TECHNICAL REPORT
KAPI`OLANI COMMUNITY COLLEGE
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Honolulu, HI
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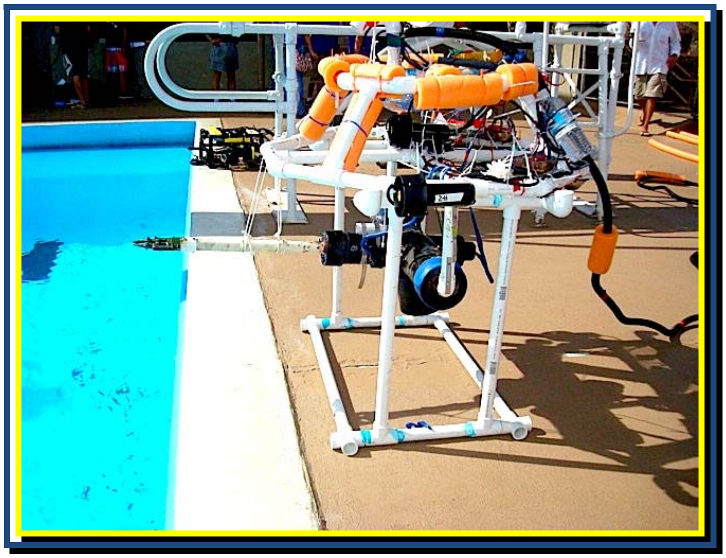
Team LIMAWAI

Presents



Da Octagon

WRITTEN FOR: **2009 MATE** International ROV Competition
May 27, 2009

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Abstract

KCC's Limawai Team built the UROV, *Da Octagon,* to complete the 2009 International MATE Competition. It was constructed over the course of the 2008-09 Spring Semester. The frame is octagonal in shape, and is constructed out of 1" PVC piping. *Da Octagon* is controlled by a digital system (via joysticks, micro-controllers, and motor drivers). This UROV has a total of three cameras placed around the UROV to give maximum visibility.

There are a total of five thrusters to maneuver the UROV, and two motors to maneuver the manipulator. The placement of the thrusters allows for optimum movement and motion. *Da Octagon* is capable of moving forward, backward, up, down, rotating in place with clockwise (CW) and counterclockwise (CCW) motion, laterally left/right, and can also tilt forward/backward.

The construction budget for this UROV was approximately $5,400.

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Design Rationale

In past semesters, the primary goal was to examine and document growth patterns of various species of algae in Maunalua Bay, HI where invasive alien algae is harvested. The UROV was designed with a "tower" shape (figure 1) that provided rigid, upright buoyancy. The "sled" legs on the bottom held the bilge pump motors, and also allowed the UROV to sit on the ocean floor while maintaining visibility, and without disturbing the algae. This design had a total of six motors (bilge pumps) that allowed for forward, backward, upward, and downward movements

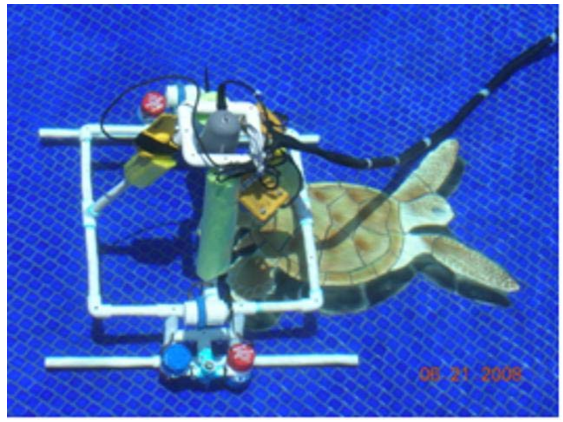

Fig 1: Old Frame Design

Changes in the design were necessary in order to compete in the MATE Competition. An articulating arm was needed in order to open and close hatches and grab various objects; motor placement that would allow for optimum maneuverability; camera placement that gives maximum visibility; and a digital system of controllers that allows for maximum driving efficiency.

Changes were made to the circuit designs to accommodate for the 48V, 40A source that would be given, as well as any logic circuit that will be needed to create an efficient digital design.

Structural Frame

The frame is made out of 1 inch PVC piping, and is octagonal in shape. There are two layers of this design, with the top layer being smaller in diameter. This "two tier" design focuses center of mass and buoyancy towards the top and keeps the UROV upright and rigid. The symmetrical shape also accommodates maneuverability when moving forward, backward, and spinning in place.

To avoid disrupting buoyancy, several holes were drilled throughout the frame to allow water to flow freely through it. To maintain upright rigid buoyancy, flotation devices were attached to the frame.

The smallest possible diameter and positively buoyant tether is best for the weight and size of the UROV. To achieve positive buoyancy, cut-up sections of pool noodles were attached at approximately 4.88 meters from the UROV and every 1.5 meters thereafter. This allows the tether to swim freely rather than 'pulling' on the vehicle while the UROV is conducting operations at full depth of the competition.

