Amador Valley Robotics Club:
Design of Marlin AUV 2019

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***Abstract*—Amador Valley Robotics Club (AVBotz) is a student-led organization at Amador Valley High School in Pleasanton, CA. The team consists of more than 30 students split into four subdivisions: mechanical, electrical, software, and business. This year, the team has improved Marlin, an autonomous underwater vehicle (AUV), to compete in the RoboSub 2019 competition. The team focused on refining the different parts of the submarine to ensure consistency throughout the variety of tasks. The software system was rewritten to ensure accuracy during the mission while mechanical and electrical systems have been refined to remove possibilities of physical malfunctions.**

Figure 1: AVBotz Team 2019

I. Competition Strategy

AVBotz has decided to refocus on three main tasks - gate, drop markers, and surfacing in the octagon. This has simplified all parts of our AUV and made the sub easier to test and debug, while maximizing the amount of points we can obtain. By focusing on these tasks, we don't require a pickup system and can simplify our movements between and at the tasks. We plan to use vision to go through the qualification gate and detect bins, and the dropper system to complete the drop markers task. We determined that the other tasks, such as torpedoes, require incredibly precise movements that our AUV is not capable of.

To prepare for competition, the team has been working hard over the year. Most of the vehicle design was completed during the school year while testing has been an ongoing process this summer. This works well because most students are too busy to be physically present too often during the school year, but have more time during the summer to test the parts they have built.

Figure 2: Our AUV: Marlin

II. Vehicle Design

A. Software

ROS: The main software stack runs on Ubuntu 18.04 with ROS (Robot Operating System), a set of libraries and tools meant for cutting-edge robotics development. We decided to switch to ROS because of its built-in message passing interface, which was an improvement on the shared memory system

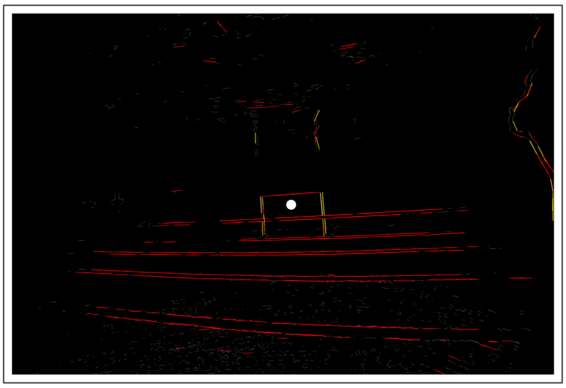

Figure 3: OpenCV vision processing

we had before. Each part of the software runs on a separate ROS node, the main ones being vision, camera, mission, and control.

Control: The control software, Nautical, runs on the ATMega2560 microcontroller and communicates with the main computer over serial. It handles state estimation and low-level communication to the hardware through serial UART pins. Each state, or submarine position, is represented with six degrees of freedom: X, Y, Z, roll, pitch, and yaw. The states are relative to a NED (North-East-Down) coordinate plane. A Kalman filter fuses the data from each sensor to reduce noise for more accurate state estimation, and euler angles are used to convert between frames of reference. To control the submarine, there are six tuned PID controllers that facilitate movement between the current position and a desired destination.

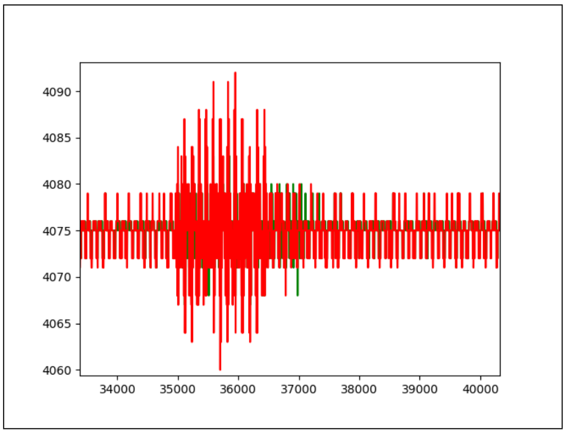

Figure 4: Hydrophone data

Pinger Localization: The software to compute the position of the pinger now runs on the Xilinx Artix-7 FPGA. We first use a DFT (Discrete Fourier Transform) to compute the phase shifts between each of the hydrophones. One challenge we faced when implementing the DFT was cycling of the phase shift, which occurred when the phase shift exceeded the range of arctan. We fixed this by ensuring that the distance between the phones was small enough to prevent phase shift cycling. Next, we convert these phase shifts into actual distances using the speed of sound in water, and use these distances in multilateration to find the location of the pinger. We then convert the location of the pinger into an angle because it is more accurate.

