EMU Aquabotics: Development of an Autonomous Underwater Vehicle (Caretta^2)

Abdel Rahman Bekawi, Ahmad Kutada Aljabali, Ahmed Elsayed, Hazem Mohamed, Shehabeldin Housein, Amina Ait Ben Ouissaden, Al-Khattab Al-Qaseem, Alhassan Khalil

Abstract— EMU Aquabotics team has designed and manufactured its first AUV called Caretta2, with the aim of competing in RoboSub 2019, which is Eastern Mediterranean University first entry into the competition, the development provided practical experience for undergraduate students in both engineering and management skills, this project serves as the start of a platform for further development in the coming years.

I. Competition Strategy

Since RoboSub 2019 is the first participation of EMU Aquabotics, majority of the time was spent developing the vehicle, leaving limited time available for testing, to maximize testing time the development of Caretta^2 was completed over two stages, the first was used to verify basic control and movement functionality, Gripper mechanism and hardware inter-communication, while the second stage is the feature complete AUV.

To best utilize the available testing time, it was decided to focus the mission strategy on the most common parts between the missions, and try to complete as many missions by focusing on the easiest version of each mission, avoiding risk of wasting time on a bonus and failing to complete it, or the vehicle getting stuck or lost.

Even though the aim in RoboSub 2019 is not to complete the entire mission, the vehicle was designed to be capable of performing all the missions, to serve as a platform for testing and development of next year's vehicle, providing water testing time while the new vehicle is being designed and providing design insights for 2020's vehicle from the mistakes made in 2019's vehicle.

II. Design Overview

The design of the circuitry was done to give the desired functionality needed by each system. Splitting the design into subparts made it easier to manage and debug, so that when a component fails the other doesn't. Safety feature is implemented on each board to assure the overall system's safety.

Software is the main enabler for all complex engineering systems, our vehicle's software system can perform complex tasks that is essential in any autonomous unmanned system. We used ROS as our primary software development tool which provides a very flexible communication paradigm for such complex system [1]. Hence, we embarked upon outsourcing using packages provided by the opensource community to build a reliable and functional system avoiding any possible time-consuming problems for our first-time participation.

III. Mechanical System

Since this is Aquabotics's debut in RoboSub, A review of previous designs as well as commercial ROVs was necessary to gain a deeper understanding of how UVs operates mechanical wise. The timeline was divided into two phases. The purpose of Phase 1 was to build a simple ROV to test our buoyancy and stability calculations, motor configuration options, isolation methods and other basic functions.

The design process mainly focused on reducing the overall vehicle dimensions and weight, ensuring that the vehicle is adequately rigid and reaching a suitable separation between the center of mass and the center of buoyancy. Increasing serviceability was also a priority as it eases assembling and disassembling the vehicle and reduces the time spent on maintenance.

The modularity of the design was also considered, although it decreased in the final stages as it added to the overall dimensions and weight of the vehicle. During the early design stages, the surge, sway and heave thrusters were placed on sliders to ease changing their position according to the then changing center of mass as some components were constantly added and removed. A sliding mechanism was also developed for the gripper to help achieve optimum camera position to view both the end effector and the mission probes.

The center of mass and center of buoyance placements were a critial aspect during the design process. The chassis was intended to be inherently stable without the heave thrusters' interfernece. However, an excess separation between both centers will increase the restoring moment, thus increasing the effort made by the thrusters during pitching and rolling. This increases the power drawn from the batteries which reduces the operation time. After testing variable separations, a balanced configuration was achieved.

Figure 1 Caretta Caretta SolidWorks Render

To keep track of our design efficiency, we calculated its actual DFA improvement as the vehicle was redesigned. The final design configuration was about 70% the size of the initial designs and 27% lighter. The side frame was redesigned to be as topology optimized as possible. Next, all the protruding parts were removed to prevent the vehicle from getting stuck on the mission probes. The body is made entirely of HDPE. During the early stages, Cusom designed 3D printed PLA adapters were used to fasten the supports on the side frame, but they were deemed inefficient as they could not withstand fatigue, especially during transportiaion as the testing facility was not close to the workshop. They adapters were replaced with more reliable, available off-the-shelf Aluminum links. Eight BlueRobotics T200 Motors were placed in a vectord configuration, with the added option of choosing between 30^{o} and 45^{o} for the surge motors.