A spring loaded attachment was designed for the mating mechanism, so that it can also open the hand wheel hatch. There are two spring loaded shafts that protrude from the mating port. The shafts are spring-lowered in between the handles of the hand wheel, and then the entire UROV Is rotated to move the hatch to an open/close position. The shafts depress on themselves when the UROV docks with the male mating port on the "sub", allowing the ports to connect without hindrance.

For visibility, three cameras are used; two Sea Viewer cameras that have fish-eye lenses; and one modified internet camera. The fish-eye lens cameras give a wide view and clarity. One of these will be placed on top of the UROV overlooking the front end. The other Sea Viewer camera is located directly on the arm so that it maximizes visibility when articulating the manipulator. The third camera is placed inside of the mating port to properly align the male and female parts of the mating mechanism.

Propulsion

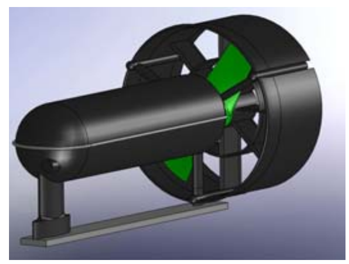

Fig 2: Thruster

The previous design was to use modified bilge pumps retrofitted with propellers. While this worked well for the prototype, the project needed motors with more torque, as the UROV will be larger and denser than previous designs. 5 SeaBotix UROV thrusters were purchased that are rated for 154.2 meters depth. The layout of motor placement, as well as their resulting motions is as follows:

- 2 motors on the right and left side of the bottom level
  (Forward/Backward, & Spin CW/CCW motions)
- 2 motors on the front and back of the upper level
  (Upward/Downward, & Tilt Forward/Backward motions)
- 1 motor located at the center of the bottom level
  (Lateral Right/Left motion)

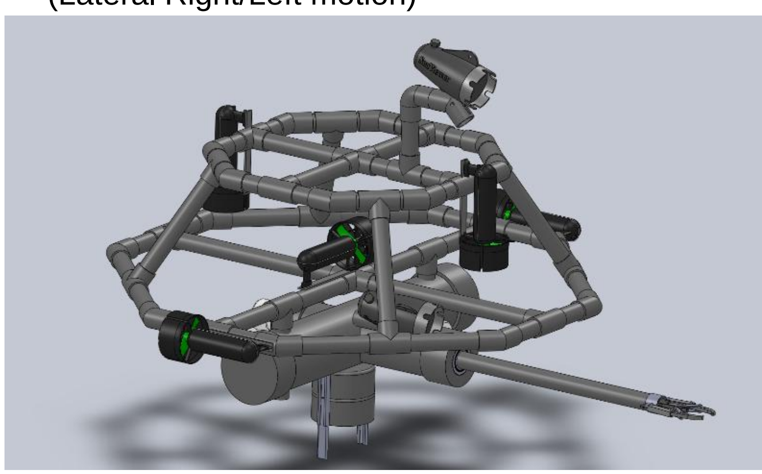

Fig 3: Frame with motor placement

Each thruster was attached on the UROV by using an aluminum plate that bolts onto the frame. This was designed to stay in place and allow for easy replacement of the thrusters.

Manipulator

The "manipulator", or arm, is the most complex and intricate system of the project. The arm accomplishes most of the tasks in this competition. A lot of time and effort was put into it.

Initially, waterproof motors were tested to eliminate the need of waterproofing the entire structure of the arm. However, this proved ineffective, as the waterproof motors did not have enough torque to manipulate, and articulate each movement efficiently. After much research, DC Brushless motors were found to be the solution, as they have a very high torque, and they are "splash-proof". Needless to say, the structural design for the manipulator will have to be waterproof.

The original design included three motions: "Elbow" (bending), "forearm" (rotation), "claw" (grabbing). Bearings were used to minimize friction, which allows smoother rotation. However, after many hours of testing, the UROV was found to have such great maneuverability, the "Elbow" movement was eliminated. Instead, the arm is fixed at a forward position.

The placement of the arm on the UROV will be located at the bottom level, and concentrated at the center of mass. This means that the center of mass on the arm itself (namely the motors) will need to be located at its rear. Two shafts and a drive belt were used to accomplish the needed movements.

Manipulator: Claw

The first subsystem of the manipulator is the claw. It will need to be able to "grab" various objects, namely the PODs, and the air ventilation line. A bearing puller was purchased and modified to specifications (figures 4 & 5) from ToolTopia.com. Modified specs are as follows

- 1 ton capacity
- Reversible jaws
- Maximum reach: 22.2cm
- Maximum spread: 24.1
- Jaw thickness: .9cm
- Heat treated quality steel.

Fig 4: Bearing Loader

This "claw" is attached at the front of the arm, protruding 68cm outward. The claw opens and closes when the threaded rod is screwed in and out of the center shaft. The motor is located at the opposite end of the arm. As such, an aluminum rod was connected from the threaded screw to the motor. Precision issues arose during alignment of the claw screw/shaft and the motor which created a "wobble" effect, putting extra stress on the motor. To compensate, a flex shaft added to the rod eliminated the "wobble".

