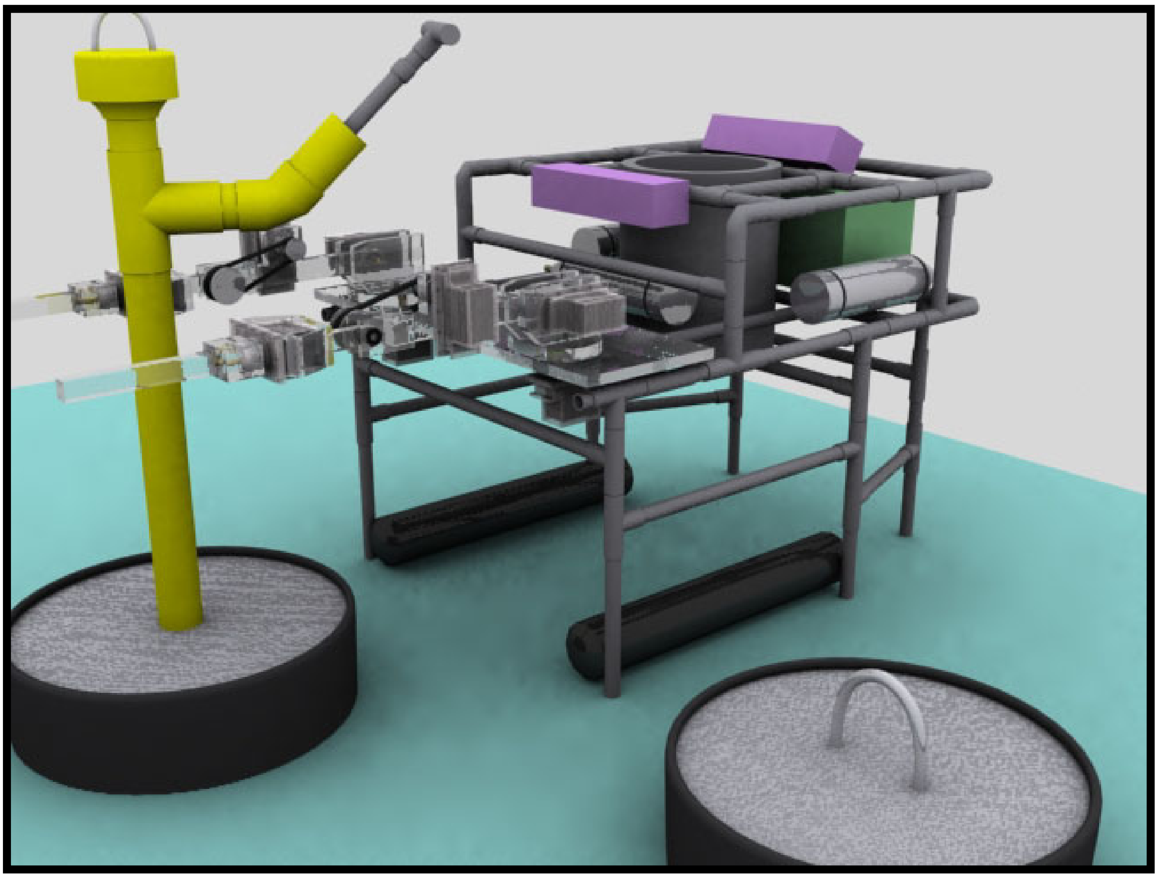
# Penguin
## A Remotely Operated Vehicle (ROV)



A graphic rendition of "The Penguin"


**Department of Electronic Engineering**
**City University of Hong Kong.**

**Mentors :**

Dr. Robin Bradbeer
Dr. Lam Yeung
Mr. Paul Hodgson

**Team Members:**

Christopher, W. L. Chan
Lionel, B. Dai
Allen, J. B. Ke
Ken, C. K. Law
Jason, B. Y. Li
Hedy, S. Li
Jeanne, J. Lin
Richard, C. C. Tang
Brian S. Yip


香港城市大學
City University
of Hong Kong

# Table of Contents

# Abstract.

The Hong Kong City University Team has designed the "Penguin" Remotely Operated Vehicle (ROV) to perform a series of specific missions in shallow (<10m) water. Key design criteria included manoeuvrability, small profile to currents, buoyancy stabilization and speed. The result is an ROV that combines the controlled use of power and thrust with easy to use features. Our report explains the design process applied, the problems encountered and the challenge in overcoming them.

# The Design Rationale.

## *Overview*

The Penguin ROV is the combination of ideas from two separate ROV design groups that were combined for this project. Each group had their own ideas and concepts that could be channelled into the final design. This allowed us to maintain the traditional competition ROV structure, but refined with subtle features and advancements. This was particularly important since the unit had to be designed to work in difficult environments including very cold water (~0ºC), currents of 0.5 m/s and in waves of 0.5m high, and at the same time be able to penetrate ice cover through a small ice hole. Unit strength and modularity for transportation was also a consideration since our unit would have to be transported half way around the world in order to participate in the competition.

We were also conscious of the environmental needs when choosing the materials to be used. Consequently, most of the power was sent to the robot along the umbilical, and any on-board batteries were environmentally friendly. All materials were inert and non-toxic.

## *Overall system design*

Figure 1 shows the overall system diagram. A 20 conductor umbilical (from a previous project) was used, with a length on 15 m. Two 'break-out' boxes were constructed so that all the land-side and robot-side cables could be connected to the umbilical. All sub-assemblies had to be modular so repair could be simplified by just changing modules.

