Qubo II: Slow and Steady

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***Abstract*—For the 2019 competition, Robotics at Maryland will submit an improved version of Qubo - the robot last taken to competition in 2017. This version of the robot features a modular frame and redesigned electrical system that allow changes and adjustments to made more easily while at competition. The robot also has a robust software system that can be tuned and adjusted to meet the requirements of the obstacle course.**

***Index Terms*—Autonomous underwater vehicle (AUV), Printed circuit board (PCB)**

I. Introduction

Qubo is an autonomous underwater vehicle (AUV) that has been continuously iterated on for the past 3 years. The robot features an aluminum frame with acrylic hulls to store electronics and batteries. There is also a plastic camera hull mounted to the front. Eight thrusters provide movement. Qubo is the continuation of a multi-year hardware platform design, with the focus for the 2019 competition on improving the electrical and base system robustness.

II. Competition Strategy

Just as the previous competition, Robotics at Maryland's strategy was to continue to perfect Qubo, a new hardware platform meant to last the team for multiple future competitions. The goal for the 2019 competition was to refine and revise the minimum viable robot presented at Robotics at Maryland's last competition, to fix issues that arose during manufacturing and to finish systems that did not come online in time for the competition. For this goal, Robotics at Maryland chose tasks that the robot would be able to complete using only computer vision and the robot itself. At this point, the team plans on attempting the gate and buoy tasks. If no issues arise with the robot during the competition week, futher tweaks can be made, such as aiming for the 40% section of the game, and transversing the gate at different rotations.

All of the teams working hours were spent developing and testing required components for a fully capable minimum viable robot. Due to the issues procuring certain parts critical to the function of the robot, the team wasn't able to get the robot in the water to test before competition. Due to issues encountered during previous iterations of the core system of the robot, the electrical system was split from a monolithic central board to several, self-contained boards that connect together. This allowed the team to work on and order each board at different times, and let the team test them as they were finished. Modularity was made a focus of the new systems to prevent small errors from taking down large amounts of hardware, a lesson the team learned from experience.

III. Vehicle Design

This years iteration of Qubo features several new and innovative features across all subsystems. The improvements aim to streamline the flow of data between software processes and create smoother interfaces between electrical and mechanical systems.

A. Electrical System

The electrical system features three boards that regulate power and route signals between the various processors, sensors and actuators on the robot. The individual components are listed below. The first three boards sit in the main electronics hull, while the battery support board sits inside the dedicated battery hulls.

- ARM Processor Board
- Hypertronics Interface Board
- Power Supply Board
- Batteries
- Thrusters
- Battery Support Board

This year, several changes were made to the electrical system that improve the functioning of the robot as a whole. The electrical system now features a Hypertronics male and female wire-to-wire-connector pairing. These high-precision connectors feature positioning pins that allow the male and female halves to be easily connected and disconnected. The male end of the hypertronics system is mounted to an interface PCB while the female end is connected directly to our electronic speed controllers (ESCs). An I2C signal is sent by the TiVa microcontroller to the interface PCB which has a chip that decodes the I2C into 8 separate PWM signals (one per thruster ESC). Thus the Hypertronics system acts as the primary physical interface between the thrusters and the main CPU. The addition of this connector is also what allowed for the entire electrical subsystem (three PCB's and 2 CPUs) to be mounted on rails that slide in and out of the electrical hull.

A battery board was designed to sit on the battery hulls and act as an ideal diode. Each battery board prevents reverse current from entering the battery it is connected to. This prevents batteries from charging each other. The battery boards also shut off power from the batteries to the rest of the robot if they detect user-selected over-voltage, under-voltage, or over-current scenarios. By adding these boards the robot has become safer to operate since the likelihood of a battery-related accident is now lower.