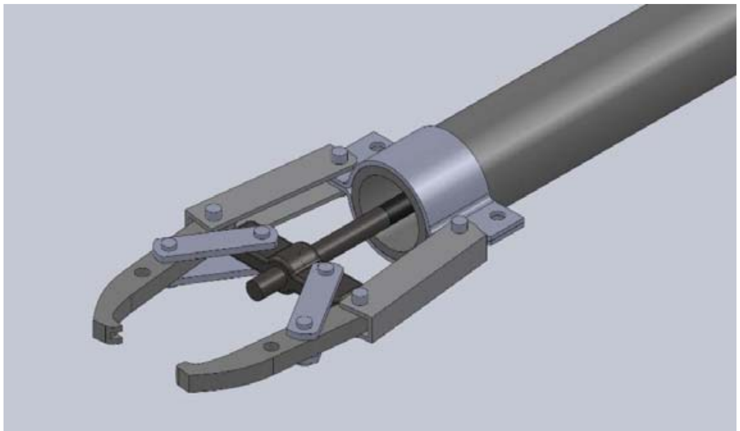

Fig 5: Completed Claw

Manipulator: Forearm

This rotating forearm is constructed of 1" PVC piping. It is attached to the arm via a bearing, which gives smooth rotation. Several designs were considered of how to link the motor to this forearm by differential gears, welding, precision gears, housings, etc. A drive belt will be used for the final design. It's easy to implement, has less slippage, and worked beyond expectation during testing.

To ensure waterproofing of the motors several precautionary steps were taken. First, every cap is sealed with a rubberized sealant. This will keep the water out from the caps, but not the bearings. The motor sections are compartmented, and packed with Lithium grease. This way, water will be trapped away from the motors.

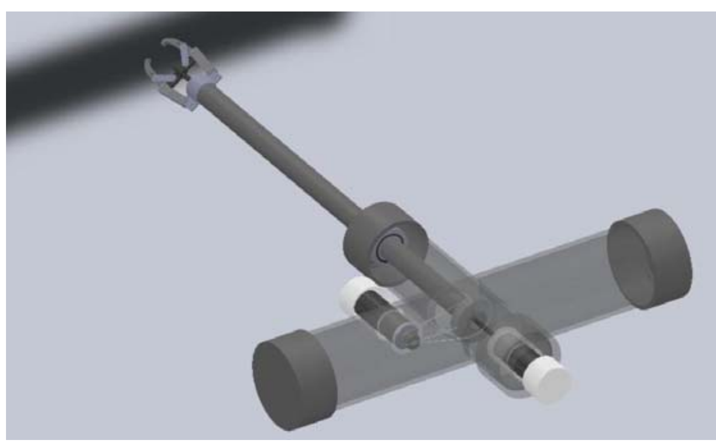

Fig 6: Completed Arm

Because the claw is directly connected to the forearm, and the forearm is separate from the rod that opens/closes the claw, when the forearm rotated in either direction the claw would open/close by itself. This would mean that when the driver of the arm wants to rotate the arm, counter rotation of the claw needed to take place. To fix this problem, advanced programming was required. Please refer to the Programming section for details.

Bottom-side Power and Control System

A DC-DC converter was required for the entire electrical system, which runs on 24V DC. Each component receives its respective power supply from the converter. The 10 gauge power and ground line supply seven motor drivers with over 450 watts of continuous power. This line provides 24 Volts with a maximum current draw of 28 Amps

The wiring directly on the UROV, while easy to implement, is the source of most major problems. Water is prone to get into and short circuit any electrical connections you hope to have. This problem was solved by eliminating the need for a waterproof housing for our circuit components. Instead, epoxy molds were created that literally waterproof each individual component. First, one-foot connection leads were soldered on to all points needed on the motor-driver circuits. Then, the stock heat sinks were retrofitted with tall-channeled aluminum heat sinks. Once the circuit was tested and approved by the programmer, a balsa-foam mold for the circuit was built. Finally, the motor-driver circuit was inserted into the mold and epoxy was poured around the entire circuit while allowing the heat sinks to protrude out of the epoxy. The heat sinks are directly in contact with the water which allow for maximum heat dissipation and in turn allow for maximum power output without having motor driver failure.

