Amador Valley Robotics Club: Design of Marlin AUV 2018

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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. Building from previous generations of experience, the club has upgraded and refined Marlin, an autonomous underwater vehicle (AUV), to be prepared for changes made to the competition in RoboSub 2018. This year, instead of pursuing a complicated design, a lot of focus was placed onto refining low-level, but fundamental parts to Marlin. This includes software changes to the control system, such as the integration of a Kalman filter for accurate state estimation. In addition, rather than attempting all of the tasks, our new objective is to focus our efforts upon a smaller selection of tasks that we can be sure to complete. Reflecting these aspirations, the mechanical and electrical systems on Marlin will focus primarily on providing accurate vision, acoustic, and state data rather than manipulating objects.**

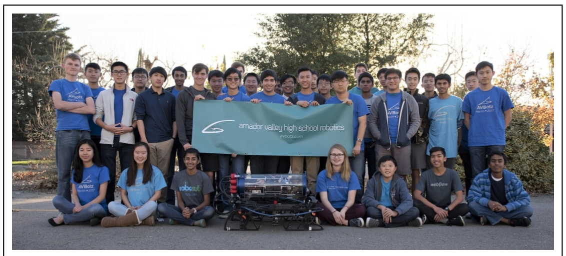

Figure 1: AVBotz Team 2018

I. Competition Strategy

Departing from the overambition of previous years, AVBotz has refocused on a smaller selection of tasks - gate, dice, roulette, and pinger. This consolidated approach has resulted in a simpler and more reliable system that is easier to debug and test. For example, while a pump-based ball system was proposed for “Buy a Gold Chip” and “Cash In” tasks, it was never implemented because of the strict constraints for software. We believe it is unlikely that the sub would be able to autonomously position itself within the narrow parameters needed for the pump intake to effectively draw in the golf ball. Instead, a simple pneumatics ball-dropping system was created to take advantage of the two blue chips that Marlin starts with, in order to complete the “Play Roulette” task. For the “Enter Casino” and “Shoot Craps” tasks, regular OpenCV processes coupled with machine learning models ensure that Marlin is able to locate these objects underwater. We chose to focus on these tasks because, apart from dropping chips onto a roulette table, they can be completed using Marlin’s different degrees of freedom. For example, ”Shoot Craps” can be completed using a series of well-coordinated movements, including ramming and backing up to optimize the number of points obtained. In addition, while we implemented a torpedo system, we decided to forego the “Play Slots” task as it would require many extra hours of pool testing to calibrate the path of the torpedo.

To realize our vision, our team has worked hard this year. A majority of the focus was placed on planning and design during the school year while much of the testing happened during the summer. As a high school team, many students are busy with college applications and standardized testing on top of their regular coursework and jobs during the school year. Because of this, we only meet once a week. However, once summer begins, we increase our meetings to 6 days a week and put in countless hours at team members' swimming pools as well as our school's pool.

Figure 2: Our AUV: Marlin

II. Design Creativity

A. Mechanical

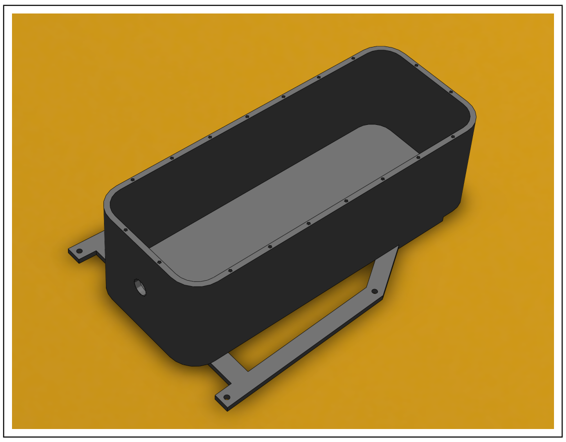

Figure 3: DVL Mount modeled in Solidworks

The mechanical subdivision is responsible for the design, manufacturing, and maintenance of Marlin's structural components. The objective of this year was mainly to improve some of the shortcomings we identified last year, and to accommodate radical new changes on the AUV for the updated competition. Some designs for certain competition areas were designed but not implemented on Marlin due to software integration difficulties. Mechanical objectives also included creating all of the new props in order to simulate the competition arena. These included the orange pole and gate, dice, and roulette table among others. Some highlights of this year included a brand new DVL mount designed by mechanical, which allowed us to mount the Explorer DVL we purchased (see Figure 3). In addition, the pneumatics dropper was modified, allowing the team to complete more challenges set forth by the competition. Finally, a new pneumatics box was created in order to fix the waterproofing problems presented by the previous one. The new pneumatics box boasts an IP68 rating and allows mechanical to easily access the contents without worrying about water leakage. Overall, the changes presented and executed by mechanical ensures the rest of the divisions can perform their jobs without worrying about the structural integrity of Marlin.