Vision: We have continued using the Tensorflow Object Detection API. To increase available training data, we transitioned from manual image labeling to Amazon's Mechanical Turk service. This allows for the rapid creation of several thousand annotations, giving our models increased generalization capability. We were able to largely offset by switching model training to a Nvidia Titan RTX instead of Tesla V100's on Google Cloud. The new GPU also enables simultaneous training and evaluation due to its larger VRAM capacity.

B. Mechanical

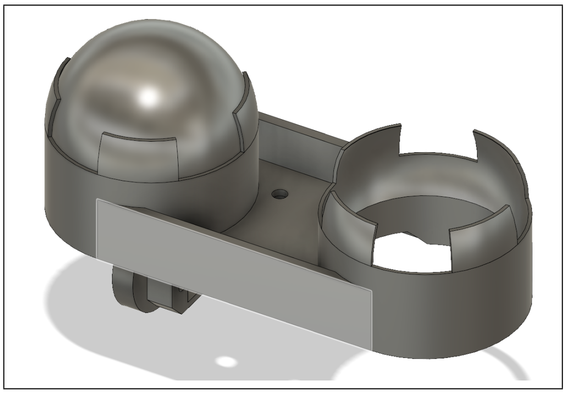

Figure 5: Re-designed ball dropper in Solidworks

Dropper: This module was re-designed this year in order to improve consistency and accuracy. In previous years, we identified that water currents played a large role in the accuracy and deployment of our ball system — in some cases where we did not expect it to play such a role. This year, our ball system relies on two 10-gram servos in order to “pop” markers out of our dropper. This design both allows us to quickly deploy our markers while allowing water to flow through, thus minimizing the water’s impact on our markers.

Marker: Last year the markers we used were golf balls, but our results indicated that they were too light, and easily deflected by water currents during their descent. This year, we created new markers that are heavier, in order to obtain a more controlled descent.

Props: Mechanical objectives also included creating the props for this year’s competition, focusing on a cheap-yet-durable method of recreating the detailed images of the competition — namely the buoys, bins, and torpedoes task. We settled on using vinyl posters, which are extremely durable and easy to use.

New Submarine: A major focus of this year was the creation of a new submarine, designed to address the major structural issues of our current submarine. One principal issue was the asymmetrical cross-section of our previous submarine, Marlin. The larger cross-sectional area of the lower-half of the submarine meant that forward motion was a challenge — as the submarine moved forward, the drag caused by the lower half of the submarine tilted the entire vehicle forwards. With a re-designed hull and a more modular electronics rack, we hope that this new submarine will unlock new capabilities and improve AVBotz’s performance in future competitions. Unfortunately, due to time and resource constraints, the submarine was not able to be manufactured for this year.

C. Electrical

Power Delivery: The sub’s power supply consists of a 4-rail unmanaged system. Two Venom 6S lithium-polymer batteries, wired in series through a 100A fuse, power the 48V rail. The sub’s eight thrusters are powered by this unregulated 48V rail, allowing them to achieve maximum power with minimal conversion losses. The second rail, running at 24V, is powered by a Cincon CFB600W-48S24 DC-DC converter through a manual toggle switch. This rail feeds a Picobox-300w ATX PSU which powers the motherboard and GPU. Even with the processor and GPU near full load, the CFB600W never goes above 60 percent utilization, which allows us to cool it passively through the aluminum rack. The 5V and 12V rails are powered by another DC-DC converter.

