Kapi‘olani Community College
Team Limawai
Ka`imiolakai ROV

Technical Report for the 2010 MATE
International UROV Competition

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Abstract

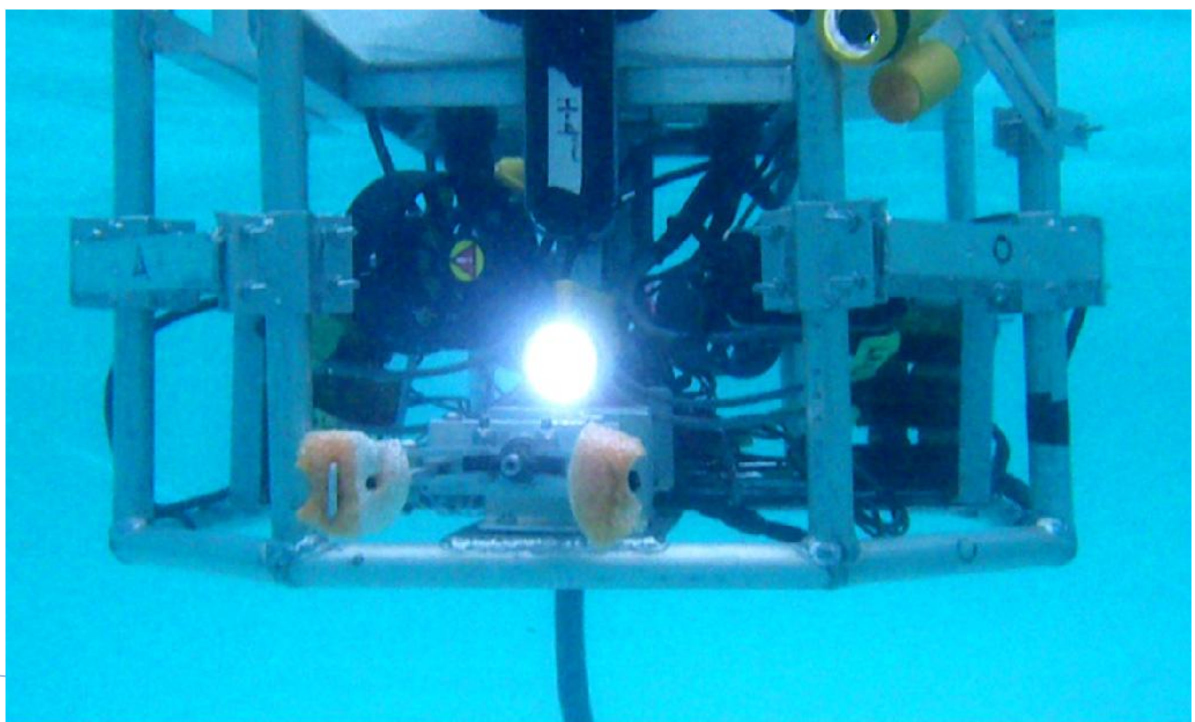
Kapi`olani Community College's Team Limawai designed and fabricated the Remotely Operated Vehicle (ROV) *Ka`imiolakai (The Sea Life Seeker)* for the 2010 MATE International ROV Competition. By repairing a geo-observatory, taking sensor readings, and collecting samples of organisms,the ROV will conduct a simulated undersea repair and geologic mission near Lō`ihi seamount, an active undersea volcano. Built with a budget of approximately the ROV features an aluminum frame measuring 60cm long x 50cm wide x 35cm, a mass of 16kg, and a flow-through design. Polystyrene ballast located on the top tier of the frame provides stability and is shaped to provide neutral buoyancy. Two payload tools, a manipulator arm for object acquisition and crustacean retrieval, and a collection tool with a cutting edge for microbial mat sampling are included on the chassis' front side. Also incorporated to the chassis are six 24V Seabotix thrusters, individually sealed motor driver circuits, a sealed powerbus, and a sealed container housing a PIC micro-controller. Major design focuses were electrical redundancy and implementing line replacement unit (LRU) components. The tether, PIC, and six thruster assemblies use removable SureSeal underwater connections for LRU design to expediently replace components that may break during the competition. The full electrical system allows the pilot ease of control in performing mission tasks and using mission time efficiently. Team Limawai learned the importance of consistent communication within the group to competently and creatively address issues that arise in integrating systems to construct a full ROV system.

Figure 1: Ka`imiolakai descends into the Hawaiian waters.

Kapiʻolani Community College

Team Limawai

Table of Contents



Design Rationale

Task #1

Aside from data retrieval, our UROV is capable of light repair tasks making our ROV a multi-functional vessel. As a repair vessel, we are required to restore power to the Hawaii Undersea Geological Observatory (HUGO). Located next to HUGO, there is an underwater elevator holding a high-rate hydrophone (HRH-attached by two J-bolt pins) and a power cable. We are assigned to manipulate these objects.

The manipulator on the ROV is powered by a brushed DC Rule brand bilge pump for its submersible design. The motor itself does not have any locking mechanism; therefore we chose our manipulator to utilize a “bearing loader” design for its ability to hold the majority of force applied without relying on the motor as a brake. Fabricated by our mechanical team to grip each pin with more than two Newtons of force, the manipulator will extract each pin to release the HRH. We will then use the manipulator to acquire the HRH, while utilizing our on-board hydrophone to accurately locate an audible sinusoidal signal projected from one of three “rumbling” stations.