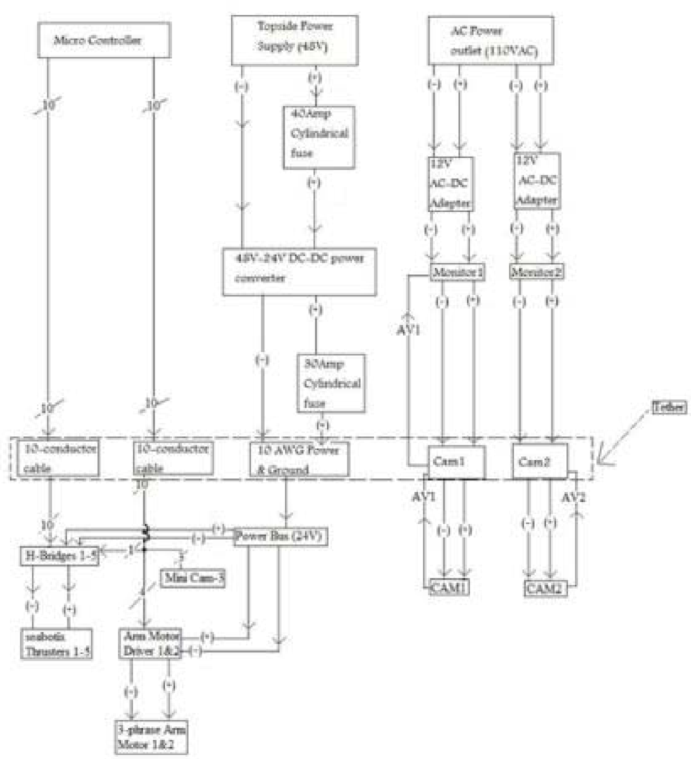

Fig 7: Schematic Representation of entire power and control systems

Topside Control Systems

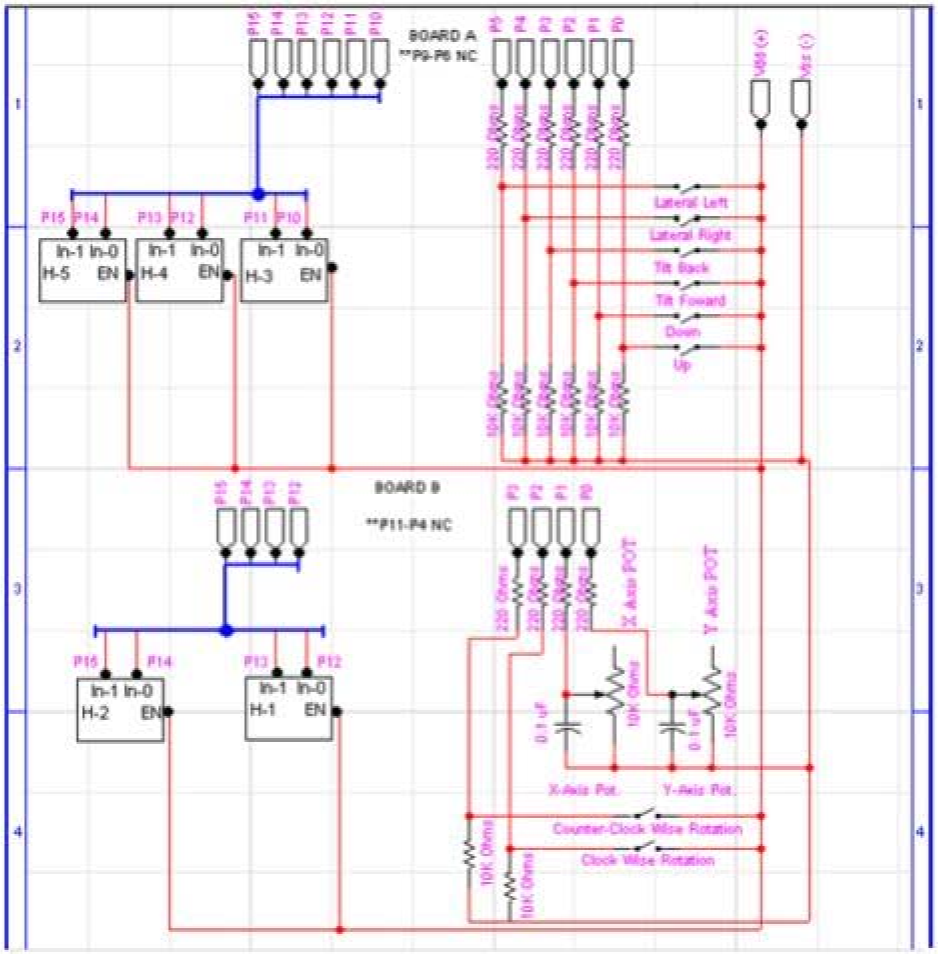

Fig 8: Schematic for micro-controllers to motor drivers

The digital controls for the electrical system are controlled by BASIC STAMP micro-controller boards. Momentary switches only input 0 or 1 (0V or 5V) when using digital controls. Therefore, the most useful programming statements are IF/THEN statements, as they revolve around TRUE/FALSE statements. Potentiometers were used to control motor speed and direction. Potentiometer or "pots" are dials with variable resistance. By turning the dial in different directions the resistance value will either increase or decrease. The STAMPS used had the capabilities to measure RC time; a capacitor was then wired in parallel with the POT. The system was programmed to put logic 1(5V) and logic 0 (0V) through it, pause for 10 nanoseconds and measure RC time. Again, because the pot had different resistances at different positions, the RC time would also be different with each position. Within the program RC time was scaled to a range that would be easier to work with; 0 – 100 for example.