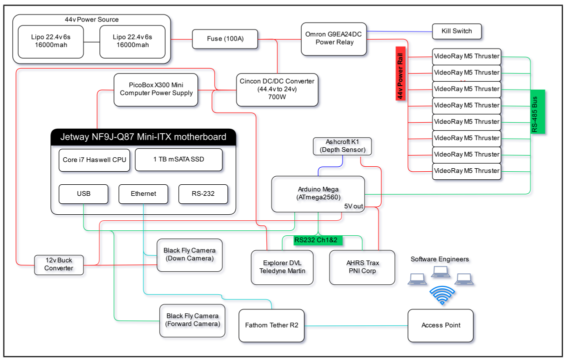

Figure 6: Overview of Marlin’s electrical system

Internal Communications: The sub’s internal components communicate over various protocols. The front-facing camera communicates with the motherboard using a USB 3.0 interface running at 5 Gbps, while the lower-resolution down-facing camera is connected over Ethernet and powered via PoE. The ATMega is connected to the motherboard via a UART-to-USB converter running at 115200 baud. The AHRS and DVL are connected to the ATMega via an RS232-to-UART converter. Finally, the eight thrusters are connected to a single RS485 bus, which is connected to the ATMega via a RS485-to-UART converter.

Tether: For RoboSub 2019, the sub’s tether has been upgraded to handle gigabit speeds while being easier to maintain and transport. We spliced a Blue Robotics Gen 2 Fathom tether to a 13-pin Subconn connector on one end and an Ethernet jack on the other. The new tether is neutrally buoyant, more flexible, and more visible underwater. The new tether also allows for Power over Ethernet injection, which paves the way for a future self-contained wireless tether buoy design.

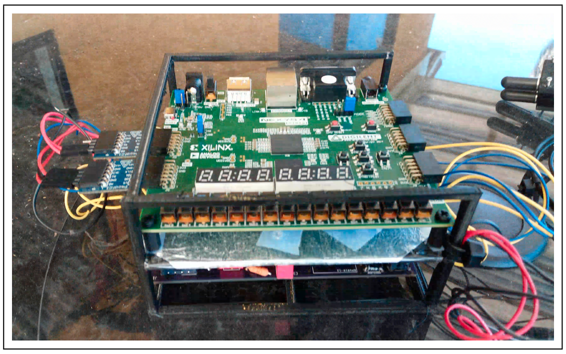

Figure 7: FPGA with hydrophone circuits

Hydrophones: This year, we improved our hydrophone signal processing pipeline. The new signal processing pipeline has two steps: signal conditioning and signal acquisition. During signal conditioning, the output of the hydrophones (several millivolts peak-to-peak) is fed through a 3-stage bespoke processing board: the preamp stage amplifies the relatively low-level and noisy signal from the phones – since the hydrophones are piezoelectric, they are intolerant of any load being present on the leads and have a tendency to saturate over time. The signal then enters an adjustable amplification stage, which allows us to fine-tune the gain to avoid clipping with different input levels in the future. The final stage is filtering: a second-order low-pass filter and a first-order high-pass filter provide antialiasing as well as help protect the acquisition hardware. Placing the entire signal processing system onto a custom made PCB allows for very low signal noise and few if any harmonics to be present in the signal. Acquisition is done with the help of two Pmod AD1 analog-to-digital converters connected to a Xilinx Arctix 7 FPGA coded with a custom architecture based on the Microblaze IP. This hardware configuration allows for sampling at up to 700 kilosamples a second, which is plenty above the Nyquist limit for the frequency range we're interested in.

Computing: The sub's high-level mission control and vision code runs on a Jetway Mini-ITX motherboard with an Intel Core i7-4790t processor, 16GB of RAM and a 1TB mSATA SSD for logging large amounts of vision and hydrophone data. An Nvidia GTX 1080 Ti GPU is connected to the motherboard to allow real-time neural network inference. The low-level hardware interface and motor control code runs on a Rugged Mega board with a ATMega2560 microcontroller chip.