To analyze this signal the hydrophone is connected to an individual signal line wired directly to the shoreline computer head phone jack. We decided to sacrifice one auxiliary signal wire in our tether via the Ethernet cable to save on-board microcontroller processing power. Since, our graphical user interface displays our audio spectrum with built a in Fourier Transform function, we decided there was no need to waste processing power and the cumbersome task of hardware coding in C based programming language. We utilized the expedition of C# coding language and the processing power of our shoreline computer to constantly sample at over 6000 times per second for real-time data. The real-time data allows the pilot to check the temperature of each vent quickly to decrease overall mission time. After setting the HRH into its appropriate location using the onboard hydrophone, we then maneuver to HUGO and remove the power port cap with the ability of our manipulator. After removing the power port cap we move back to the elevator-stationed power cable and retrieve it with our multi-purpose manipulator. Our ROV, with use of its carefully tuned duty-cycled thrusters, will position the power cable (held by the manipulator) into HUGO’s relatively small power port with accuracy, successfully completing task one.

Task #2

Transforming into fully-functional data retrieval vessel, the UROV will now use its invaluable ability to see in the darkness of a small brittle cave sensitive to damage and retrieve delicate crustaceans after traveling past a 90-

degree turn to the back wall. The compact 60cm X 50cm X 35cm ROV will swiftly maneuver around the turn with help of the six strategically placed thrusters and custom dark-detecting LED banks to illuminate the cave upon entrance for the pilot's visibility to safely preserve one of nature's beautiful seamounts.

The improved thruster placement was chosen to give the pilot 4-degrees of freedom orientated as such: 4-lateral thrusters placed on each corner of the ROV at 45-degree angles and two center line vertically placed thrusters. This configuration gives the pilot a wide variety of motion including translational, lateral, spinning, up and down, and pitch control. The thrusters are controlled by an XBOX 360 controller, with a combination of 14 momentary switches and six potentiometers that can be reconfigured to a different pilot's intuitive button reactions.

When the ROV has safely made its journey to the back wall of the cave it will then turn on its powerful 1100GPH, bilge pump driven, crustacean extractor. The ultra-bright LED banks illuminate the back wall giving the pilot an extremely well-lit area to find the correct crustaceans to extract. The suction mechanism was chosen so that the UROV does not risk damaging the fragile cave back wall or even worse risk killing a valuable crustacean specimen with the force of the strong manipulator.

Once, the three crustacean samples have been safely pulled into the ROV's vacuum they will drift effortlessly into an on-board holding tank for their protected journey before returning to the competition officials on shore.

Task #3

While the crustaceans are making themselves comfortable in their temporary home they will experience the ride of a lifetime. As the ROV departs the cave, it will then make easy headway with all four lateral thrusters at 100% duty-cycle giving approximately one extra thrust magnitude greater than last years forward moving thruster configuration. The new thruster configuration expediently moves the ROV through the water to other tasks saving valuable mission time.

The new destination: a hydrothermal venting site where the precisely accurate thermistor probe will measure three hydrothermal vents ascending a vast chimney created by undersea volcanic activity. The thermistor is soldered to a thick rubber insulated wire in a rigid steel tube so that it does not hang or get in the way of objects or obstructions.

Temperature data measurements are required by MATE to be within a five centigrade precision threshold of the predetermined temperature values at each vent spire. The high precision thermal threshold of our thermistor will allow the pilot to take the most accurate and precise temperature readings of +/- 0.02 centigrade within the competition's given threshold. Graphing the temperature and depth comparison through the graphical user interface allows the pilot to view and present the charted data without impairing the pilot's ability to control the ROV. Our pressure sensor will verify that the given depth by the mission coordinators was measured correctly. Once the data is verified, the ROV will then descend to the base of the chimney to carefully collect a vent spire sample using our manipulator to extract the sample until it is in the ROV's control.

Task #4

Now that the vent spire is within the UROV's control the pilot will maneuver to an absolutely amazing undersea arena rich in sulfur and iron oxide and home to many microbes, piquing the interest of many scientists on the island O'ahu. Our vessel will utilize its spring loaded piston design to extract a specific volume of a microbial mat sample. This sample will then be under the UROV's control along with the crustaceans and vent spire to safely return to the surface dismounting its samples for scientists to analyze, successfully completing our mission.

Once shore side, an ROV technician will carefully unscrew the holding tank releasing the crustacean specimen to the competition officials and detach the predetermined volumetric agar collector. The predetermined minimizes mission time by having the exact amount of agar ready for the competition officials to check off.

Figure 2: The "claw" moves into position to grasp the pin.