A custom made enclosure, mainly consisting of two Aluminum endcaps, two Aluminum flanges and an acrylic tube, was deigned to specifically house the used electronics. It features both mechanical and chemical isolation. Two O'rings were placed between the flanges and the tube and another two were placed between the flange and the endcap. The cables passed through a gland which was tightened. Next, marine grade silicone was added inside the gland to further ensure isolation. The electrical components were mounted on circular Aluminum plates which together with the Aluminum endcap, acts as a heat sink.

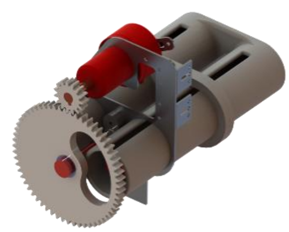

Figure 2 Torpedo Mechanism

Caretta^2 Features three mechanisms: a gripper, a torpedo firing mechanism and a mark dropper mechanism. A readily isolated, modified DC pump was used to power all three mechanisms. This was achieved by designing a custom coupling for each mechanism to suit its need. The gripper mainly relies on a ball screw coupled to the motor's shaft, which smoothly transforms rotational motion into linear motion with minimal backlash. A quad end effector is used as it is suitable for picking up the garlic and the crucifix, moving the handle in the "Stake though Heart" mission and sliding the pin in the "Expose to Sunlight" mission. The torpedo firing mechanism operates by compressing of a spring and holding it using the face of a gear. A smaller gear is fixed on the motor using a special coupling, which drives a larger gear. This gear has a cicular opening slightly larger than the torpedo's diameter, which realeases the torpedo when the gear rotates. In addition, there are three mechanical comprssion levels integrated within the torpedos' housing. The speed of rotation mainly relies on the software. Similarly, the mark dropper mechanism has a gear mechanism which releases the housed balls when the gears rotate, without the need of a spring.

IV. Electrical System

Our approach is to design simple and reliable electrical system by using off-the-shelf electronic components. Electrical system consists of 3 major parts, each to be developed separately. Eventually, everything to be merged providing a harmonious system.

A. Sensor integration

The vehicle uses Pixhawk as an attitude heading and reference system (AHRS) where IMU, Compass and Gyro are integrated in it. Blue robotics Bar30 was incorporated providing the vehicle with depth readings. Two stereo cameras are integrated in the system, Zed camera for object detection and Intel RealSense for localization and tracking. Hull monitoring are achieved with the DHT-11 temperature and humidity sensor and SOS leak sensor. All sensors to communicate to the main control unit through an intermediator board or directly to the mini pc.

B. SONAR

Four TC4013 hydrophones are arranged in a uniform rectangular array (URA) to localize a sound source implementing direction of arrival (DOA) algorithm. Hydrophones are connected to STM32 development board where the signals to be digitalized and processed. The array is mounted on the very front and bottom of vehicle to avoid any reflections from the vehicle body and surface of the water, also, thrusters to be turned off also to minimize noise.

C. Power Distribution

Two Li-Po batteries of 16000mAh capacity connected in parallel are used to power up all the components, providing enough running time. The power system is configured to operate in two different modes, external power supply and batteries. Wet connector are fixed on the hull endcap to connect the power supply to the vehicle. BlueRobotics safety kill switch is to control the switching between the modes.

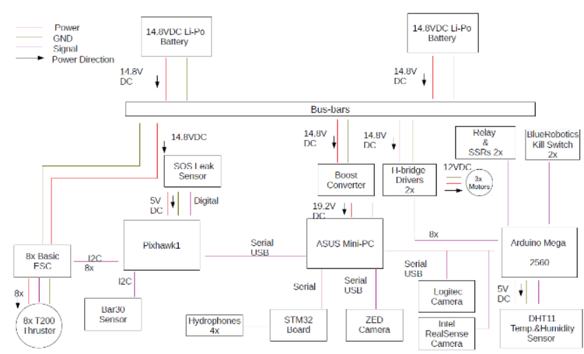

Figure 3 Circuitry Block Diagram

V. Software System

Caretta[2] software is built on top of ROS kinetic and ROS terminology to be used through this section. The software system coordinates the data flow between the main control unit the mini-pc and different hardware parts including sensors, electrical boards, and thrusters. Various pre-written ROS packages are used to achieve this task. ROSSerial to communicate with embedded boards, MAVROS to facilitate the communication with the Pixhawk and ROSJOY to operate the vehicle in ROV mode where it's helpful to collect underwater records for vision software development. The design composed of 4 main ROS packages Control, Navigation, Autonomy and Image processing.