A duty cycle was implemented using the potentiometer readings. If for example, the UROV were to move with 50% thrust capacity it was programmed such that (after scaling) when the POT was at 50 the signal to the motor would be on for 50 nanoseconds, and off for 50 nanoseconds. This would mimic 50%

full thrust capacity. The same would also hold true for any percentage of thrust capacity.

The whole purpose of using POTs, besides variable resistance and duty cycles, was to implement a joystick to control the UROV, which is controlled by potentiometers. The joystick had 2 potentiometers, and 4 momentary switches. Four more switches were needed and installed in convenient locations on the joystick frame. Five motors that controlled the following motions/movements are as follows:

- Forward/Backward/Turning (Motors 1 and 2, located on the Left and Right side of the UROV)
- Spin in place (Using the same 1 and 2 motors)
- Up/Down (Motors 4 and 5, located at the front and back of the UROV)
- Tilt (Forward/Backward) (Using the same 4 and 5 motors)
- Lateral (Side – To – Side) (Motor 3, located directly center of the UROV)

The Forward/Backward movements were controlled with two potentiometers, in an X and Y axis format. Control of the Forward/Backward/Turning would then be most efficient and effective for the pilot of the UROV. The X and Y axis are limited in range to a circle shape to allow the use of Pythagorean Theorem. Using quadrants, it can control the motor duty cycle, and also their respective direction. For example, if the joystick were to be pushed in the "first quadrant" (forward and right motion), the program will use Pythagorean Theorem to take the magnitude of both X and y axis, and use it for the dominant motor; in this case the left motor because this motor will work harder for forward and right movement. The recessive motor will be the resulting magnitude minus the distance of the X axis to the origin. Meaning, the closer the X coordinate is to the axis, the stronger the recessive motor's duty cycle will be. If the driver pushes the joystick directly forward, the UROV's forward thrusters will then operate at the same output. This puts the X coordinate very close to the origin, if not directly on it, and that duty cycle will be at maximum capacity. The same can be said for the dominant motor. If the X coordinate were to be zero, than both duty cycles will be the same. The following is a diagram representation:

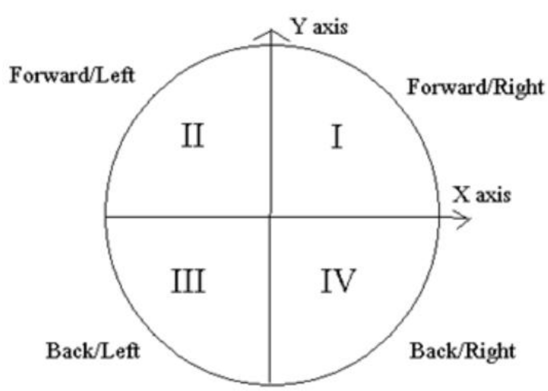

Fig 9: Joystick (Digital Representation)

There are patterns that develop for each movement. For instance, quadrants I and II will have both motors going in the same direction, just with different Duty Cycles. For I, left motor will be ON for a longer duration than the right motor. For II, the right motor will be ON for a longer duration during the Duty Cycle than the left motor.

To go straight up, it is programmed to one of the momentary switches on the joystick. If the driver pushes the button corresponding to UP movement, the program sends the respective signals to the UP/DOWN motors. The same can be said for all other movements: Tilt (Forward/Backward), Spin (Clockwise/Counterclockwise), and Lateral (Side-To-Side).

The use of Parallax Microcontrollers, allow *Da Octagon* to be programmed in pool side, if need be. During practice (and the regional competition) if the driver needs the UROV to move faster (for example), the Duty Cycle can be scaled and re-programmed to the micro-controller in a matter of seconds. Anything that the driver needs to be changed with programming can be done instantly.

The motor driver for the arm motors (two motors total) used open collector inputs. This means that instead of the usual 0V or 5V, it took in 0V or disconnected. The first logical step to take was to wire momentary switches directly to ground and each respective input. However, the controls were rather strange. There were two “buttons” essentially - one for direction (disconnected) for Clockwise rotation of motor, and 0V for Counterclockwise; a strange orientation to control as the operations. A logic circuit was designed to make the two push buttons to be for either direction instead. For mechanical reasons (which was addressed in the Manipulator: Arm section), when one particular motor turned on (in either direction) another motor needed to move in the opposite direction, or the arm would not function. This required a different logic circuit for the second motor, as it was directly dependent on the first motor. Suffice to say, at this point programming was more time efficient than creating a logic circuit. A program was written that will do all of the above mentioned requirements. The motor driver required open-collector inputs. A simple open collector NOT gate from the micro-controller was used to accommodate the Active-Low inputs of the motor driver circuit.