UROV Components

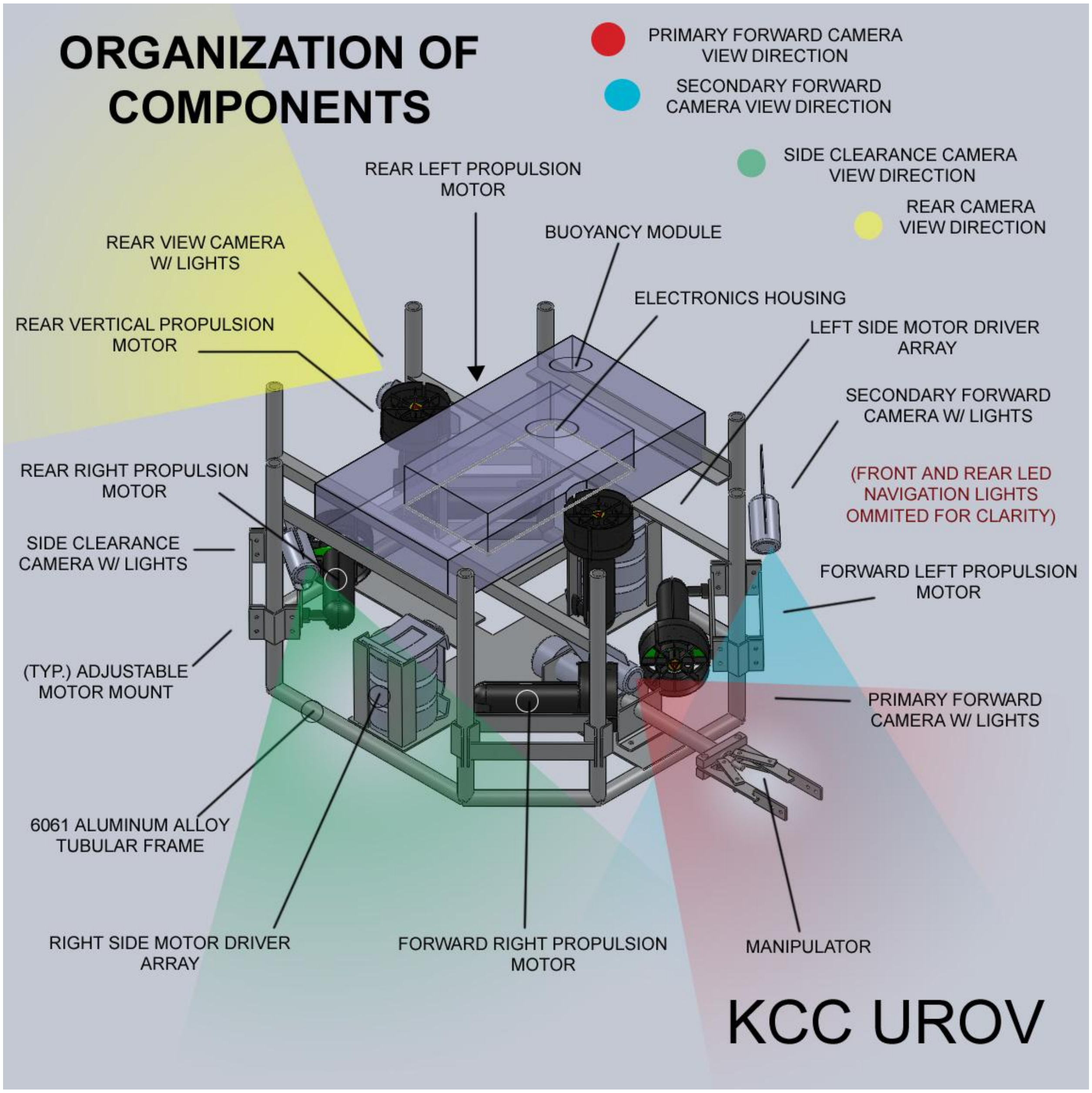


Figure 3: UROV Organization of components diagram.

Frame

The chassis of our UROV is the structural foundation upon which all mechanical and electrical components are integrated. Our chassis and frame design reflects an emphasis on strength, durability, versatility, and modularity. These characteristics are reflected in the materials we selected, the techniques of manufacturing, and the fundamental design of the chassis and component mounting systems. The robust construction of our frame and the flexibility of our mounting options provide our UROV with the platform we need to integrate the multi-functional capability we need to face a wide variety of situations.

Our UROV's external frame utilizes a monolithic octagonal structure constructed of 6061 aluminum alloy tubing. The Capable of withstanding a wide range of forces and environmental conditions, the primary frame is manufactured via gas tungsten arc welding in order to fully utilize the strength and integrity benefits of the metal chassis. The durability of the structure itself provides a large degree of versatility as to the conditions we can operate in, Thus our frame provides a substantial service life on a platform that can support many different .system configurations.

With the large number of components being included on this UROV, a strong emphasis has been placed on a modular design approach and versatile mounting options. One cornerstone of the frame design was in the design of the mounts for our propulsion system. The propulsion mounts were designed and fabricated for adjustable vertical placement while maintaining the relative angles of the motors and the direction of the thrust. All other components are fixed to the frame via fabricated clamps or fasteners allowing for removability and quick replacement where desired.

Manipulator

The forearm of the manipulator is a stationary aluminum shaft, mounted horizontally on the lower tier of the ROV. Inside of the forearm is a stainless steel driveshaft that is fastened to a modified 12VDC Rule brand bilge pump. We have modified the pump by removing the inlet housing and the fan to utilize the pump to spin the driveshaft. The end of the drive

Figure 4: The manipulator motor and drive shaft.

shaft has been machined with threading to open or close the claw to the pilot’s discretion. The “claw” opens and closes when the threaded rod screws in and out of the center shaft.

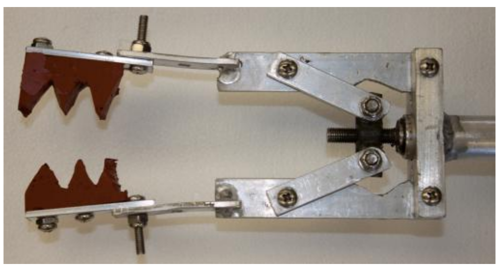


Figure 5: The "bearing loader" style claw.

Crustacean extractor

For this task we are to pick up three crustaceans mounted on the back wall of the cave and bring them back to the surface. We have decided to create a permanent unit that is capable of containing all of the crustaceans, thus saving us the time of returning to the surface.
We designed and tested a vacuum powered by a single 12VDC, Rule bilge pump 1100gph that is connected to a flexible vacuum hose that is routed underneath the manipulator.The inlet of the suction basket is mounted directly underneath the claw, shaped like a funnel in order to avoid obstructing the hose, and focusing the flow within the inlet thus easing the collection process. After all the crustaceans are collected, they will be housed within the ROV until returned to the surface.

Agar collection

We are tasked with collecting a specific amount of agar, for this we designed a cylindrical piston type collector that is spring loaded with a force strong enough to cut into and extract the agar. Once the correct amount is collected, a locking mechanism will contain the agar until returned to surface.