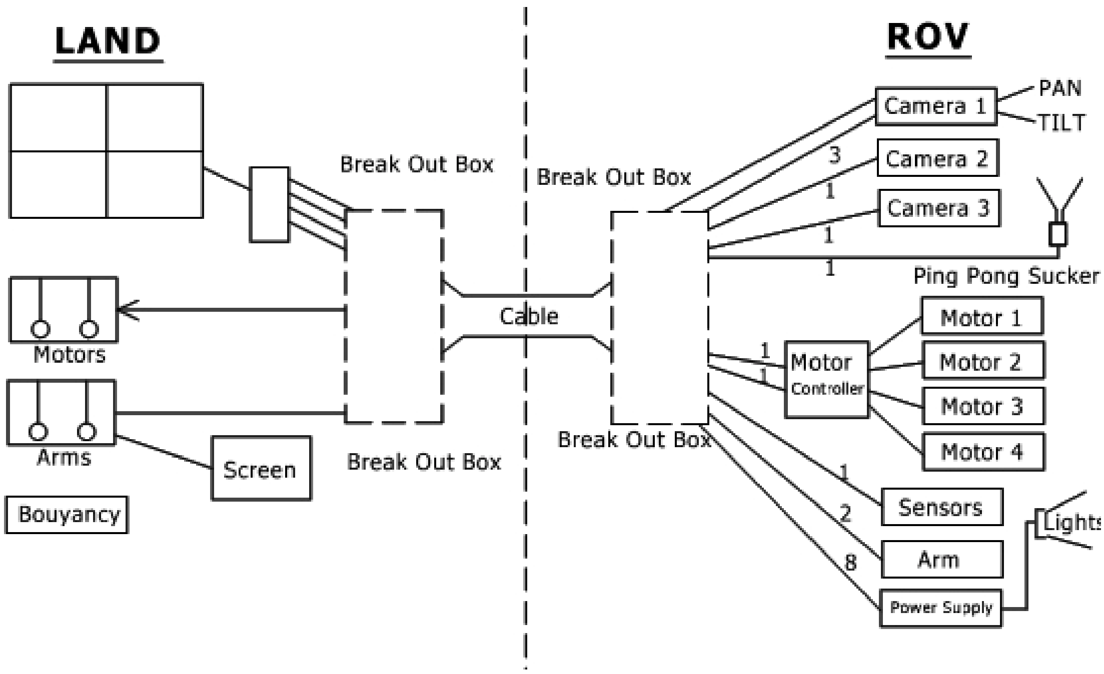



Figure 1 Overall system design

## *Basic Structure and Materials*

We wanted to build a unit that could be copied easily and form a stable platform for other competitions in the future. We maintained and refined the traditional PVC pipe frame structure for simplicity and for ease of assembly and repair if damaged during transportation. The shape was a critical factor and one of the key issues so several different designs were tried in the testing tank. The electronics were divided up to minimize the number of conductors required in the umbilical so waterproofing of these elements was also required. Again, PVC was used for these housings. The frame is shown in Figure 2 below with the arms, and Figure 3 shows the thrusters positions. There is an option to use 360$^{o}$ omni-wheels so that the ROV can be manoeuvred whilst in heavy negative buoyancy on the bottom, so that it is anchored for the mission, especially that with current flow.

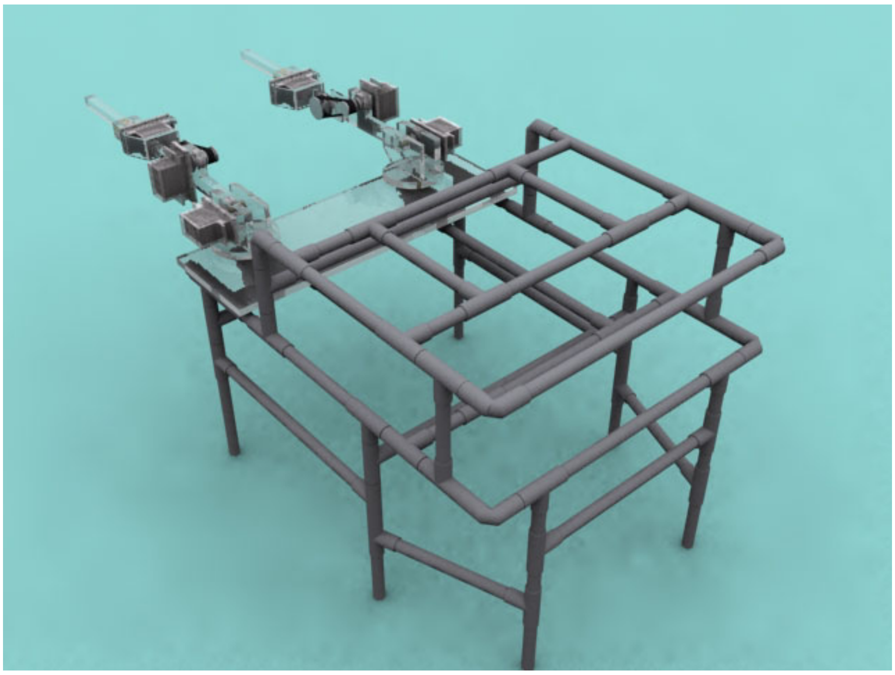


Figure 2 The frame design

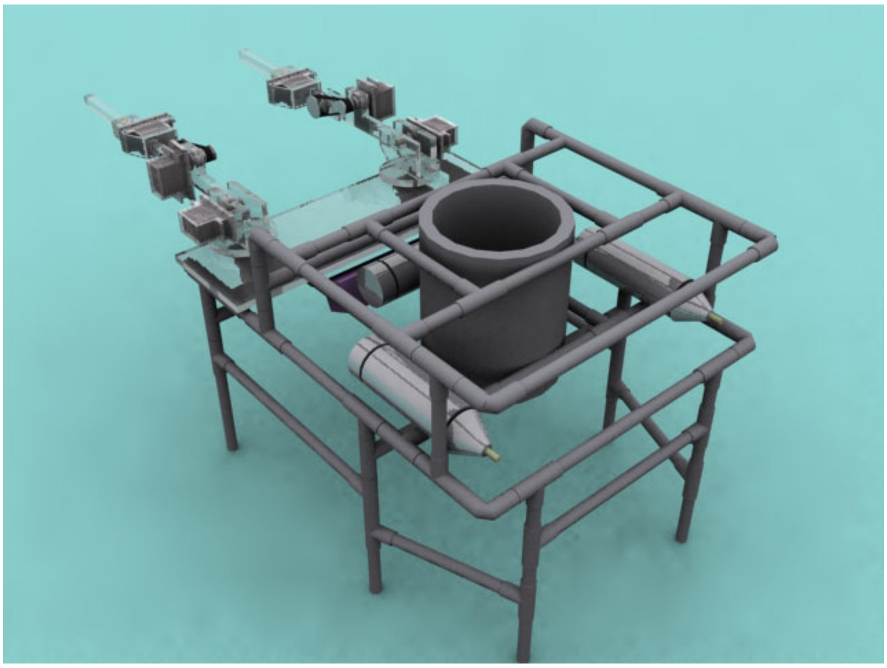


Figure 3 Frame with thruster positions

## Propulsion System.

The system was designed to use four ducted thrusters; two for forward propulsion, one for vertical and the other for sideways. Calculations for the thrust needed to overcome the water pressure from the 0.5m/s current on the cross-sectional area of the rov, gave us a figure of 3kg thrust per thruster. 70 mm diameter, 98 mm pitch carbon fibre propellers were chosen, and the maximum thrust calculated could be provided by a 70W dc motor rotating at 1130 rpm, geared down from 8,500 rpm. This would also provide a forward speed of 1.5m/s under optimum conditions. The propulsion control system was designed to provide a maximum of 6A at 12V, the speed controllable by a pwm-based circuit, controlled from the surface commands over the communications system.

Figure 4 Completed thrusters

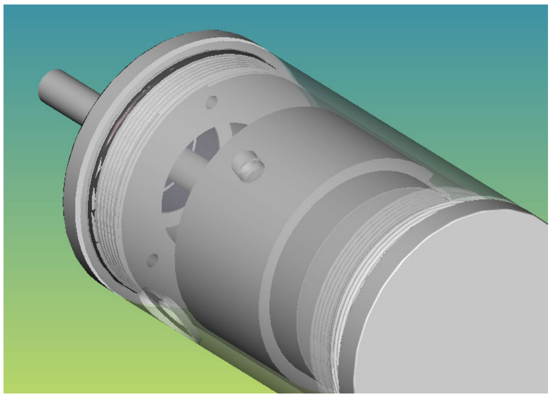


Figure 5 Exploded diagram of the thrusters

The dc motors were housed in an aluminium casing, with the shaft from the gear box going through a neoprene seal, as shown in Figures 4 and 5. The power cable was passed through the rear of the housing using a cable gland, the system rated to 10 m. The thrust of the system was measured against input voltage and current, but the results have not been analysed in time to include in this report.

The motor control circuit is shown in Figure 6.