B. Electrical

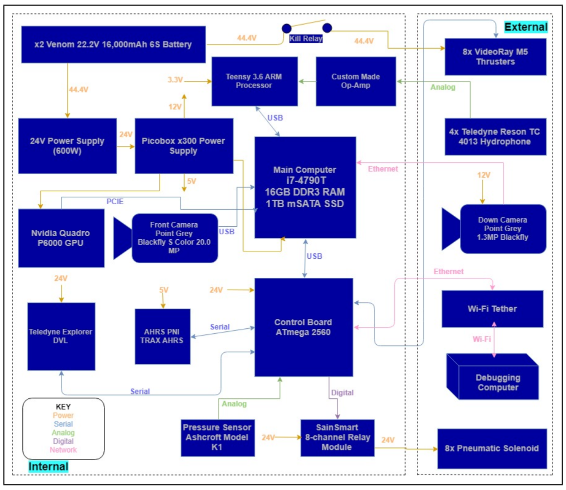

Figure 4: Overview of Marlin's electrical system

The electrical subdivision is responsible for all of Marlin's internal and external electrical components (see Figure 4). This year, electrical mainly focused on improving Marlin's rack as a whole to ultimately expand and enhance Marlin's efficiency and performance. Recognizing the limits of the current electrical setup, this electrical looked to partially remodel the electrical system. These adjustments include using a new Cincon DC-to-DC converter to increase power capacity from 300W to 600W, and mounting a new picobox x300 power supply. This expansion of power capacity and the rearrangement of power rails now allow Marlin to support an Nvidia Quadro P6000 GPU, which enables Marlin to handle more accurate and more advanced levels of vision processing. In addition, the electrical team replaced the original Point Grey 1.3MP front camera with a Blackfly S Color 20.0 MP (Sony IMX183) machine vision camera. By utilizing the new modularity of the electrical system, the team was also able to mount a Teledyne Explorer Doppler Velocity Log (DVL). The mounting of the DVL enables Marlin to precisely obtain velocity data to establish a more accurate control system. Electrical also added a newly remodeled kill switch and acoustic system. As a result of this remodeling, Marlin now has a centralized external power switch as a part of the kill switch (original function of killing motor power is maintained). Furthermore, the updates to the kill switch allowed for more efficient debugging of the electrical system. As for the acoustic system, remodeling was done to better align the system with the changes in the hydrophone algorithm (Time Difference of Arrival to Phase Shift). By keeping what worked and diligently replacing what failed, the current electrical system of Marlin is the most powerful of any vehicle in the history of AVBotz.

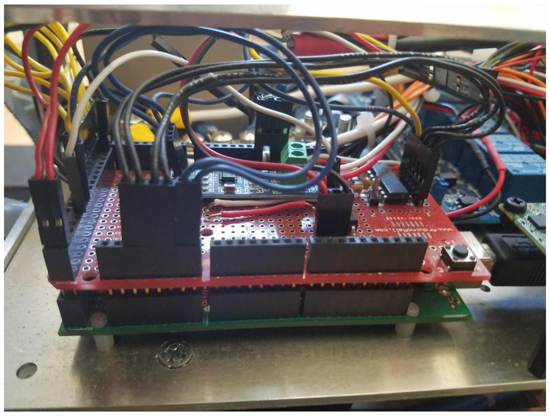

Figure 5: Atmega2560 Microcontroller

C. Software

The software subdivision is responsible for writing the software stack that powers Marlin for RoboSub, ranging from lower-level hardware communication to higher-level task and route planning strategies. Both the control system and mission system were completely rewritten, reflecting changes made to the competition and weaknesses in prior software systems. Nautical, the new control system, handles low-level communication to the hardware on Marlin and accurate state estimation. It operates on an ATMega2560 microcontroller, and interfaces to the sensors (AHRS, DVL, etc.) and thrusters through serial UART pins (see Figure 5). Estimated states in Nautical are represented using six degrees of freedom: X, Y, Z, roll (phi), pitch (theta), and yaw (psi). The AHRS returns accurate attitude data, while a Kalman filter is used to fuse accelerometer, DVL, and depth sensor readings to provide accurate position data along the body axes. The model for the Kalman filter is represented using position, velocity, and acceleration across the X, Y, and Z axis. On the other hand, six PID controllers mapping to the different degrees of freedom on Marlin are used to move efficiently between states.