Electrical Waterproofing

The traditional method of waterproofing electrical components on UROVs is to create a single waterproof housing to protect all electronics. However, should the container fail and water leakage occurs, all electronics within the housing are at risk. We chose to individually waterproof our high-power full voltage motor drivers in a shape and size of our choosing.

Figure 6: A fully waterproofed H-Bridge motor driver.

A unique waterproofing design pioneered by Team Limawai is the utilization of epoxy resin to encapsulate each individual motor driver. Using SureSeal waterproof connectors integrated within the epoxy molds, the design facilitates quick modification or repair/replacement. This waterproof design allows heat sinks to protrude into the water for heat dissipation, with only a thin layer of epoxy to electrically insulate them from the water.

Figure 8: Airtight electronics housing

The balance of our electronics; microcontroller, pressure sensor, dark-detection circuit, and various voltage converters are all interconnected. This made it preferable to house them in a single container. We chose a commercial Pelican brand micro case rated to 30 meters submersion which is well beyond our expected mission specifications. We drilled holes and added SureSeal electrical connections and tested this combination to 3.4 meters for thirty minutes with no leakage. This container satisfied our design goal for easy access to the microcontroller. We are concerned that this critical piece can be easily exchanged in the event of burnout.

Power Distribution

We are given a 48VDC supply from the MATE competition and one 120VAC power strip. We used 120VAC to power our computers, monitors, and cameras with their respective AC-to-DC converters. We recycled last year's TRC Electronics 48VDC-to-24VDC converter to step down the voltage for all of our electronics and motors on the ROV. A 24V wire and a ground wire are sent to a bus that distributes directly to the motors and into the airtight housing. In the housing the 24V is reduced to 12V, 5V, and 3.3V by regulators to power all electronic components.

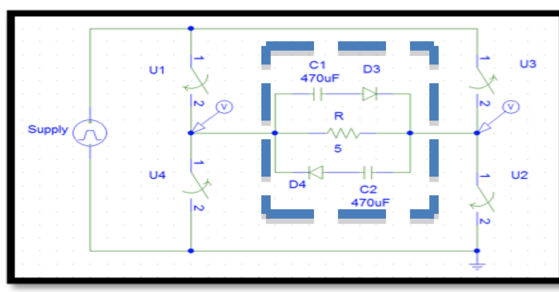


Figure 7: Capacitance based circuit in blue dashed lines.

The thruster H-bridge as we used last year, gives a pulsating thrust when operated in the low-speed range. To smooth out the ROV's motion in low-speed operation, this year we added a capacitor based smoothing circuit.

Tether

The lifeline of any remotely operated vehicle requires a tether that sends power, as well as the necessary communication signals to control and retrieve data from the ROV. In total, the tether consists of one 24V power wire, one ground wire, one 9-conductor

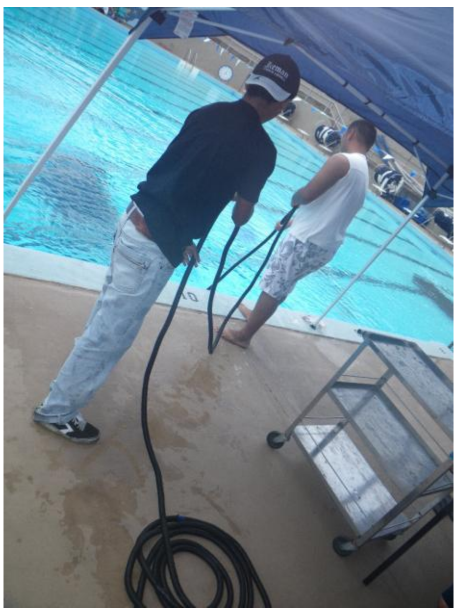


Figure 9: Shohon handles the tether during testing

Ethernet cable, and four coaxial camera wires. All wires are wrapped in corrugated tubular electrical sheathing. The slight negatively buoyant tether is 15 meters in length and 2.54 cm in diameter extending from the rear of the ROV.

Sensors and Lighting

Lights: Each video camera has its own LED system that gives localized illumination. Additionally, we have added on the front and rear sides of the ROV 60 high-output LED banks that assembled and made waterproof. These light banks are controlled by our dark detecting circuits that can sense when the UROV is operating in dark areas such as the cave or deeper depths. The sensitivity can be

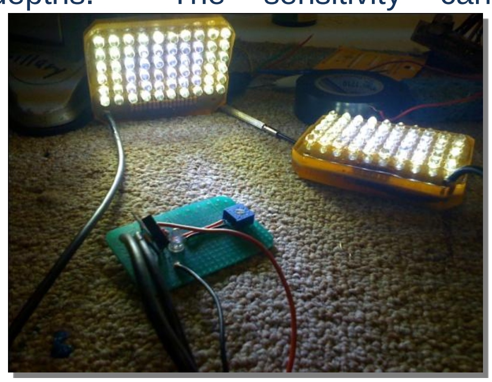


Figure 10: LED bank with Darkness-detecting circuit

controlled by a variable resistor in our micro controller housing and overridden manually by the pilot if necessary.

Hydrophone: Attached to the top-forward of the craft is a precisely accurate hydrophone used to detect the audible vibrations from one of three “rumbling” stations in which we move a simulated high-rate hydrophone acquired to further measure seismic activities. The hydrophone is nestled in a ¾” PVC housing, 4 cm in length to provide protection and act as a uni-directional microphone aimed in the direction of the forward navigational camera. The data from the hydrophone is sent directly up an auxiliary wire within the Ethernet cable to the shoreline computer headphone jack displaying visual data on our graphical user interface (GUI) as well as output to speakers for audible confirmation.