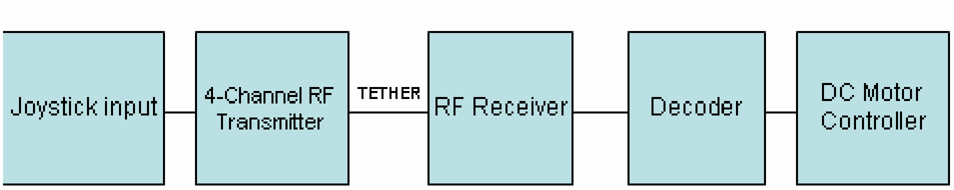



Figure 6 Block diagram of thrusters control circuit

## Buoyancy System

Neutral buoyancy and unit stability was established by using positive buoyancy at the top of the ROV and weights on the lower section. Air filled plastic pipe was used for the positive buoyancy. Similar plastic tubes filled with sand for the negative buoyancy. The design allowed for the sand to be added and removed from the lower tubes to attain neutral buoyancy, and also for the unit to be transported empty.

## Cameras

A total number of three waterproof cameras were used. One fitted with a wide angle lens and tilt and pan functions to allow for general orientation of the ROV with respect to the surroundings was mounted in the centre of the rov frame. This was based on a dome security camera inside a watertight compartment made from acrylic. The pan and tilt functions were under the control of the arm operator unless taken over by the rov operator.

The other cameras were primarily for narrow vision particularly those installed to guide the operator when carrying out the missions. One fixed camera gave an overall front facing view, the other was mounted on the top of the frame pointing upwards so as to assist with operations under the ice cover.

The actual location of each camera was critical. They had to contribute to an overall streamlined design, and yet placed in locations that made the image data useful, but away from obstructions caused by other sections of the ROV. One other difficulty was the cavitation bubbles, created by the propellers when the thrusters operated under full power, sticking to the camera ports causing blurred images. Figure 7 shows how the modifications made to a commercial underwater camera used for the two fixed positions.

Figure 7 Adapted underwater camera

## Extra Sensors

A Navigation Underwater Sensing (NU-SENSE) system was developed by the team to supplement the camera image data available to the operators. The idea was to provide information to help the operator handle and locate suitable working positions for the ROV with respect to the mission props. The system employed simple sensors connected to a PIC on the ROV. Figure 8 shows the unit display. Information was sent serially to a display unit located next to the ROV controls so only needed one core of the umbilical. Information displayed included the current yaw, pitch and roll situation of the ROV as well as the depth and water temperature. The system diagram for this is in Appendix B.

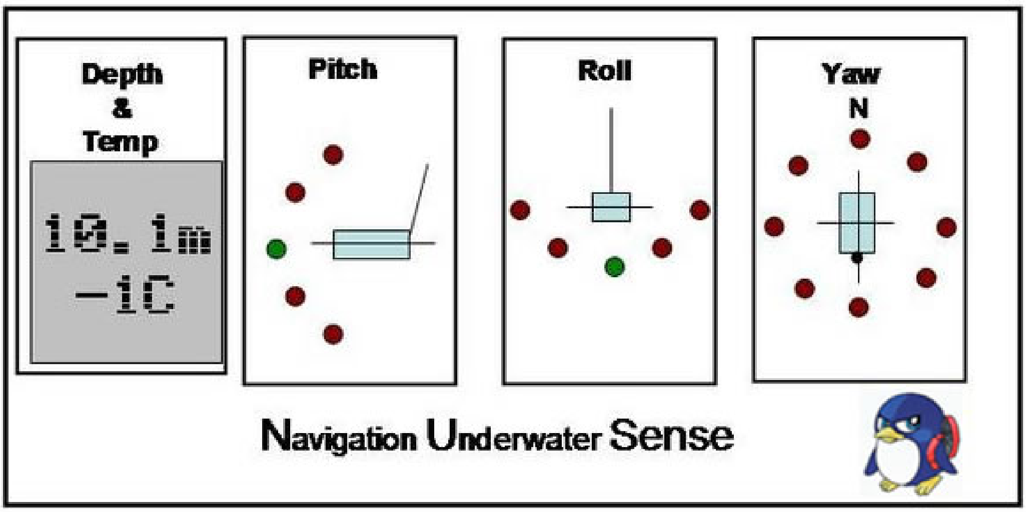



Figure 8 The display of the NU-SENSE system

## Manipulator

The actual function of the bulk of the ROV is to get the tools into a suitable working location and then to maintain this location so that work can be carried out. The tool system is actually an independent system on this ROV. There are two four-joint robot arms, each with a simple gripper - as shown in Figures 9 and 10. The joints use servo motors and are controlled from the surface using the communications system. Each arm has 4 DOF. The arm position could be pre-programmed so that the gripper is in approximately the correct position for each of the tasks required. Final positioning is then done manually using the control console.

The arm servos were controlled from joysticks on the console, and the position data was sensed by a PIC microcontroller, processed into RS232 format, sent along one of the conductors, and then decoded by a PIC in the arm controller on the ROV. The pan and tilt camera is designed to follow the arm movement, thus making operator control easier.

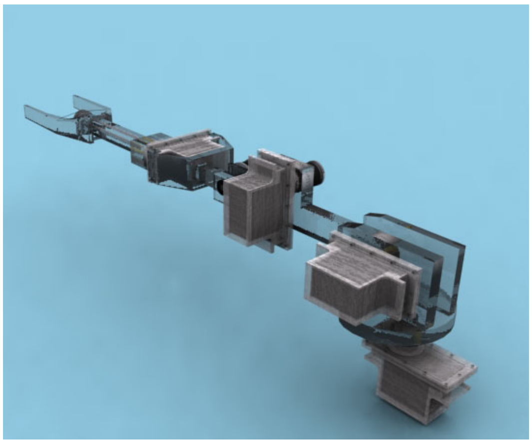


Figure 9 Manipulator arm outstretched

Figure 10 Manipulator arm

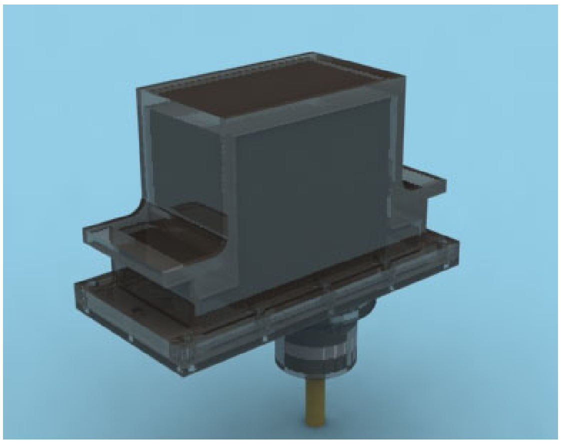


Figure 11 The acrylic watertight housing for the manipulator arm servos

The servos are housed in acrylic watertight compartments with sealed shafts, as shown in Figure 11.

## *Vehicle Control Systems.*

In order to minimize the cabling to the ROV, the multiplexing systems of a 4 channel radio remote control was used to condense the motor control data so that it could be transmitted down one wire to a compatible receiver. Actually this simplified the design considerably and allowed for spare parts. This also allowed the joystick control associated with r/c to be modified for use with the four thrusters. In addition, the use of a microcontroller in the motor control unit allowed these signals to be combined so that, for example, rotation of the robot, would only require one control, although controlling two motors. Basically, the antenna of the r/c transmitter was removed and the rf signal sent along the umbilical. The attenuation of the signal, at 35 MHz, was less than in air! The signal was received using a standard 4 channel r/c receiver and them the output from this was fed to the power electronics and/or the microcontroller, as needed.