B. Mechanical System

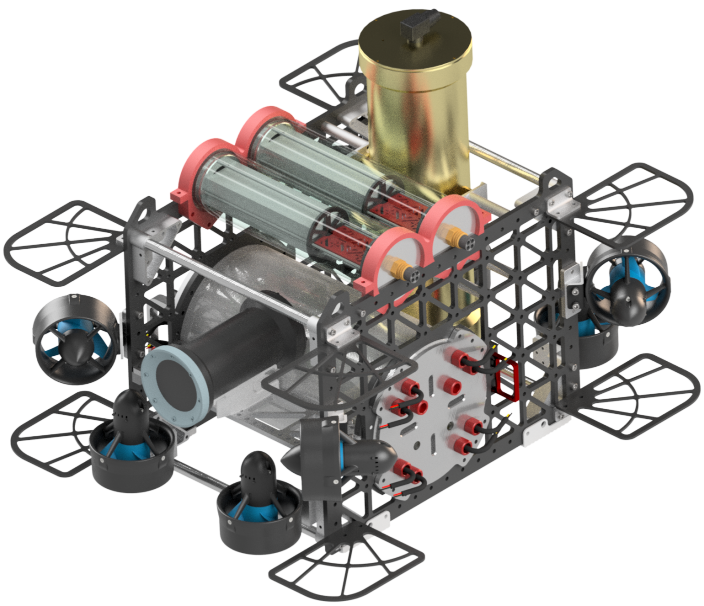

Fig. 1. CAD Render of Qubo, with preliminary DVL mounting

Qubos mechanical system is composed of a main pressure hull, eight Blue Robotics T200 thrusters, two camera hulls, and an aluminum frame. The main pressure hull houses the electronics system and the computers. Two camera hulls are placed in the vertical center plane, one forward facing, and one downward facing. The robot relies heavily on vision for maneuvering. Mechanisms for firing a torpedo, dropping markers, and manipulating objects will be added in the future.

The mechanical design of Qubo emphasizes modularity and ease of machining. One of the lessons learned from Qubos predecessor, Tortuga IV, was that a simple frame design can reduce the serviceability of and limit access to internal components. In Qubo, the frame was designed with respect to the hardware configuration. The design eliminates the spatial dependency of systems, and allows for quick part removal, swapping, and modification. Additionally, the robot was designed to reduce machining complexity. Only a few parts require CNC milling, while others can be manually machined or 3D printed.

The propulsion system is intended to give the robot fine control of its movements. In RoboSub, the ability to perform forward, strafing, and yaw motion while maintaining depth is critical. On Qubo, four downward facing thrusters are placed in a rectangular pattern. Together, they maintain a horizontal operating plane which other four thrusters move on. The sideways thrusters are aligned to provide vector thrust 45 degrees from the center plane. Ideally, they provide more thrust for forward motion, and direct control for yaw. Further, the high degree of freedom allows the robot to perform complex maneuvers if so desired. This configuration requires the thruster to quickly reciprocate and deliver similar forward and backward thrust. Each thruster is mounted via an adapter that can be quickly detached and swapped in case of a malfunction.

1) Frame: The frame consists of two water-jetted aluminum panels with four main aluminum rods holding them together. The water jetted pattern offers option to mount additional hardware. The front and back plate provide additional mounting space. Each side is reinforced with cross beams. Stress analysis shows the frame can withstand several times its operational load. To protect the thrusters in the event of a collision, laser-cut Delrin bumpers are fitted onto the frame. To prevent corrosion, all fasteners used are stainless steel and the aluminum members are protected by a sacrificial anode.

2) Battery Hull: The two batteries are housed in separate, cast acrylic battery hulls sealed with aluminum endcaps on either side. The endcaps were fabricated from stock 6061 aluminum rods by manual lathe and mill machining. The battery hulls are mounted inside of the top of the frame so that they can be removed easily, and are mechanically constrained by the frame. This helps ensure that the hull remains sealed as the battery heats up and the internal pressure of the hull changes. The battery and battery boards are mounted upon 4 orthogonal stainless steel hexagonal stay rods screwed into the inside of the endcaps. All of the support mounting for the hull and the battery boards are made using 3D printed PLA.

C. Software

The software system for Qubo is divided into two categories depending on which computer they run on. High level software runs on the Jetson, and embedded software runs on the Tiva. Most of the code base for Qubo has remained the same as previous years, maintain the same system levle organization and the reliance on ROS. All of the code is free and open source, and can be found on Github.

1) High Level Software: The high level software system on Qubo has remained relatively untouched since Robotics at Maryland's last competition. It was written using the Robotic Operating Sustem (ROS) as a base, to take advantage of the large number of utilities available and community support. Work was done on the control system after the last competition, using the simulation software Gazebo and the Gazebo plugin UUVSimulatior to simulate underwater environments. Members worked to perfect and experiment with the control system presented in the last report, a simple PID control along each degree of freedom. Using the simulator and a simplified model of the robot, base values for all PID constants were found.

2) Embedded System: The embedded system saw the most work between competitions, as many problems were found during and before Robotics at Maryland's last competition. The system still uses the same general layout and design as the previous report; a TI Tiva C running various task using the FreeRTOS real time operating system. New tasks for the system were written to interact with the hardware in our system. Specifically, tasks to communicate with our I^2C based PWM controller, ADS chip, and temperature sensor were written and tested. Inter-task communication was also rewritten, and now uses FreeRTOS message buffers to transmit small amounts of data around the system. The embedded system still communicates with the high level system using Qubobus, a bytestream protocol developed by the team and described in the previous report.