Thermistor probe: Temperature measurements can also be acquired by the craft via thermistor probe protruding out of the front of the craft. The thermistor probe is located at the forward right of the ROV utilizing the secondary forward viewing camera for aiming the thermistor probe into the venting chimney to measure venting fluid temperatures. The thermistor is fixed to a flexible rubberized cable which

Figure 10: Thermistor probe assembly

Software

The surface software was written in the C# language utilizing Visual Studio 2008 with the Microsoft XNA Game Studio 3.1 DirectX libraries. The PIC32 software was written in a combination of Visual Studio 2010 and Microchip's MPLab.

Through vigorous analysis and utilization of vector decompostion, the software team was able to reduce the thruster algorithm from our previous years 500 plus lines of code to 4. The Xbox 360 controller transforms the pilot's commands into formatted data that the surface software is able to read. The software analyzes the translational and rotational data and applies any threshold or speed modifications the pilot has set. By pilot request, all translational (but not rotational) data may be modified by an additional trigger control. The trigger is a potentiometer and the software is able to apply a modifier in the range of 100% (not depressed) to 50% (fully depressed). Additionally, there is a half and full scale modes that further reduces any speed on the ROV. The half and full scale are applied to both translational and rotational movements. In addition, the pilot is also able to control the

Software Block Diagram

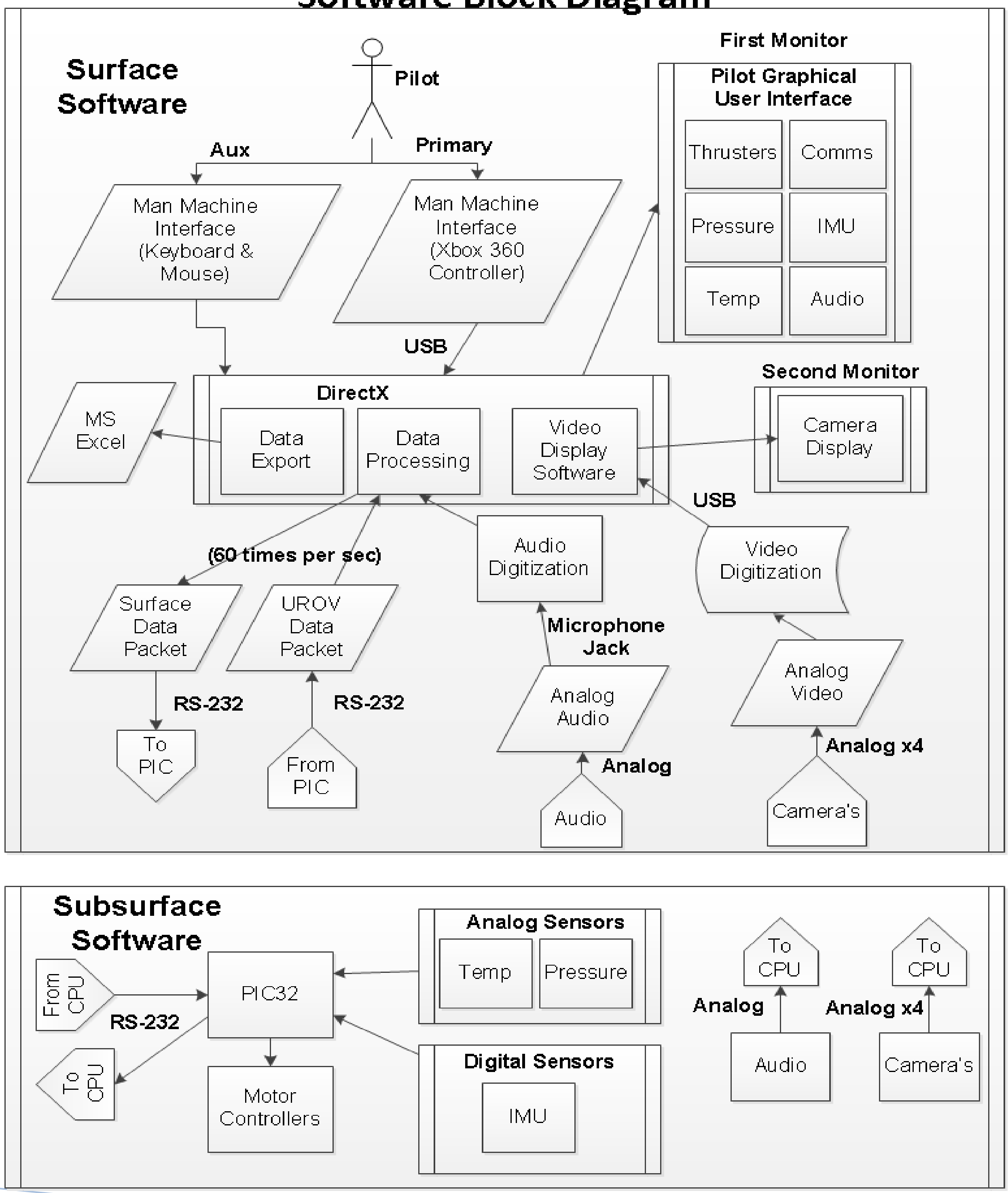


Figure 11: Software Block Diagram

manipulator through the Xbox 360 controller.

Once thruster and manipulator commands have been computed, the surface software assembles a single data packet containing thruster and manipulator commands and transmits the packet down to the ROV. The software reads and decomposes a single data packet from the ROV containing temperature, pressure (depth), Inertial Measurement Unit (direction, acceleration, and velocity) data. Each sensor is processed by their respective algorithm and formatted for onscreen display. The pilot has the ability to configure many elements of the interface. Communications, audio sampling, and camera display are just a few of the many elements that can be configured.