III. EXPERIMENTAL RESULTS

A. *Particle Filter Localization*

To improve submarine localization with its environment, we experimented with Particle Filter Localization. We start by initializing a set of particles around a simulated map of the environment. Depending on the motion of the submarine and detected objects, we reassign probabilities to each particle. Then, we eliminate particles that are unlikely to represent the submarine's true location and resample particles. However, while particle filter localization worked well in simulations, it was not as accurate in real life.

B. *Dynamic Mission Planner*

To improve our performance at competition, we decided to implement an optimal path solver. Since brute force was too slow to work on larger test cases, we used an approximation that was still accurate enough for our purposes. The algorithm had at most 10 percent error on test cases, and we plan to use it at competition if we are able to solve enough tasks for its use to be justified.

C. *Distance Calibration*

Much of the competition requires computing distances to objects in the pool, which is difficult because we don't have a sonar. In order to overcome this challenge, we experimented with recent machine learning algorithms designed to operate on monocular images. We tested the Monodepth algorithm, as well as its updated counterpart Monodepth2, and will continue to do so at competition.

IV. ACKNOWLEDGEMENTS

The AVBotz team would like to thank Mrs. Bree Barnett Dreyfuss for allowing us to host weekly pool tests at the Amador Pool to test changes made on the vehicle. Furthermore, we would like to thank the following sponsors for donating their resources to help AVBotz: Datron, Nvidia, Tanius Technology, Positronics Incorporated, Teledyne Marine, Videoray, Cincon, Xilinx, Subconn, and PNI Sensor. Without the contributions of these sponsors along with our sponsors from previous years, AVBotz would not have been able to build and refine Marlin.

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APPENDIX A
EXPECTATIONS

Table I: Subjective Measures

	Maximum Points	**Expected Points**
Utility of team website	50	46
Technical Merit	150	120
Written Style	50	41
Capability for Autonomous Behavior	100	95
Creativity in System Design	100	90
Team Uniform	10	9
Team Video	50	45
Pre-Qualifying Video	100	100
Discretionary Points	40	18
Total	650	564

Table II: Performance Measures

	Maximum Points	**Expected Points**
Weight	See Table 1 / vehicle	-100
Marker/Torpedo over weight or size by 10%	minus 500 / mark	
Gate: Pass through	100	100
Gate: Maintain fixed heading	150	150
Gate: Coin Flip	300	
Gate: Pass through 60% section	200	200
Gate: Pass through 40% section	400	
Gate: Style	+100(8x max)	
Collect Pickup: Crucifix, Garlic	400 / object	
Follow the ”Path” (2 total)	100 / segment	
Slay Vampires: Any, Called	300, 600	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	1400
Drop Garlic: Move Arm	400	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	
Stake through Heart: Move lever	400	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	
Expose to Sunlight: Surface in Area	1000	1000
Expose to Sunlight: Surface with Object	400/object	
Expose to Sunlight: Open coffin	400	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	
Random Pinger first task	500	500
Random Pinger second task	1500	
Inter-vehicle Communication	1000	
Finish the mission with T minutes (whole + fractional)	Tx100	

APPENDIX B
SPECIFICATIONS

Table III: General

Team Size	30 people
HW/SW Expertise Ratio	1:1
Testing Time: simulation	100+ hours
Testing Time: in-water	100+ hours

Table IV: Mechanical Components

Component	**Vendor**	**Model/Type**	**Specifications**
Frame	Custom	Aluminum T6061	Density 2.7 g/cm Strong corrosion resistance
Waterproof Housing	Custom	Acrylic hull sealed with 2 rubber O-rings	Diameter: 9.5 in (24 cm)
Waterproof Connectors	SubConn	Circular Series Micro-Circular Series Power Series Coax Series	[Varies Based on Series]
Thrusters	VideoRay	M5 Thrusters	Power Input: 48V DC Max Thrust: 23lbs built-in electronic speed controllers
Propellers	VideoRay	Standard propellers	90mm (3.5 inches) 3 blade propeller with collet (smooth shaft)

