication. Usually, most of our robots would require short cabling or none at all. However, for the ROV, we required very long cables to transmit power and data to and from the ROV to the surface. We learnt about signal attenuation and the workarounds for this problem.

Discussion of future improvements

One of our future improvements is to make the ROV smaller. This would help the ROV to move through tight corners much more easily. Even though the ROV is based on a modular design, we see that there is room for improvement on this front. We would like to create more space on the ROV to mount new and varied payload tools in the future. Another area that we would like to improve on our ROV is automatic capability, in essence, turning our ROV in an AUV (Autonomous underwater vehicle).

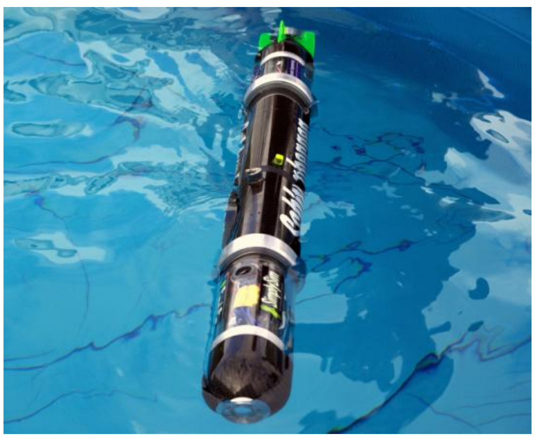


Figure 28: Photograph of the Blackghost AUV, courtesy Wikipedia. This AUV can navigate through an underwater course without human intervention.

Reflections on the experience

"We not only have to consider the mechanical but also the hardware and software engineering when designing the ROV. I think it is the cooperation between hardware and software, because one problem cannot be solved just from one end. There may be multiple ways to solve a problem but we need to find the easiest way to solve the problem."-Eric Leung, Final Year, Computer Science.

"Working together in the ROV project, I have made good friends, overall it has been a fun and exciting experience."-Ryan M.S. Wong, Final Year, Electronic Engineering.

Figure 29: Eric and KK discussing improvements on the ROV design.

“Working on the ROV project has been both an exciting and fun experience”-Law Sau Lak, Final Year, Electronic Engineering

“Working on the ROV project, we not only learn about technical and problem techniques but also soft skills such as communication, team work, and time management. I have learnt a lot of technical information as well, which I am sure will help me in future in my engineering career. I also learnt a lot about the problem solving and debugging techniques we used. Additionally, I learnt and gained experience in working on an engineering project. I learnt about engineering project management and also team coordination.”-Sheshan Aaron, Year 2, Electronics Engineering

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- http://aquaticus.info/
- http://www.materover.org
- http://www.marinetech.org
- Underwater Robotics: Science, Design & Fabrication, (*Dr. Steven W. Moore, Harry Bohm, and Vickie Jensen)*

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- HKUST, Student Affair Office (SAO)

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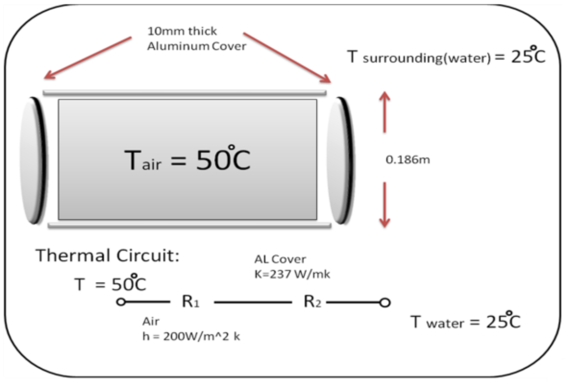
Appendix

Equation Set 1: Heat Transfer calculation for the electronics tube.



Assumption:

1. 1-D steady-state condition
2. Constant prosperities
3. AL cover and water has the same temperature

To calculate:

$R_1 = R_{convection} = \frac{1}{h(2A)}$

$= \frac{1}{(200)(2)\left(\frac{\pi}{4}\right)(0.186)^2}$

$= 0.09200$

$R_2 = R_{conduction} = \frac{L}{K(2A)}$

$= \frac{0.01}{(237)(2)\left(\frac{\pi}{4}\right)(0.186)^2}$

$= 7.7643 \times 10^{-4}$

So,

$Q = T_{water} - T_{air} / R_1 + R_2$

$= \frac{50-25}{0.09200+7.7642x10^{-4}} = 269W$

269W which is much larger than the heat lost from the motor driver (~50W), so no overheating occurs inside the Electronic component Tube.