The software then digitizes audio data by sampling the microphone in on the computer. The microphone input is connected through the tether to the hydrophone on the ROV. Once the audio has been digitized, the software utilizes Fast Fourier Transforms (FFT) functions from the open-source Math.NET Iridium library (http://www.mathdotnet.com/). Once FFT data is calculated, they are plotted in real time on the screen

The software calculates temperature vs. depth in real time and the pilot is able to store three data points. These data points are used in Task 3. As an additional option, the pilot can export the data and graph to a Microsoft Excel spreadsheet where it can then be printed if the judges desire a hard copy. A separate software application also utilizing DirectX reads digitized video and displays them onscreen for the pilot.

On the ROV, the PIC32 code was kept to a minimum. It consists of RS-232 communications code, motor driver controls, and digitizing temperature and pressure sensor data. Information about the current orientation, and 3 dimensional acceleration and velocity is read digitally from the IMU.

Both the surface and subsurface packets contain a 32 bit cyclic redundancy check (CRC) over the data portions of the packet computed by the transmitter. The receiver verifies the CRC. If there is a mismatch, the packet is discarded. As an additional safety feature, if the ROV does not receive a data packet within 1000ms, it turns of all thrusters until a new valid data packet is received.

On-Board Electrical Schematic

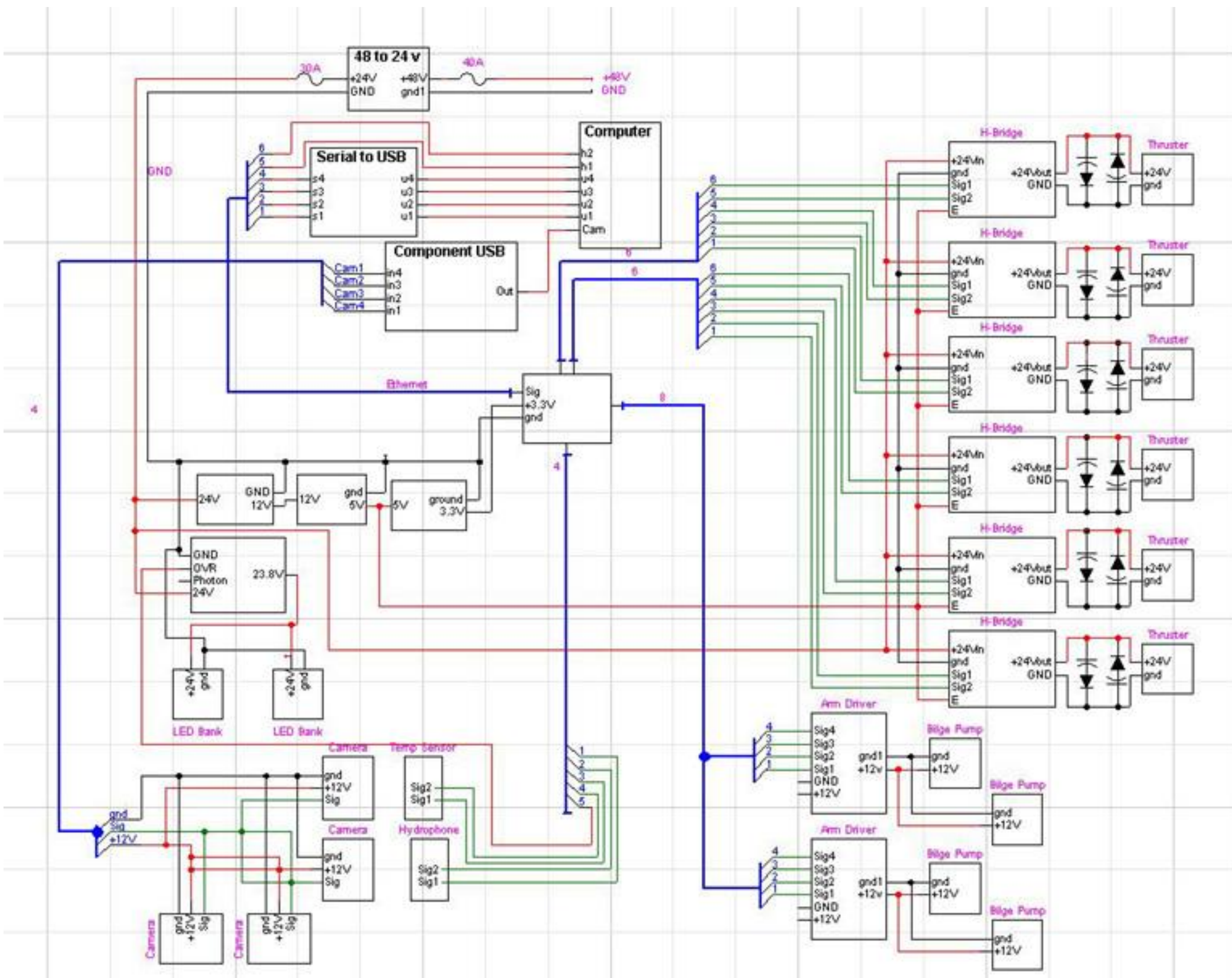


Figure 12: Onboard electrical schematic

Challenges

Compared to last year's competition, this year we require a much greater degree of fine movement. This proved to be a large problem for us originally, as due to our limited budget we were restricted to brushed DC thrusters. The 'all on' or 'all off' jerking motion of these thrusters made precision movements nearly impossible. We needed a way to smoothen the precision movements of the ROV while maintaining a minimal budget. Brushless DC motors would have provided the necessary changes, but would also have depleted our funds. Instead, applying our growing knowledge of transistors and BJT's we made plans to create a variable input voltage circuit. We were unable to properly bias the transistor to use it as an amplifier without frying the chip, so we pursued an alternative method – capacitors. Our software and hardware team worked together to calculate the proper duty cycle and sized capacitor to effectively lower the average power delivered to the thrusters. This is by no means a flawless solution, as there is still an obvious pulse when trying for smooth, low speed motion; however, it is a near night and day difference compared to last year.