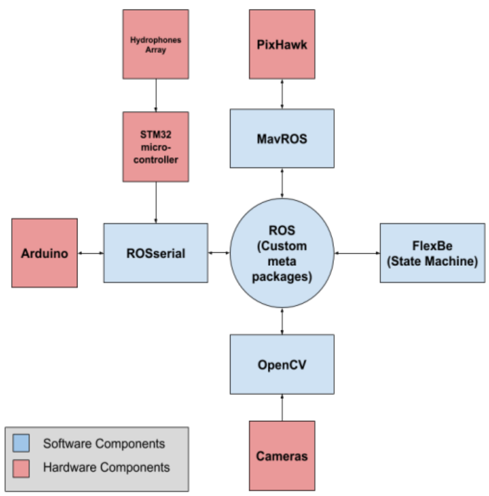

Figure 4 software hardware block diagram

A. Control

ArduSub is our thruster motion control with a PID system, we used the firmware along with its compatible hardware the pixhawk to provide maneuverability for Caretta[2] in all six degree of freedoms. an off-the-shelf controller with an available ROS driver, is used to save development time and effort, and ensure ease of integration within the vehicle.

B. Navigation

The new Intel RealSense T265 tracking camera were incorporated in the system, as an optimum solution with the available resources to provide the vehicle, with the essential odometry data for localization. Navigation package receives a point in space as an input and then navigate the vehicle to reach the goal point. ArduSub and Navigation stack are consolidated to provide smooth, fast and accurate movement in 3D space.

C. Autonomy

Autonomy package is the mission planner to complete the competition tasks. It is implemented using FlexBe state-machine tool to design a robust and modular state-machine. Following an approach of incremental design to develop autonomy behaviors, ensuring functionality in all possible events during the competition race. Recovery behaviors are included to recover the vehicle if lost or stuck.

D. Image processing:

The primary limiting factor for the design and development of the vehicle's computer vision and image processing algorithms, is the processing capabilities of the on-board computer, thus the use of computationally expensive process such as DNN object detectors had to be limited, while maintaining an acceptable level of accuracy.

To meet these requirements, YOLO-Lite [2] was chosen as the object detector, despite not being the most accurate, because of its vastly superior performance compared to other options including Tiny YOLO, furthermore, YOLO Lite is coupled with OpenCV's Median Flow tracker, by splitting the camera stream into major and intermediary frames with a 1:15 ratio or one major frame every 0.25 seconds, major frames go through the object detector, and intermediary frames are processed by the tracker to keep track of the detected objects at a relatively low processing cost.

Table 1 Object detection models performance

Model	Accuracy	FPS	Training Time (hours)
YOLOV3	57.3%	0.2	16
YOLOV3-tiny	31.7%	3	12
YOLOV2	46.4%	1	12
YOLOV2-tiny	23.5%	6	15
YOLO-LITE	33.6%	11	14

VI. Experimental Results

All written codes are tested on the software in the loop (SITL) simulator to verify overall system functionality. Given that testing time underwater were very limited due to the amount of time spent for vehicle development and lack of facilities, we tried to test all software elements in simulation, and develop state-machines mimicking some of the competition missions.

Most of the basic vehicle functionalities were tested in the first stage of the project which was an ROV with limited autonomous capabilities.

Isolation method was tested using negative pressure by bumping the air outside the isolation hull, afterwards it was tested in water.

VII. Acknowledgements

Eastern Mediterranean University Aquabotics team would first and foremost like to thank Asoc. Prof. Dr. Qasim Zeeshan for all the technical and non-technical guidance he provided, and Prof. Dr. Hasan Demirel for his great continuous support through each development stage of the project.

The team also would like to thank our sponsors, Turkish airlines and Shipyard Famagusta.