## Power system

The power from the surface batteries was fed to the ROV using multiple conductors in the umbilical so as to reduce the voltage drop, and to ensure that thinner wires could be used in each conductor, thus making the umbilical more flexible. The voltage at the ROV end of the umbilical will obviously fluctuate with the load, and our power supply assumed an input voltage varying between 24 and 36 V. The incoming power was split into various regulated boards. The motor voltage was generated by 4 separate switched mode power supplies rated at 12V dc and 8A. These were used so as to minimise the power dissipation in the power unit, as getting rid of the excess heat underwater needed a lot of thought in the design. The system block diagram is shown in Figure 12

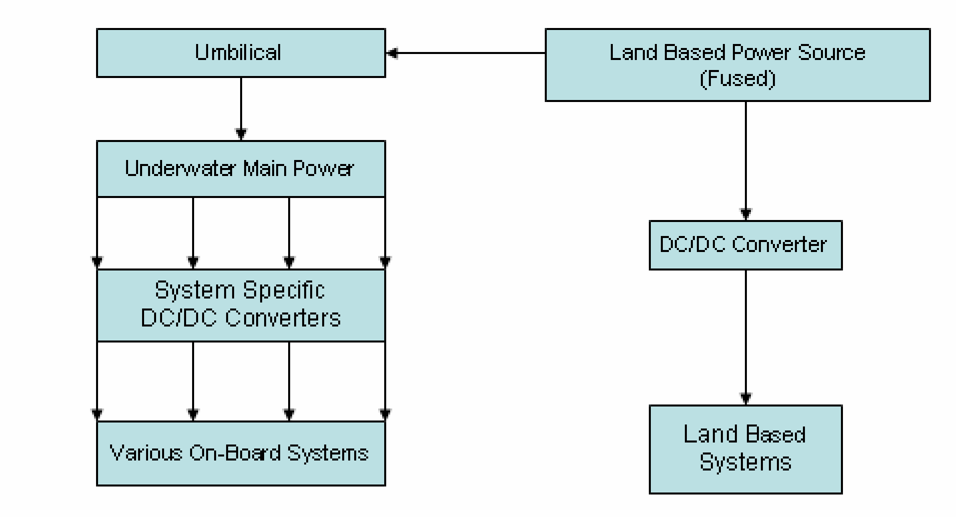



Figure 12 The power system block diagram

The electronics power supply of 5V and 12 V were generated using standard series regulator circuits.

## The umbilical cable

It was agreed to use an existing umbilical cable from a previous project. This had the advantage that a professionally made seal for the connector was available for the rov end of the cable. However the existing cable was 30m long so this was shortened to 15 m with a new connector at the control break-out box end. The resistance of the conductors varied between 2-3 ohms. This determined the power supply to be used at the land side and the voltage losses in the cable assuming a maximum current of 40A. It was decided that four parallel conductors would be used for the power supply. The conductor assignments are shown in Figure 13. The cable was slightly negatively buoyant, so this is a problem to be solved during the test runs of the whole system.

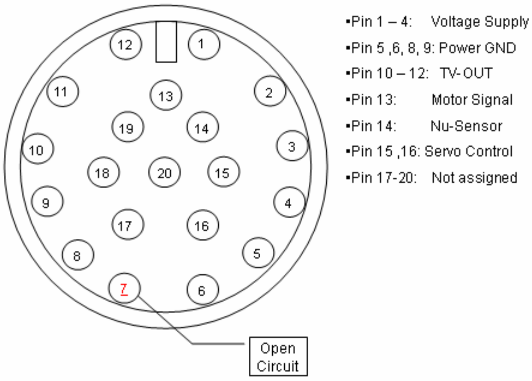



Figure 13 The umbilical conductor assignments

### *Lights*

As the lighting environment at the contest is not known, the lighting system was designed to be flexible. A power connector will be made available on the rov break-out box, switched from the surface using one of the channels available in the arm control system. An external light can be fixed on the frame as necessary. However, there will also be the option of using battery-powered hiLED diver lights that can be strapped to the frame as necessary. There is some illumination in the fixed cameras but this needs to be tested under trial conditions to see if it is suitable.

### *Algae collector*

One of the main missions of the contest is to collect algae from under the ice cover. The underneath of most ice is not smooth, so some sort of suction device is necessary. We use a small 500 gph bilge pump motor, with a small funnel attached - see Figure 14. There are strings of elastic (rubber) across the mouth of the funnel at 2.5 cm intervals. This is enough for a ping-pong ball to be sucked through and then trapped by the bands. A fixed camera is close to the algae sucker so as to help the operator see where to go.

Figure 14 Algae (ping-pong ball) sucker

## Challenges.

There were two main challenges met during the design phase.  The first was to determine what part of the electronics was to be placed on the ROV unit itself.  The second was to try to figure out how to design and build the robotic arms needed to carry out the missions.  The latter made more difficult because they need to be easy to control.  The first problem was predicated on the number of conductors in the umbilical.  The second problem was made even more complicated when we realized that we would have to make the arms so that they folded up into the ROV so that it could go through the ice hole, and would able to extend all by themselves.

There were lots of smaller challenges like figuring the most efficient frame shape and the useful sensors that could be used in the NU-SENSE system.  We had lots of ideas but realistically only the sensible ones could be used.

After the ROV was constructed it was a challenge to figure out how to waterproof the electronics and keep them waterproof during any repair, maintenance and adjustment.  The whole electronic module was actually flooded once.

### *During the Design Phase.*

The design methodology of this ROV was radically different from previous years.  Initially two separate machines were produced and tested.  Then the two design and building teams were merged and this ROV was produced from a single brainstorming session.  Ironically not all of the problems or difficulties were solved by the two teams working independently.  This was the first time that a Hong Kong team has taken part in the Explorer competition, so there were no guidelines or experts from previous years. The time for brainstorming ideas, as well as learning how to implement them actually turned out longer that the time needed to build the robot.

As the team are first year university students they have little experience of designing such a large project. However, the project itself caught the imagination of many final year and postgraduate students associated with the lab. and they proved very helpful in pointing us in the right direction, as well as teaching us lots of practical engineering that we would not normally get in our academic courses.

## *Operating the ROV*

This ROV was designed to be operated by two people. One driving the ROV platform and manoeuvring it into a suitable position for the second operator to use the arm to carry out the detail work on each mission. The control unit for the Penguin had two LCD screens - each operator can see any one or all of the cameras at any time. This allows both operators to assist one another if the ROV gets into difficulty. The NU-SENSE display screen is also clearly visible by both operators allowing one to concentrate on what they are doing and the second to monitor everything else.

The control system, based on simple to use modified remote control unit (RC units) most people are familiar with using the joysticks on these units. It only took a short time for the operators to train to use the system.