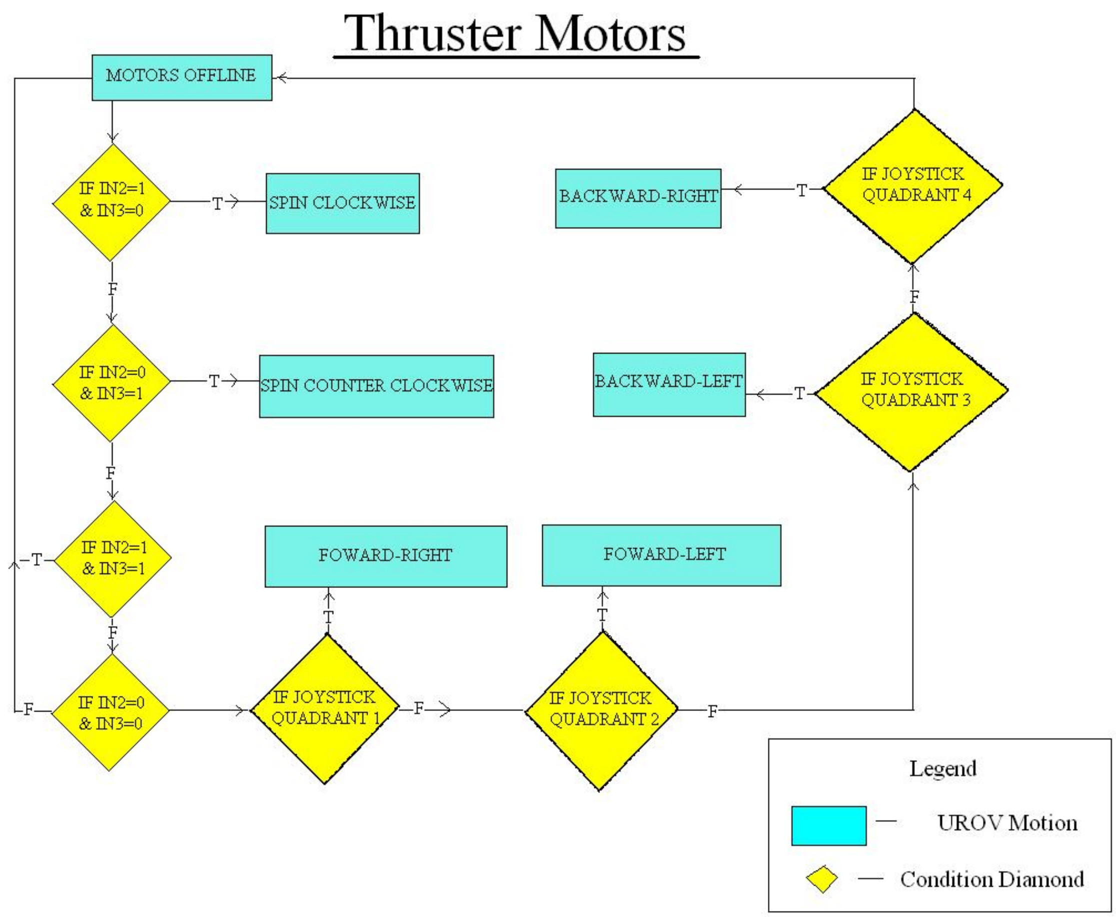

Fig 10: Software Flow Chart A

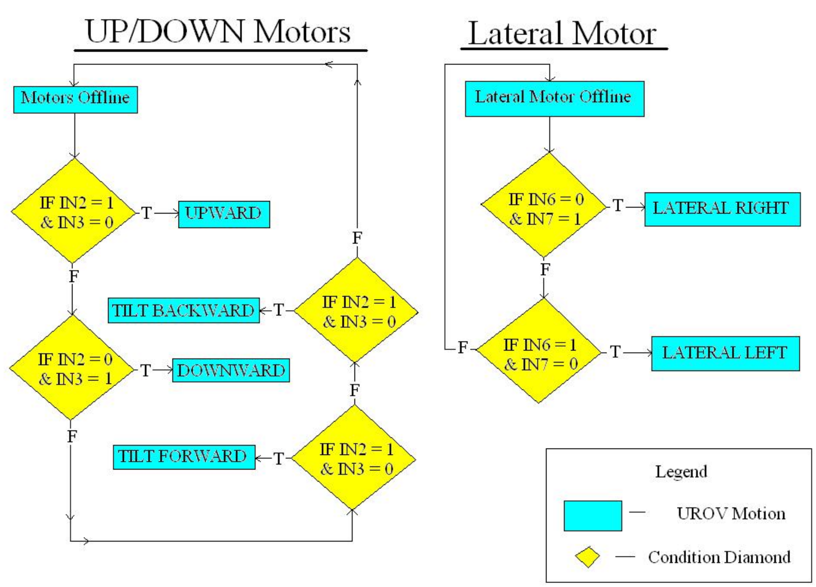

Fig 11: Software Flow Chart B

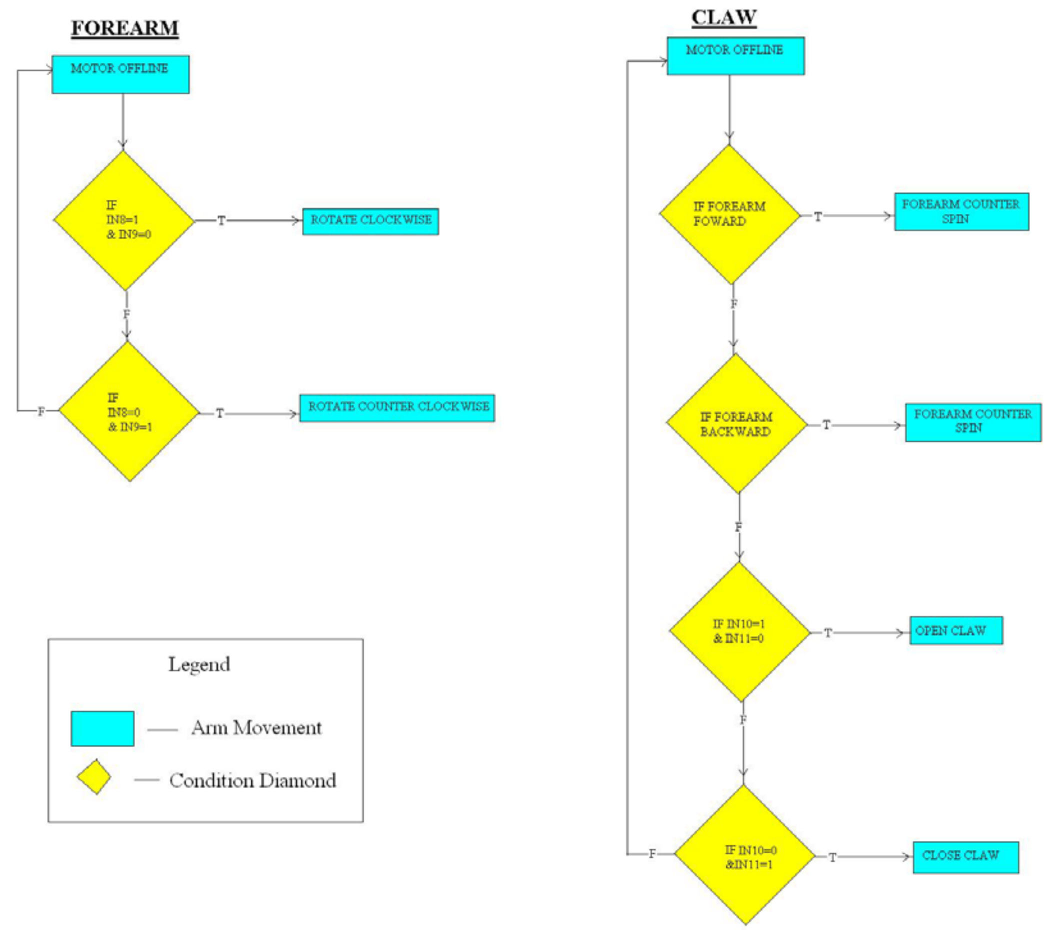

Fig 12: Software Flow Chart C

Tether

The tether is the most important part of the UROV for two main reasons: it connects control to the vehicle and determines the maneuverability of the vehicle. The tether contains 24 meters of 25-conductor cable for all signal wires, 24 meters of ten-gauge power and ground line, and 24 meters of two video cables. Unfortunately, the 25-conductor cable and power cables never came in and we have not received any notice from the manufacturer nor will they respond to our calls or emails. A local electronics store sold 10-conductor cable and could be doubled up to form 20 conductors. There was a definite gain in tether size and a loss in conductors. The loss in conductors turned out to be acceptable with the recent change in mechanical engineering of the arm (which only required two motors as opposed to three). The signal wires reduced from 21 to only 17, allowing the use of the remaining three conductors for one extra camera used inside of the mating mechanism.

Description of a Challenge

Our decision to epoxy our motor drivers, while a good idea, needed further thought. After several hours of testing we found that several of our motors were getting weaker and weaker. However, out of the water all motors worked flawlessly.

Troubleshooting Techniques