Troubleshooting

Initially, within our manipulator system, a deficiency of power and torque was experienced when powered through the motor driver circuit . This deficiency had an adverse effect on performance during our practice runs . Tracing the supply of power to the manipulator we found that the current being supplied by the motor driver was insufficient to power the motor. Considering our budget constraints, we decided to implement out motor drivers from our previous year to power our manipulator. The power increase was so dramatic, the manipulator would lock itself closed due to friction. This brought to light a flaw in the mechanical design which we have remedied by utilizing nylon washers on the bearing surfaces to alleviate the friction and allow the manipulator to operate efficiently.

Future Improvements

While we recognize the vast improvements in our UROV compared to our previous year's model, we also appreciate the many aspects of our design that can be improved on further. . The robust construction of our frame is appropriate for this year's application; however we recognize the potential benefits of implementing lightweight, neutrally buoyant composites where durability is less of a concern. Though our budget limits our access to advanced materials such as neutrally buoyant Seaboard, we are confident in our ability to find and design for effective alternatives that could provide us the performance we seek. The mechanical systems on this year’s ROV are quite simple, yet marginally effective due to our advanced mobility. Next year we would like develop a more sophisticated and efficient mechanical system that would offer greater intuitiveness and performance for any potential operator..

Our growing experience with our newly implemented IMU, will allow us to implement much more sophisticated driver aids. Our motor drivers could be reduced in size, and smaller motors are available which would greatly reduce the size and weight of our craft. These improvements combined with a naturally buoyant frame would allow us to make a much smaller craft, allowing us a greater degree of mobility. Along with smaller thrusters we would like to finalize the development of transistor based motor drivers – allowing us to achieve the performance of brushless motors with our brushed DC motors.

Lessons Learned

Communication is the key to success on a team as large as ours. Our team tripled in size compared to last year, and unfortunately our communication did not. We now know that with an increase in manpower, the efficiency and organization of the communication infrastructure must also be expanded. Some teams fell to the wayside for far too long, leaving us scrambling to recover in order to make deadlines.

Develop the integrated system, not individual components. A number of problems arose as a result of developing and testing individual parts of a system apart from the components they would be eventually in line with. Had we done our final rounds of testing with everything installed we would have had much more warning.

Testimonials

Eric Jordan:

“I have nearly learned graphical programming using the Microsoft DirectX library. In developing our communications system, I’ve learned at a fundamental level how the I2C and RS-232 protocols work. Attempting to implement Microchips Peripheral Library proved to be very difficult

due to poor documentation and examples. Instead, I went through the PIC32 datasheets and learned clock for clock how I2C should work. I successfully implemented a complete I2C library; however, we discovered that it would not work with the length of our tether. We then switched to using RS-232. Again, I did not use Microchips Peripheral Library and implemented a custom solution.

I have learned how difficult communicating from PC to PIC really is. In a wideband world with communication speeds measured in the Megabits, implementing our entire communications system with a baud rate of 38.4Kbps has proved challenging. I learned how to tear down the data that needed to be sent and received and only send the data that is truly needed."

Dave Horton:

"*My primary role on team Limawai is as the designer, welder, and fabricator of mechanical systems. In this capacity, I've designed, developed, and evaluated systems specifically for underwater applications. Working extensively with concepts such as waterproofing, buoyancy, and stabilization behaviors of a bottom-heavy underwater vehicle, I have been able to establish a much more profound understanding of a purpose-oriented engineering design."*

In the course of working on this project with team Limawai, I have had countless opportunities to expand my skills and gain insight on real-world engineering. Working within the mechanical and structural subgroups, I've learned to appreciate the work that goes into producing an integrated electrical/mechanical system.

Lōʻihi Seamount

The Lōʻihi seamount is an active undersea volcano lying approximately 35 km southeast of the island of Hawaiʻi. The youngest of the Hawaiian-Emperor volcanic sea-chain, Its elongated shape earned Lōʻihi (long) its name. Marked by three craters and a caldera 2.8km long by 3.7km wide, Lōʻihi's summit rises 3000km from the seafloor. Initially thought to be extinct, Lōʻihi has experienced frequent earthquake swarms since 1970.

The 1996 Lōʻihi earthquake swarm was the largest of any Hawaiian volcano. The Hawaii Volcano Observatory recorded over 4000 earthquakes in the July-August swarm, including over 40 measuring between magnitude 4.0 and 5.0. In August 1996, during an expedition launched subsequent to the quakes, major geological changes in Lo'ihi were revealed by samples recovered by the unmanned submersibles PISCES V and IV.

Young lava samples brought evidence of an eruption during the seismic activity at Lo’ihi. Hydrothermal vents around Lōʻihi had temperatures ranging from 30°C to over 200°C following the eruption. Vents at the summit collapsed into a large crater, named Pele’s Pit after the Hawaiian fire goddess. New sulfur-oxidizing bacteria were found in sites previously only containing iron-oxidizing bacteria. An improved data collection device was built following the 1996 cruise.

The first ever undersea volcano observatory, the Hawaii Undersea Geo-Observatory (HUGO) was deployed to Lōʻihi’s summit in 1997. HUGO provided real-time seismic, chemical, and visual data to scientists. It was Outfitted with pressure sensors, high rate hydrophone, and temperature sensors. A 47km power and communication line connected a surface station at Honuʻapo bay to HUGO’s junction box. This fiber-optic line was the only direct connection from the surface to HUGO. The power and communication line failed twice, once in 1998 and once in 2002. PISCES V retrieved HUGO in 2002. HUGO has yet to be redeployed.