# Budget

| **Expenditure** | | | | |
|---|---|---|---|---|
| **Item** | **Qty** | | **Unit price** | **Sub-total** |
| **Frame** | | | | |
| Aluminium pipe | 2 | m | HK$100.0 | HK$200.0 |
| PVC pipe | 20 | m | HK$5.0 | HK$100.0 |
| PVC joints | 30 | pcs | HK$3.0 | HK$90.0 |
| **Thruster** | | | | |
| Motor | 4 | pcs | HK$106.0 | HK$424.0 |
| Aluminium pipe | 2 | m | HK$108.0 | HK$216.0 |
| Aluminium bar | 1 | m | HK$360.0 | HK$180.0 |
| Propeller | 4 | pcs | HK$189.0 | HK$756.0 |
| Gasket | 8 | pcs | HK$4.0 | HK$32.0 |
| **Arm** | | | | |
| Servo motor | 8 | pcs | HK$350.0 | HK$2,800.0 |
| Arcylic boxes | 8 | | HK$500.0 | HK$4,000.0 |
| Control joysticks | 4 | pcs | HK$150.0 | HK$600.0 |
| Gasket | 16 | pcs | HK$4.0 | HK$64.0 |
| **Power** | | | | |
| Umbilical cable | 20 | m* | HK$8.0 | HK$160.0 |
| Connector (20 pins) | 2 | pairs* | HK$550.0 | HK$1,100.0 |
| Fuse | 6 | pcs | HK$5.0 | HK$30.0 |
| Fuse box | 1 | pc | HK$45.0 | HK$45.0 |
| Battery | 1 | pc | HK$360.0 | HK$360.0 |
| **Controller** | | | | |
| 4 channel RIC controller | 1 | pc | HK$800.0 | HK$800.0 |
| Control box | 1 | pc | HK$20.0 | HK$20.0 |
| Buttons | 24 | pcs | HK$5.0 | HK$120.0 |
| **Camera** | | | | |
| Camera fixed | 2 | pcs | HK$273.0 | HK$546.0 |
| Camera pan and tilt | 1 | pcs | HK$2,000.0 | HK$2,000.0 |
| AV cable | 15 | m | HK$5.0 | HK$75.0 |
| **Electronic system** | | | | |
| PIC 16F88 | 30 | pcs* | HK$20.0 | Free samples |
| PIC 16F887 | 20 | pcs* | HK$20.0 | Free samples |
| NU sensor system | 1 | pc | HK$800.0 | HK$800.0 |
| LCD Display board | 1 | pc | HK$250.0 | HK$250.0 |
| Circuit board | 6 | pcs | HK$250.0 | HK$1,500.0 |
| Watertight boxes | 4 | pcs | HK$130.0 | HK$520.0 |
| Connectors/receptacles | 22 | pcs | HK$100.0 | HK$2,200.0 |
| other components* | 1 | | HK$3,450.0 | HK$3,450.0 |
| | | | Total | HK$21,118.0 |

* some old parts reused - not costed 1 US$=HK$7.8

| **Income** | |
|---|---|
| Donation from EE dept, CityU | HK$10,000 |
| Donation of parts Oceanway | HK$5,000 |
| | |
| **Reused or free parts** | |
| Cables, connectors | HK$2,000 |
| PIC microcontrollers | HK$500 |
| Miscellaneous components | HK$1,500 |
| Re-use from HK ROV contest | HK$2,000 |
| Total | HK$21,000 |

# Troubleshooting Techniques

Special consideration was given to the ease of repair of this unit. Quite apart from the fact that it would have to be transported half way around the world subjected to rough luggage handling and customs inspections (fast unpacking and repacking) en route, it is almost traditional for electronic/electrical/mechanical systems to fail at the exact instant they need to perform. The ROV was designed to be modular with a plug, check and then play structure to the sub-systems. By using modified off the shelf components for the power and control systems allowed a reasonable quantity of spare parts to also be produced. Other specially produced modules like NU-SENSE were produced with simple RS232C internal communication protocols. This allowed a PC with an RS232C connection to check the sensor unit and confirm it was functioning. This could be done without removing the sensor unit from the ROV.

All of the ROV sub-modules are connected to a breakout box on the ROV. This allows them to be unplugged and spare modules to be connected for testing without having to physically remove anything from the ROV. This shortens the time required to sort out faulty sub-modules from working ones.

# Future Improvements.

Everything made can undergo improvements to make it better and more adapted to the tasks it was meant for. This is true for the Penguin.

The key obvious improvement is the dream to make the Penguin autonomous and allow movement and control without the wires that connect it to the surface. This could be done using high intensity LEDs of a cyan hue or low frequency electromagnetic wave to transmit data wirelessly between the ROV and the operator. The main advantage of this would be the elimination of the drag from the umbilical.

It may be possible to further multiplex the signals to allow the control data to flow through a single conductor, possible fibre optic, with on-board power. It should be possible to provide a battery on the ROV to further cut down the size of the umbilical. Perhaps the power supplied to the ROV could be for battery charging only.

The NU-SENSE system can also be expanded to include useful features like a sonar reading distance to the sea-bed, ROV speed and possibly a location unit showing the position with reference to some reference point. There are a lot of interesting sensors that can be aged to this sub-module.

Other improvements include using a lighting source that does not impact on the surrounding environment. All of our cameras should be able to detect light spectrum outside of the visible light so it gives a less behavioural impact to the animals around.

# Lessons Learned.

There is always alot to learn from projects like this. Perhaps the main thing that this project taught all of us was how to find and sift through reference material to decide the usefulness and whether it can be adapted to suit our needs. Other things like general electronic system construction and how to successful water proof electronics and other skills that would be mastered in this project.

For the team as a whole the idea of taking a concept and literally starting from nothing physical, designing two robots at the start and then combining everything to one ROV taught everyone a lot. It was not just a matter of choosing the best part of the machine but rather figuring out how to build a robot that could perform the required tasks in a quick and efficient manner.

Finally the underlying message in this project from day one was the environment. The mentors and the key sponsors (WWF Hong Kong) created an atmosphere that made us all aware of the damage we are doing to the environment-the life support system of this planet.

# Project Significance.

This year, 2007, it is the "International Polar Year". We are designing an ROV that will operate under the ice. How cool is that? But seriously we are hearing a lot of information of climate change causing these ice covered areas to melt. It appears that the polar areas are a key indicator of the changes we are causing to the weather systems of this planet, our home. These changes will lead to the possible extinction of majestic and beautiful animals like corals, penguins and polar bears. It will also cause drastic changes in the lifestyle of important indigenous peoples like the Inuit and other regional native North American groups. These peoples have lived in harmony and sustainability with their surroundings for eons, now they are loosing their way of life through no fault of their own. Predicted climate changes will also gradually change our quality of life if we do not act sensibly and change.

Engineers have designed and built nearly all of the machines, processes and equipment that has lead to most of the environmental challengers that we face today. Engineers need to learn to start working with the environment. Interfacing to it as though it was a system, because that is what it is rather than fighting against it and taking the attitude that nature needs to be overcome. Basically, our predecessors in the engineering community have messed up the planet, it is now our job to clean it up!

This project has carried an environmental message to all of us. We are the engineers of the future and it is through such challengers, as this one offered by MATE, that we can be reached in a way that is very different from the traditional educating medium of lectures. The natural environment is different and it deserves access to different methods of communication. It is interesting to note that most of the environmental information we are currently hearing is happening outside of our course. This just increases the importance of competitions like this one.