The first thing we did was to check all electrical connections. We thought that there might have been chaffing on the power lines and water got inside, but careful inspection revealed that this did not happen. All wires were safe and dry in their insulation.

The next thing checked was the programming. Perhaps there was an error in the program that created a weaker duty cycle where it wasn't supposed to be. After careful inspection of the program, we found it to be flawless. The program was free of syntax, logic, or other errors with the control system.

The source of the power loss was found by detailed visual inspection of the motor drivers. We discovered two things: A large build up of solidified chlorine, and corroding steel screws. The screws were going through the motor drivers, and connecting to the chassis of the motor drivers. Here's what was giving power loss:

The screws going through the epoxy of the motor drivers were grounding to the chassis while the heat sinks were showing potentials on a Digital Multi-Meter. The screws were close enough to the heat sinks and began to go through oxidation. As they oxidized chlorine molecules built up on the heat sinks. In a sense, we inadvertently created a battery. So the steel screws corroded, mixed with chlorine, and "plated" the aluminum heat sinks.

We solved this problem fairly easily. We pulled the screws out from the motor drivers and applied a light coat of epoxy on the heat sinks and filled the holes that were once created to fit the screws with epoxy. A light coat would ensure that heat can dissipate into the water without giving off a charge as well. The motor drivers were simply strapped in place instead of screwing them down.