Table V: Electrical Components: Low Level Control

Component	**Vendor**	**Model/Type**	**Specifications**
Control Board	Rugged Circuits	Rugged MEGA	Microcontroller: ATMega 2560 expanded with Arduino Protoshield
Inertial Measurement Unit (IMU)	PNI Sensor	TRAX AHRS	Communication: RS232 Static Heading Accuracy: .3° Non-static Heading Accuracy: 2.0° Tilt Resolution: .01°
Depth / Pressure Sensor	Ashcroft	Model K1	Accuracy: ±0.50% or ±1.00% span Pressure Ranges: Vacuum to 20,000 PSI
Doppler Velocity Log (DVL)	Teledyne Marine	Explorer DVL	Type: Phased Array Transducer Frequency: 600kHz Max Depth: 1000m

Table VI: Electrical Components: Main Computer

Component	**Vendor**	**Model/Type**	**Specifications**
CPU	Intel	i7-4790T	Number of Cores: 4 Number of Threads: 8 Processor Base Freq: 2.7GHz Max Turbo Freq: 3.9GHz
Motherboard	Jetway	NG9J-Q87 Mini ITX	USB 2.0 Ports: 4 USB 3.0 Ports: 2 HDMI Ports: 1 PCI-E 3.0 x 16 Slots: 1 RJ45 LAN Ports: 2
RAM	Corsair	Vengeance 16GB	2x8GB DDR3 SODIMM RAM Memory Speed: 1600MHz
Storage	Samsung	1TB mSATA 860 EVO SSD	Max Seq Read Speed: 550 Mb/s Max Seq Write Speed: 520 Mb/s
GPU	Nvidia	GTX 1080ti	CUDA Cores: 3584 Memory: 11GB GDDR5X Max Power: 250W

Table VII: Electrical Components: Cameras

Component	**Vendor**	**Model/Type**	**Specifications**
Front Camera	FLIR	BFS-U3-200S6	Resolution: 5472 x 3648 Megapixels: 20MP Frame Rate: 18FPS Sensor Type: CMOS
Front Camera Lens	Computar	V0828-MPY	Mount: C Mount Horizontal Angle: 77.3° Vertical Angle: 61.7°
Down Camera	FLIR	BFS-U3-13Y3C-C	Resolution: 1280 x 1024 Megapixels: 1.3MP Frame Rate: 170FPS Sensor Type: CMOS
Down Camera Lens	Theia	SY125M	Focal Length: 1.3mm Resolution: ≤5MP Mount: CS Mount Horizontal Angle: 135° Vertical Angle: 119°

Table VIII: Electrical Components: Hydrophones

Component	**Vendor**	**Model/Type**	**Specifications**
Hydrophones	Teledyne Reson	TC4013	Frequency Range: 1Hz to 170kHz Resistant to seawater
Data Acquisition and Signal Processing	Digilent	Nexys 4 DDR Artix-7	Block RAM: 4,860 Kbits Logic Slices: 15,850 Internal clock: 450MHz+ DDR2: 128 MiB

Table IX: Software

Programming Language 1	C++
Programming Language 2	Python
Operating System	Ubuntu 18.04
Open Source Software	OpenCV (Image Processing Library), ROS (Robot Operating System)
Algorithms: Vision 1	OpenCV K-Means Clustering, Canny Edge Detection, Gaussian and Median Blur, Contour Detection, Blob Detection
Algorithms: Vision 2	Tensorflow using the FasterRCNN framework
Algorithms: Acoustic	Online DFT, First Order Infinite Impulse Response Filter, Phase Shift
Algorithms: Localization and Mapping	Kalman Filter
Algorithms: Autonomy	Markov Decision Process

APPENDIX C
COMMUNITY OUTREACH

AVBotz members participate in multiple community outreach events throughout the year to inspire younger students to pursue STEM fields. Over the course of the academic school year, members of our team taught students at our local middle schools every week. Our team also helped organize, plan, and volunteer at ACE Code Day, a free event for 6th through 12th graders in our county to either attend classes led by our members or participate in a hackathon. Classes covered topics from Intro to Java to Machine Learning and exposed around 300 students to the field of computer science. The AVBotz team also presented Marlin at IGNITE, an event centered around innovative arts and technologies. Through all these different outreach events, our team members hope to promote robotics and engineering and inspire students to explore the field of robotics.