The PISCES V, IV and RCV-150 ROV have been continually used for Lōʻihi research missions. PISCES V has performed over 50 Lōʻihi research missions, including HUGO repair missions. Lōʻihi’s treacherous terrain makes many missions too dangerous to complete for any submersible.

Acknowledgements

Team Limawai would like to thank the National Science (NSF) for providing Kapiolani Community College: Science, Technology, Engineering and Mathematics (STEM) program with funds to support undergraduate research, including our UROV program, and the following individuals and organizations.

KCC STEM Faculty & Staff:
Dr. John D. Rand
Herve Collin
Nari Okui
Alicia Cinense
Keolani Noa
Keoki Noji
Cecilio Soliven
Phillip Blackman
Travis Watanbe
Jason Cutinella
3-D Innovations
RobotPower.com
InSynergy Engineering

Appendix

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Expenses:

Kapi'olani Community College 2010 UROV Expenses

UROV Electrical System				
Qty	Item	Unit Price($US)	Total Cost($US)	Supplier
1	IPS 34	$2.95	$2.95	
1	IPS 40	$3.35	$3.35	
1	SH2 x 405 Header	$3.95	$3.95	
1	Weller Soldering Iron	$69.95	$69.95	
1	Weller ST6 Soldering Tip	$5.95	$5.95	
1	470 µF Capacitor	$1.80	$1.80	
1	2 x 40 Header	$3.95	$3.95	
5	2 Position Connector	$0.50	$2.50	
12	SH1 x 405 Header	$1.95	$23.40	
2	IN4002 Header	$0.50	$1.00	
2	6A 400V Diode	$1.00	$2.00	
1	⅛ W Potentiometer	$2.50	$2.50	IC Supply
16	⅛ W Resistor	$0.20	$3.20	
2	SH1 x 36 Header	$2.00	$4.00	
2	Roll 16AWG Wire	$6.95	$13.90	
1	LM324 OpAmp	$2.65	$2.65	
3	FHS-36 Header(Male)	$2.95	$8.85	
4	SH1 x 405 Header(Female)	$1.95	$7.80	
1	10' USB Extension Cable	$8.95	$8.95	
1	40amp fuse	$2.69	$2.69	
1	Fuse Block	$17.49	$17.49	
1	30amp Fuse	$2.29	$2.29	
1	12-10 Gauge Ring Terminal	$3.49	$3.49	Larry's Auto Parts
1	16-14 Gauge 1/4" Female Terminal	$3.49	$3.49	
1	16-14 Gauge 1/4" Male Terminal	$2.09	$2.09	
1	24V Brushed DC Thruster*	$395.00	$395.00	SeaBotix
Various Sure Seal Connectors			$491.93	PEI Genesis
6	Simple-H motor drive	$80.00	$480.00	Robot Power
VARIOUS 22AWG Wire			$34.75	
Various Electrical Supplies			$424.75	
2	100' Black 22AWG 2 Conductor	$26.95	$53.90	
2	100' Chrome 22AWG 4 Conductor	$49.95	$99.90	Jameco Electronics, Inc.
1	100' 24AWG 9 Conductor	$44.95	$44.95	
2	100' 5 Conductor 25AWG	$54.95	$109.90	
2	100' 3 Conductor 24AWG	$39.95	$79.90	
20	3.3V Regulator	$1.19	$23.80	

UROV Electrical System				
Qty	Item	Unit Price($US)	Total Cost($US)	Supplier
2	USB to Serial Cadapter	$18.95	$37.90	
5	5.5' Mini USB Cable(Male)	$2.25	$11.25	Jameco Electronics, Inc.
6	D-Sub Serial Connector	$2.59	$15.54	
2	Razor IMU	$124.95	$249.90	Sparkfun Electronics
6	Underwater Camera	$82.99	$497.94	LammensCo, Ltd.
Course Building Supplies				
Various Course Supplies			$32.65	Kaimuki Ace Hardware
Various Course Supplies			$202.89	City Mill Co.
UROV Mechanical Supplies				
Various Mechanical Supplies			$500.00	
1	1Yd x 30" Fiberglass Cloth	$6.69	$6.69	
1	4:1 Epoxy Resin (16 Oz.)	$23.99	$23.99	City Mill Co.
1	4:1 Epoxy Hardener (8 Oz.)	$11.49	$11.49	
1	Miller TIG Welder	$1,550.00	$1,550.00	
2	Tank Argon Gas	$300.00	$600.00	
1	1/16" Aluminum Filler Rods (1lb Tube)	$15.00	$15.00	Airgas Gaspro
1	1/16 x 7" Tungsten Welding Electrodes (10pk.)	$25.00	$25.00	
1	Welder's Helmet	$150.00	$150.00	
Expense Subtotal			*$5,560.68*	

Donated Items			
Qty/Amt	Item(s)	Donated Value	Vendor/Source
80ft	6061 Aluminum Tubing & Plates	$100.00	Cecilio Soliven
3	Simple-H Motordrive	$240.00	Robot Power
4hrs	SolidWorks Training	Labor Donated by Mr. Collin Nishida	3D Innovations, LLC
$5,000	Monetary Donatio	$5,000	KCC STEM
$1,000	Monetary Donation	$1,000	InSynergy Engineering
$50	Monetary Donatio	$50.00	Master Care
Subtotal		*$6,390.00*	

Recycled Items from 2009				
Qty	Item	Unit Value	Value	Vendor
5	24V Brushed DC Thruster*	$395.00	$1,975.00	Seabotix
100ft	100' 10AWG Wire*	$0.38 per foot	$38.00	CarQuest Hawaii
Subtotal			*$2,013.00*	

**Vendor provided item at great discount to team*

Total Expenses	-$6,373.21
Total Donated Value	$6,390.00
Total Recycled Value	$2,013.00
Grand Total	$2,029.79