# References

http://en.wikipedia.org/wiki/Remotely_operated_vehicle
http://www.sleddogcentral.com (Very obscure but fascinating!)
http://www.marguette.edu
http://www,wwf.org hk
http://www.ee.cityu.edu.hk/rovcontest
http://www.marinetech.org
http:// www.oceanicengineering.org
http://www.mtsociety.org

**Or you can visit our design blog/eForum**

http://penguincityu.19.forumer.com/index.php

# Reflections.

Hong Kong is a very busy place. Sometimes we forget what it is like to interface with our natural surroundings. Engineers here also spend a considerable time involved with projects that have to overcome nature. Each member was asked how this project had impacted them. Their responses are below:

***Christopher, W. L. Chan.***
This event was such a life experience that I felt glad being able to participate in it. From sketches to the final ROV, everything in the process was "priceless" and changed me not only in knowladge, but every aspect rather.

***Lionel, B. Dai.***
In this project I was touched by the many interesting sensors and tried to build them in our circuits and program them. What's more we worked together like brothers, though we are from different places.

***Allen, J. B. Ke.***
I am feeling vey glad that in this project I can learn so many things that are out of the boundary of my major. And I learned some knowledge much earlier than my classmates. The guys in the team are from different places ,with different ideas. It's cool. It's a fun to COOLRIZE solutions to our problem

***Ken, C. K. Law.***
This competition is a great life experience and it is useful for whole my life. Our teammate comes from different region with different background. In the meantime, we overcome the language, technical problem, sharing knowledge and the life experience together. We become a real group. This experience can't be learnt from book, even from work.

***Jason, B. Y. Li.***
As a student studying electronical engineering, it's my first time exposed in the mechanical world. I really learnt a lot when I design and build the manipulators.

***Hedy, S. Li.***
I have learnt that communication is very important within a team and every one must know what he should do clearly, otherwise we may do things repeatedly.

***Jeanne, J. Lin***
That's a very meaningful project I think. I am in charge of making the control system. During designing the circuit, I use what I learnt to solve the problem. I love this game.

***Richard, C. C. Tang.***
I have learnt something about how to do a project from zero as well as how to solve a problem by searching and learning something new. In addition, I have learned that how important team work is! I will remember the time our whole team spent together to complete our ROV and I really enjoyed this work.

***Brian S. Yip.***
This event has taught me to think more about the environmental protection from the engineering perspective. Engineering can do more than just generating wealth through new gadgets. It can also save us from destroying our own sweet home. This might be trivial in the whole broad scheme of knowledge I have learned throughout the project. But if all engineers are taught to put a bit more consideration of the environment in their designs, the future might not be as bad as we are predicting it to be. This is why this event is so important to me.

***Mentors***
One wonders at the irony of being involved with activities to advance the understanding of environmental issues, and the enormous carbon footprint of jetting 18 people and 3 robots halfway round the world to take part in this contest!!

Secondly, the rather indulgent use of nylon cable ties in these projects should also be questioned – they are not environmentally friendly. Maybe the next contest can ban them in lieu of hemp rope ties or similar!

## Working as a Team.

Communication is very important. This and discussion are crucial elements for the team to succeed. Division of responsibility is important and it is important to make the tasks challenging and fun. This helps adopt a work team spirit so that we can devote time to the project and our teammates. Working under stress and with different people help to train us to be efficient and cooperative. But perhaps the biggest thrill is designing something and having your friends help you build it.

One of the things that make team work and mentoring difficult is that it was tricky to find a time that we all could get together to work on the project. There was a lot of discussion needed and coordination required to build this ROV. One of the team members suggested a solution that works very well and kept us together on this project even though we were physically apart. We made use of an internet forum to swap ideas and data between us, making the times we could all get together for detailed decisions very efficient. This in turn allowed us to spend sometime as a team enjoying the amusing side of what we were doing.

## Acknowledgements

All of the CityU ROV Team would like to thank our sponsors and the people who advised us during the construction and testing of the machines we built. Without this help and the constructive critism received we would still be in the tank testing. We also would like to thank those generous people who provided the transportation money that allowed us to travel to Canada to participate in this competition.

*Organizations:*
The City University of Hong Kong.
WWF Hong Kong.
Air Canada.
Oasis Hongkong Airlines
IET Hong Kong
Oceanway Corporation
.

*Individuals:*
Mr. Alan Pun
Mr. Kenneth Ku

## Disclaimer

The details in this report are correct at the time of publication i.e. 31 May 2007. **Penguin** reserves the right to evolve.