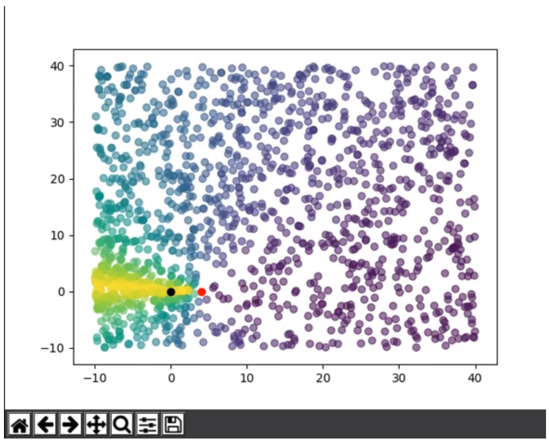

Figure 6: Particle Filter Localization

Aquastorm, the new mission system, handles high-level task and route planning. It is split into different processes run on multiple threads that communicate over shared memory. The mission process determines the optimal route for Marlin to take, based on approximated locations, time constraints, and point values. The modeling process handles localizing Marlin to the competition pool, using a particle filter of particles that represent Marlin's possible locations (see Figure 6). Known state updates are used to update these particles each iteration of the filter, and as Marlin detects objects in the competition pool, the particles are redistributed using recursive Bayesian estimation. Eventually, the particles converge to the true position of Marlin.

The webserver process creates a GUI through which the software team can interact with the rest of Aquastorm and Nautical. It is hosted on a Flask server, which allows the software team to use it in a regular web browser such as Chrome or Firefox. Image and state data is sent from Aquastorm over ZMQ sockets to the webserver so it is easily accessible for debugging.

III. Experimental Results

Throughout the course of Marlin's development in 2018, we experimented with and researched options that were either removed or never implemented into the AUV. Although many developments were not continued due to inconsistencies or better alternatives, our team still made many successful changes for RoboSub 2018.

A. Non-Linear Kalman Filter

Before implementing a linear Kalman filter, we researched the Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF). Both an EKF or UKF would have allowed Nautical to represent the state model using non-linear functions. For example, one could combine approximated speeds from thrust settings with attitude data from the AHRS using trigonometric functions for more exact state estimation. However, this proved to be computationally expensive on a microcontroller and excessive as the Explorer DVL returned accurate readings.

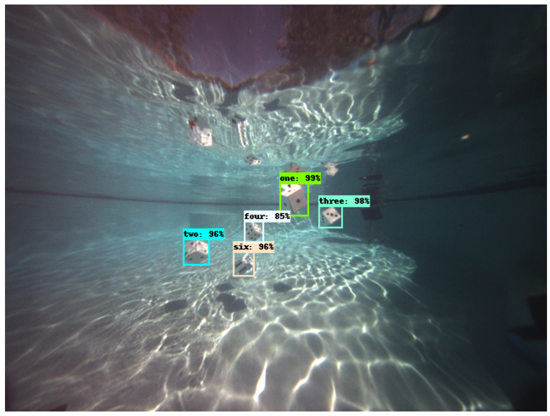

Figure 7: Machine Learning for the Shoot Craps Task

B. Machine Learning

In terms of machine learning and vision, given the improvements to generalization that neural networks realize with more data, training images were collected whenever possible at pool tests. Images were collected in a variety of conditions, and in different pools to ensure that the trained model would be robust. When training the model, we experimented with a variety of hyperparameters such as learning rate and batch size. Resources such as the Google Cloud Platform were utilized in order to quickly optimize models, as we lacked on-site resources to simultaneously train multiple models. Efforts were made to lower the time to perform inference on an image, so that the system would perform in real time. We experimented with different architectures, including other Faster-RCNNs, but their accuracy was deemed to be insufficient. Ultimately, adjusting the number of predictions in the first stage of Faster-RCNN inference allowed us to achieve reasonable inference times.