VIII. References

[1] L. Joseph, ROS Robotics Projects, BIRMINGHAM - MUMBAI: Packt, 2017.

[2] Rachel Huang, Jonathan Pedoeem, "YOLO-LITE: A Real-Time Object Detection Algorithm Optimized for Non-GPU Computers," 2018.

Appendix A: Expectations

Subjective Measures			
	Maximum Points	**Expected Points**	**Points Scored**
Utility of team website	**50**	30	
Technical Merit (from journal paper)	**150**	125	
Written Style (from journal paper)	**50**	35	
Capability for Autonomous Behavior (static judging)	**100**	70	
Creativity in System Design (static judging)	**100**	50	
Team Uniform (static judging)	**10**	10	
Team Video	**50**	40	
Pre-Qualifying Video	**100**	100	
Discretionary points (static judging)	**40**	25	
Total	**650**	485	

Performance Measures			
	Maximum Points		
Weight	**See Table 1 / Vehicle**		
Marker/Torpedo over weight or size by <10%	**minus 500 / marker**		
Gate: Pass through	**100**	100	
Gate: Maintain fixed heading	**150**	150	
Gate: Coin Flip	**300**	0	
Gate: Pass through 60% section	**200**	0	
Gate: Pass through 40% section	**400**	400	
Gate: Style	**+100 (8x max)**	0	
Collect Pickup: Crucifix, Garlic	**400 / object**	0	
Follow the "Path" (2 total)	**100 / segment**	200	
Slay Vampires: Any, Called	**300, 600**	600	
Drop Garlic: Open, Closed	**700, 1000 / marker (2 + pickup)**	1400	

Drop Garlic: Move Arm	**400**	0
Stake through Heart: Open Oval, Cover Oval, Sm Heart	**800, 1000, 1200 / torpedo (max 2)**	800
Stake through Heart: Move lever	**400**	0
Stake through Heart: Bonus - Cover Oval, Sm Heart	**500**	0
Expose to Sunlight: Surface in Area	**1000**	1000
Expose to Sunlight: Surface with object	**400 / object**	400
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 + factional)	**Tx100**	500

Appendix B: Component Specifications

Component	Vendor	Model/Type	Specs	Cost ($)
Frame	Custom	CNC cut HDPE	-	385
Waterproof Housing	Custom	Acrylic tube and aluminum endcaps	-	350
Waterproof Connectors	DWTEK	HPBH4F, HPIL4M, PBBH4F, PBIL4M	-	519
Thrusters	Bluerobotics	T200	Max thrust 5.1kgf	1572
Motor Control	Bluerobotics	Basic ESC	30A	-
High Level Control	ASUS	Vivomini UN68U	-	790
Actuators	Al-Shorok company	Bilge pump	-	171
Battery	Hobbyking	Turnigy	4S, 16Ah	233
Converter	bangood	XL6009	Boost converter	3
Programming Language 1	Python	-	-	-
Programming Language 2	C	-	-	-
Programming Language 3	Bash	-	-	-
Attitude heading and reference system (AHRS)	mroRoborics	Pixhawk1	IMU, Compass, Gyro, PID control	250
Camera 1	ZED	Zed mini	Stereo camera	449
Camera 2	Intel	RealSense T265	Stereo camera onboard SLAM	199
Hydrophones	Teledyne Reason	TC4013	Omnidirectional, sensitivity -211dB	3897
Manipulator	-	Custom design	-	-
Algorithms: vision	OpenCV	OpenCV 4.0	-	-
Algorithms: acoustics	custom	-	-	-
Algorithms: autonomy	-	FlexBe	State-machine	-
Algorithms: software	Open Robotics	ROS	-	-
Team size	10	-	-	-
HW/SW expertise ratio	3:5	-	-	-
Testing time: simulation	15hrs	-	-	-
Testing time: in-water	50hrs	-	-	-

Appendix C: Outreach Activities

group photo after the event

EMU Aquabotics team organized an event for the vehicle in its first phase as an ROV, inviting all interesting students and the university's rector

team demonstrating the vehicle in EMU stand

Aquabotics team represented Eastern Mediterranean University at the 43rd TRNC Industrial Fair, organized by the Ministry of Economy and Energy.