# Appendix A – Electrical Diagrams - arm control

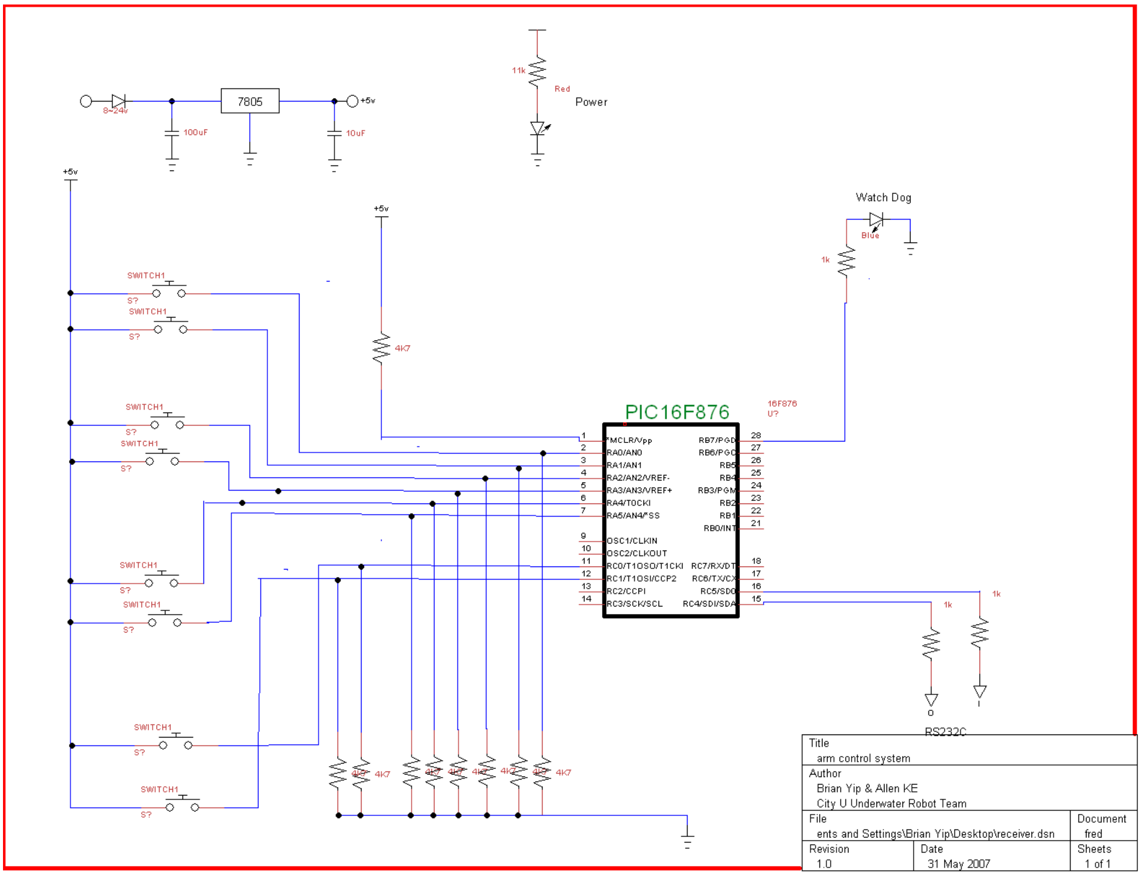



Figure A1 Servo receiver circuit

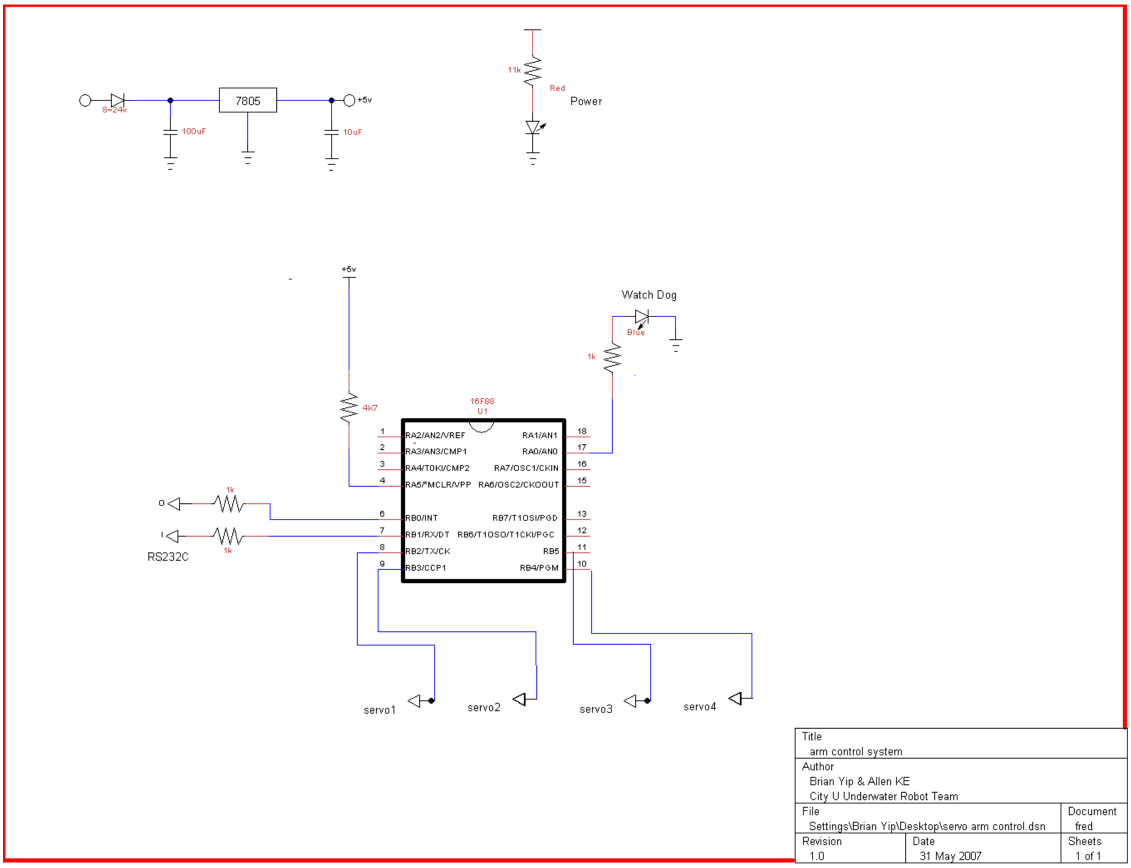
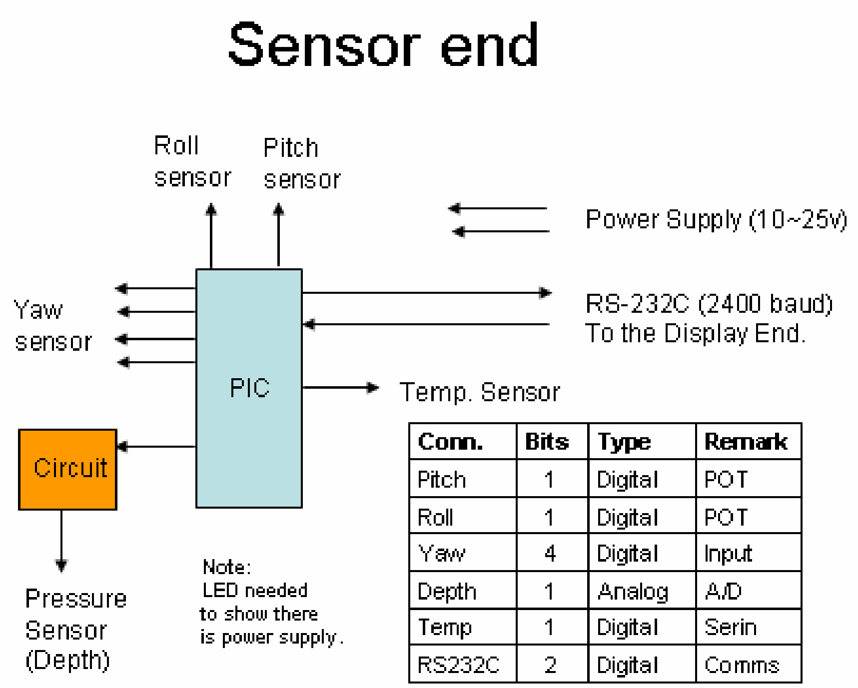
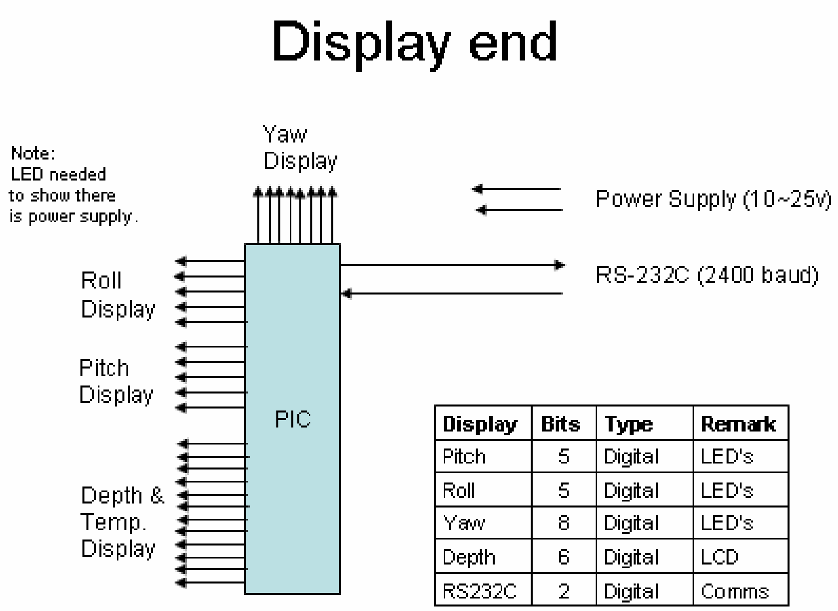