C. Hydrophones

This year for signal processing, we switched from an FPGA to the PJRC Teensy 3.6 microcontroller for its fast processor, built-in ADCs, and ease of development in C++ using well-supported existing libraries. Because of limited memory, we implemented an online DFT for only the four competition frequencies by combining batches of transformed samples with an infinite impulse response filter. A majority of developing time was spent testing and debugging various components of the software in order to ensure reliability and correctness. We determined that multilateration responded poorly to small noise in the phase shift estimates, so we instead approximate the angle of arrival using geometric methods which sacrifice precision for stability.

D. Ball System

At the beginning of the season, a ball system was designed and created that utilized water pressure using a pump to pick up, move, and drop balls to complete tasks. However, for the ball system to work, the ball intake port would have to be positioned in close proximity to the golf ball. This proved to be very challenging for the software subdivision as that required a high level of accuracy, and eventually, the ball system was scrapped in order to redirect the resources on tasks that our team would have a higher chance of successfully completing.

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. We would also like to thank Luke Shimanuki for his invaluable advice in hydrophones. Furthermore, we would like to thank the following sponsors for donating their resources to help AVBotz pull through purchases and upgrade the sub: 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
SPECIFICATIONS

Table I: General

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

Table II: 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)
Actuators	Numatics	0438D01-04A	Bore Size: 7/16” Stroke Size: 4.0”
CO2 Cartridge	JT	90g CO2 Cylinder Cartridge	Non-refillable

Table III: Electrical Components: Power Delivery

Component	**Vendor**	**Model/Type**	**Specifications**
Battery	Venom	16000mAh 6S	Battery Type: LiPo Volts: 22.2V each Cell Count: 6S Capacity: 16000mAh
DC to DC Converter 1	Cincon	CFB600-48S24	Input Voltage: 36V-75V Output Voltage: 24V Max Output Current: 25A Percent Efficiency: 92%
DC to DC Converter 2	Picobox	x300	Input Voltage: 16V-24V Output Voltage: 3.3V, 5V, 12V Max Power: 39W, 60W, 192W Percent Efficiency: >90%

Table IV: 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 V: 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	Quadro P6000	CUDA Cores: 3840 Memory: 24GB GDDR5X Max Power: 250W

Table VI: 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	Kowa	LM6HC	Focal Length: 6mm Mount: C Mount Horizontal Angle: 96.8° Vertical Angle: 79.4°
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: $\leq$5MP Mount: CS Mount Horizontal Angle: 135° Vertical Angle: 119°

Table VII: 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	PJRC	Teensy 3.6	I/O Pins: 62 Processor: 180MHz ARM Cortex-M4 RAM: 256K Serial Ports: 6 Analog to Digital Converters (ADC): 2

Table VIII: Software

Programming Language 1	C++
Programming Language 2	Python
Operating System	Ubuntu 18.04
Open Source Software	OpenCV (Image Processing Library) Tensorflow (Machine Learning Library) ZMQ (high-performance messaging Library) Armadillo (Matrix Library)
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	Monte Carlo Localization (Particle Filter)
Algorithms: Autonomy	Markov Decision Process

Appendix B
Community Outreach

This year our club participated in several outreach events, either as workshop leaders or as volunteers to help promote robotics and engineering often by showcasing our submarine. We held local events at three Pleasanton middle schools: Harvest Park, Hart and Pleasanton Middle Schools. To promote coding at younger ages we lead weekly after school lessons at Harvest Park and PMS. Many team members, especially from the software division, taught a 20 week course on Java and Python to 100 middle school students during the school year. Our members led workshops at a local hackathon, ACE Code Day, providing a plethora of workshops on robotics and computer science, ranging from a crash course in machine learning to an introduction in hardware components. Events like these allow us to share our knowledge to 200-300 future engineers and potential club members, thus promoting our club and furthering its mission. When we met with the local Lego Mindstorms robotics club at Harvest Park we arrived to find 50 middle school students ready to learn, to fix problems, and to ask questions to expand their knowledge. At HART's annual STEAM night, when our sub entered the multipurpose room, students were awed by the size and complexity of our submarine. And finally, we transported our sub to the Livermore Innovation Fair, where we explained its inner workings and capabilities to hundreds of families and children of all ages. Through all of these outreach events we hoped to inspire students to explore the field of robotics.