Lessons Learned

We all learned a lot from being a part of this project. We learned that theoretical design and physical implementation of your design rarely transfers over smoothly. We learned how to calmly analyze the situation when something goes wrong, and troubleshoot accordingly. We also learned the benefits of creating a solid design early on, as procurement takes a lot of time. Due to all the technical write-ups, presentations, and discussions we've had about this project we also learned how to quickly and concisely deliver information in a professional manner.

Although this was a very challenging and time consuming project, we all feel that we will become better engineers because of it. It was an experience none of us will ever forget, and the lessons we've learned we will use for the rest of our lives.

Future Improvements

Due to time constraints, we didn't really get a chance to build everything exactly as we designed it. We originally wanted all mechanical devices for the arm to be easily removed as needed. This meant a design that did not include rubberized sealant, as that is a semi-permanent fixture. It would have been nice to be able to remove each motor, the drive belt, and drive shaft with ease. A change in design on our part meant the taking apart of the whole arm system and putting it back together, which was not efficient on time and materials.

After some testing it was realized that our final product was a little large. In terms of logistics, this made it a little harder for us, as we needed to build a large crate in order to ship it.

We also were undermanned. A larger team would have ensured that everyone was doing their part, rather than stopping what their doing to assist someone else. Along with that, a Systems Engineer or Project Manager would have helped us greatly.

Secure Private Funding. As stated earlier, procurement is a headache. If we had some funds on hand we would have been able to get parts and materials a lot faster.

Acknowledgments

Team LIMAWAI would like to thank the KCC Science, Technology, Engineering and Mathematics (STEM) program staff (Keala and Keolani) for helping with purchasing and requisitions of the UROV parts and endless paperwork, and to the National Science Foundation (NSF) for providing the KCC STEM program with funds to support undergraduate research and hence the UROV program. We would like to thank our mentor Herve Collin for staying late at the lab and for the endless trip to the local hardware store, and Dr. Rand for the use for his pool for late night (early morning) test sessions.

SeaBotix
Mark Rognstad
ToolTopia.com
Sea Viewer
Anaheim Automation
RobotPower.com
City Mill
IC Supply
Hobbietat
McMaster-Carr
Parallax
Car Quest
Granger
Industrial Electronics
Fiber Glass Hawaii

Appendix:
KCC UROV Budget 2009

Contributions to KCC Team LIMAWAI	
Source	**Amount**
National Science Foundation	$5,000.00
Total Amount Contributed	***$5,000.00***

Table 1: Total Contributions to Team LIMAWAI

Kapiolani Community College Team LIMAWAI UROV Expenses 2009				
Supply Expenses				
Item	**Quantity**	**Unit Cost ($US)**	**Donations ($US)**	**Total Product Expense($US)**
1 inch PVC Piping	40 Feet	$1.10		$44.00
1 inch PVC Tees	18	$1.25		$22.50
1 inch PVC Crosses	2	$5.00		$10.00
1 inch PVC 45 Degree Elbows	16	$1.25		$20.00
Channeled Aluminum(4ft Bar)	1	$5.00		$5.00
4:1 Epoxy Resin (16 oz. Can)	2	$18.00		$36.00
4:1 Epoxy Hardener (8 oz. Can)	2	$8.00		$16.00
100 Pack Plastic Zip Ties	2	$4.00		$8.00
Electrical Tape (3/4in x 60ft Roll)	8	$2.00		$16.00
H-Bridge	7	$79.99		$559.93
Commercial UROV Thruster	5	$395.00		$1,975.00
Underwater Camera	1	$615.00		$615.00
Complete Underwater Video System	1	$815.00		$815.00
Marine Grade Lithium Grease(14 oz. Can)	30	$2.75		$113.29
3-Phase Motor	4	$61.20		$244.80
Motor Driver	4	$84.00		$336.00
Electrical Sheathing	80 Feet	$0.50		$40.00
10-Conductor Cable	80 Feet	$1.00		$80.00
Protoboard	3	$6.95		$20.85
Resistors	25	$0.10		$2.50
Capacitors	3	$0.15		$0.60
24 AWG Wire (100ft Roll)	3	$7.95		$23.85
14 AWG Wire (25ft Roll)	1	$10.95		$10.95
Open-Collector NOT Gate	10	$0.50		$5.00
48-24V DC to DC Converter	1	$187.50		$187.50
Stranded 10 AWG Wire (Red)	100 Feet	$0.37		$37.00
Stranded 10 AWG Wire (Green)	100 Feet	$0.37		$37.00
1:8 Powerbus	1	$44.00		$44.00
40A,125VDC,250VAC Fuse	1	$5.80		$5.80
Water Bottle (Recycled)	4	$0.00		$0.00
Video Monitor	1	$100.00	$100.00	$0.00
Waterproofed Camera	1	$50.00	$50.00	$0.00
Total Project Expense:				*$5,331.57*

Table 2: Total Project Expense