Figure A2 Servo arm control

# Appendix B - The NU-SENSE system

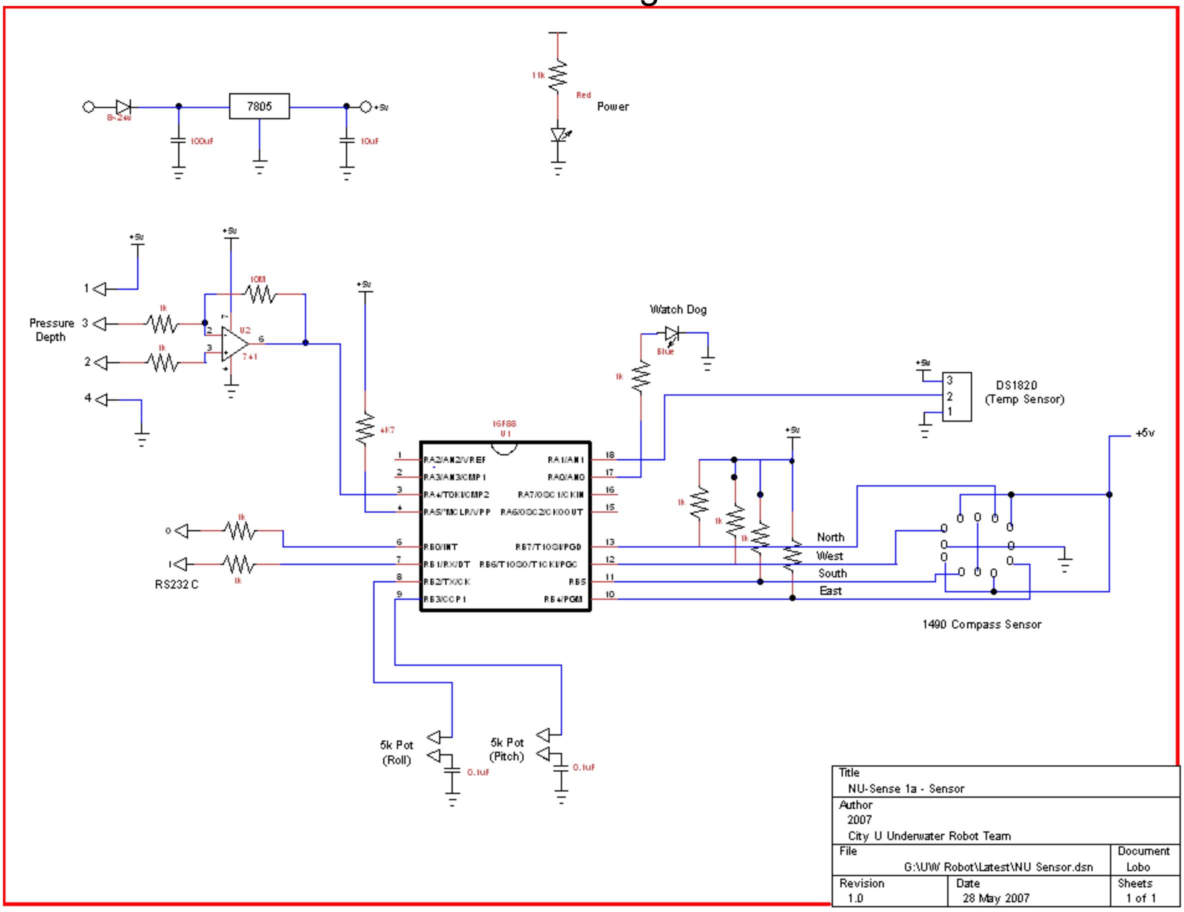


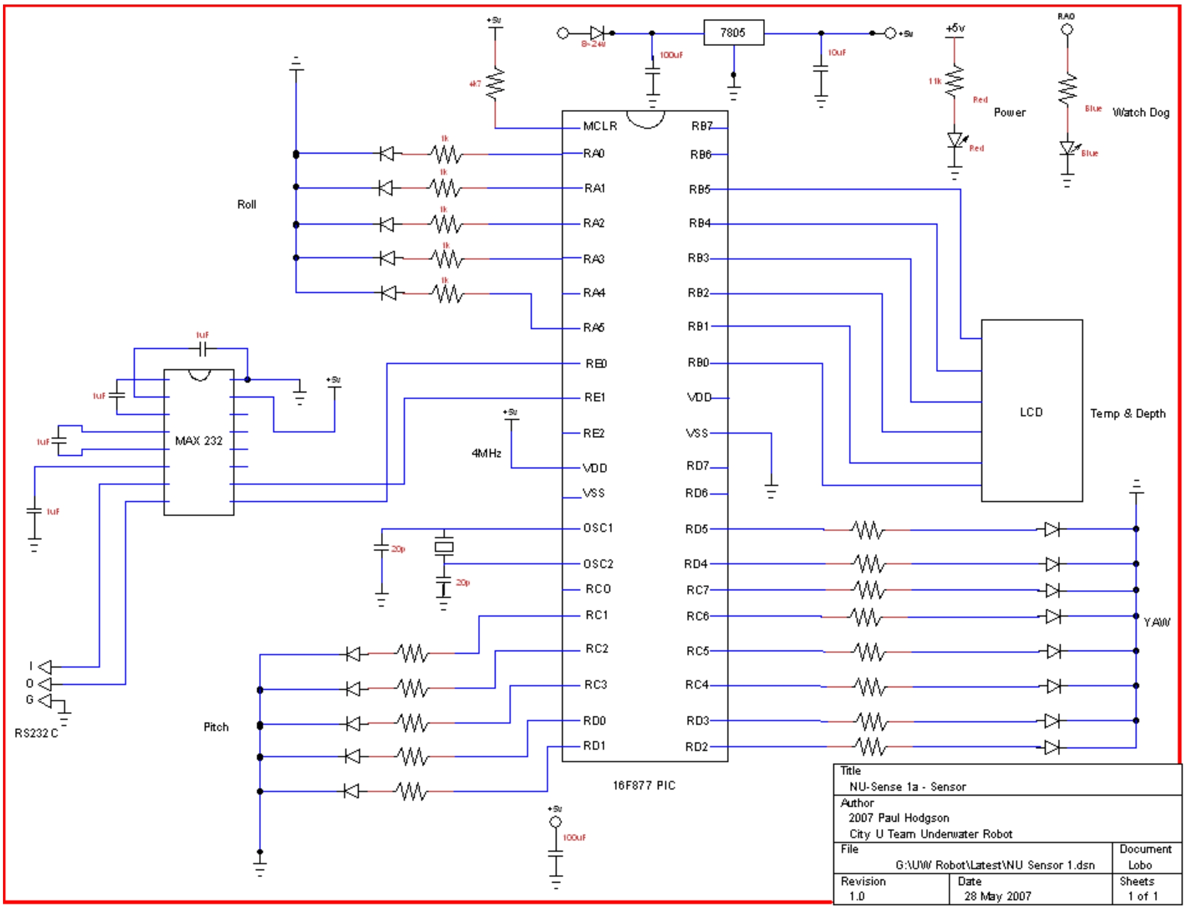

| Conn. | Bits | Type | Remark |
|---|---|---|---|
| Pitch | 1 | Digital | POT |
| Roll | 1 | Digital | POT |
| Yaw | 4 | Digital | Input |
| Depth | 1 | Analog | A/D |
| Temp | 1 | Digital | Serin |
| RS232C | 2 | Digital | Comms |




| Display | Bits | Type | Remark |
|---|---|---|---|
| Pitch | 5 | Digital | LED's |
| Roll | 5 | Digital | LED's |
| Yaw | 8 | Digital | LED's |
| Depth | 6 | Digital | LCD |
| RS232C | 2 | Digital | Comms |

# Circuit diagrams



# Appendix D – Photographs