IV. Experimental Results

Due to issues during electrical and mechanical manufacturing, the team wasn't able to run the full system underwater before the competition, so all testing was done on land or in simulation.

A. Software

The new components of Qubo's software system was tested through multiple different methods, primarily using Gazebo and hardware testing. As most of the software was written before the hardware platform was fully assembled, individual components of the systems have not been tested together.

High level control software was tested using the ROS simulation software Gazebo. A basic computer model of the robot was created and exported to use in Gazebo, where basic control simulations were done using the UUVSimulator underwater Gazebo extension. While the model does have an accurate placement of the thrusters, and an estimated location for center of gravity, it does not have any information about the drag characteristics of the robot, so only simple control programming was done.

Sensors connected directly to Qubo's main computer were tested on land by running the relevant code, and verifying sensor values were correct.

1) Embedded: As the most complex software subsystem of the robot, Qubo's embedded system was tested more extensively than the others. Each task the system is responsible for was tested independently, with codependent tasks later tested together. Software that interfaced with sensors through data channels on the embedded computer was first tested using a development board containing all of the sensors, and then with the final electrical boards as they were manufactured. Sensor inputs and outputs were tested by connected oscilloscopes and signal generators to the pins of interested.

B. Electrical

The electrical subsystem was tested on a board by board basis. The battery balancing and power boards were tested with a power supply to ensure output voltages were correct with respect to the input voltages. Specifically, the over-voltage and over-draining features of the battery boards were verified. The regulated output voltages for the power board were also verified.

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References

[1] S. Gillen et al., "Qubo: The Tortise Who Lived", 2017. [Online]. Available: https://www.robonation.org/sites/default/files/RS17_UMaryland_Paper.pdf

Appendix A: Expectations

Subjective Measures			
	Maximum Points	Expected Points	Points Scored
Utility of team website	50	50	
Technical Merit (from journal paper)	150	50	
Written Style (from journal paper)	50	50	
Capability for Autonomous Behavior (static judging)	100	25	
Creativity in System Design (static judging)	100	50	
Team Uniform (static judging)	10	10	
Team Video	50	10	
Pre-Qualifying Video	100	0	
Discretionary points (static judging)	40	0	
Total	650	245	
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle	80	
Marker/Torpedo over weight or size by $<10\%$	minus 500 / marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	150	
Gate: Coin Flip	300	0	
Gate: Pass through 60% section	200	200	
Gate: Pass through 40% section	400	0	
Gate: Style	+100 (8x max)	100	
Collect Pickup: Crucifix, Garlic	400 / object	0	
Follow the Path (2 total)	100 / segment	0	
Slay Vampires: Any, Called	300, 600	300	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	0	
Drop Garlic: Move Arm	400	0	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	0	
Stake through Heart: Move lever	400	0	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	0	
Expose to Sunlight: Surface in Area	1000	0	
Expose to Sunlight: Surface with object	400 / object	0	
Expose to Sunlight: Open coffin	400	0	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	0	
Random Pinger second task	1500	0	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + fractional)	Tx100	0	

APPENDIX B: COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Cost (if new)
Frame	Custom in-house design			
Waterproof housing	Custom in-house design			
Waterproof connectors	MacArtney Underwater Technology	SubConn Mirco Circular Series	-	-
Thrusters	Blue Robotics	T200	11.2 lbf forward thrust, 350 watt	-
Motor Control	Blue Robotics	Basic ESC	7-26 V, 30 amps max	$25 x 8
Battery	Gens Ace	GA-B-45C-5000-4S1P-Deans	14.8v, 5000mah	-
Main computer	Nvidia	Jetson TX1	ARM A57 and Maxwell GPU	-
Embedded computer	Texas Instruments	Tiva C	ARM Cortex M4	-
Programming Language 1	C++ 14			
Programming Language 2	C			
Programming Language 3	Python			
AHRS	PNI	Trax	2° accuracy heading and tilt	-
Cameras	Allied Vision	Mako G-131C	1280 x 1024 GigE Camera	-
Algorithms: Vision	OpenCV	Various basic vision processing algorithms		
Team size	20			
HW/SW expertise ratio	2:1			
Testing time: simulation	2 months			
Testing time: in-water	None			