Palomar Physics and Engineering Club: Design and Development of AUV mk1

Kanoa Nakama, Cody Pennefather, Logan Chavez, and the rest of the Palomar P&E Robosub team

***Abstract* - This paper details PalomarP&E's current progress in the design of an autonomous underwater vehicle (AUV) to participate in the Robosub 2021 competition**

I. Competition Strategy

This is the first year Palomar P&E is competing in the Robosub competition. While our members have previous experience in mechanical and electrical design, we felt our initial knowledge of software libraries related to robotics was limited. This led us to choose the simplest strategy to qualify: achieving the gate task. This allowed us to start with a more basic design and still have the flexibility to consider other tasks like the Path, Make the Grade, and potentially the Cash or Smash in the future.

In the development of the AUV our fall semester was focused on organizing our team through online means due to the unique circumstances imposed by the COVID-19 pandemic. We established communication through Discord and utilized Github and GrabCAD for project data management of the robot giving us a solid online workflow for our team. To effectively cover the responsibilities of designing the robot as well as the funding and outreach for our club we divided up into four main subteams: Mechanical, Electrical, Software, and Business.

Due to our limited software knowledge we decided that it would be more cost and time effective to develop a low cost robot to emulate the functionality that our AUV would have rather than spending time and money on a fully functioning AUV that the team would struggle to program. Referred to as the practice bot, the result was a differential drive robot with a Jetson Nano to handle ROS and computer vision, as well as an Teensy 4.0 for sensor input and motor control systems. As of now the practice bot is able to perform object tracking and line following which were essential goals for us before moving forward with constructing the AUV. Currently we are still finalizing the design for the AUV as well as sourcing funding for our vehicle.

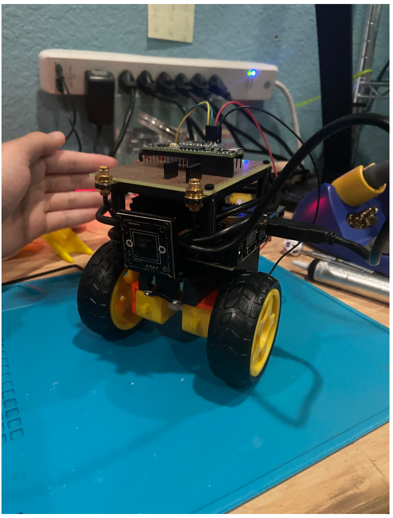

Figure 1: Practice Bot

II. Vehicle Design

In the design of P&E's AUV we chose to align our design goals with our competition strategy with keeping the design simple, but aiming for easier long-term maintenance and upgradability that could make the initial research/design phase more drawn out.

A. Mechanical Design:

The design goals for the mechanical team are outlined below:

- Waterproofing internal electronics and external connections for prolonged submersion
- Organizing the internal electronics in a safe and easy to maintain fashion.
- Designing a frame to mount enclosures, thrusters, and other external sensors or lights in a compact and easy to maintain form factor
- Determining the positioning/ orientation and number of thrusters needed for the desired movement for the AUV.

One of the team’s main constraints was not having access to on-campus manufacturing capabilities such as CNC mills and routers. Realizing this early on led to utilizing off the shelf components and making the usage of them within our design more flexible with 3D printing.

Waterproofing: For our choice of enclosures we decided to utilize off the shelf models from Polycase. This was decided due to members not having the expertise needed to construct a reliable custom waterproof enclosure and not wanting to risk the time and work needed for the processes involved for a possible failure to occur. While this did limit the internal volume housing our electronics, the tradeoff for a reliable waterproof enclosure was justifiable. Bulgin connectors were chosen to provide a waterproof connection for external I/O. They fit our need for a removable waterproof connection that also separates the internal and external wiring as to mitigate any accidental water damage when maintenancing the internal electronics after a competition run or testing.

Electronics mounting: The mounting structure for the internal electronics is still early in its CAD design but the conceptual work is complete. The goal would be to utilize a 3D printed rack that rigidly mounts the separate boards and can be removed as a unit from the enclosure entirely for testing/ repair when out of water.

Frame: The frame consists of PVC pipe as the main structure, with 3D printed custom joints and mounts bolted to the PVC pieces which gives our thrusters and enclosures a rigid body to mount to. While there were popular alternatives like HDPE panels or Aluminum extrusion, we felt that the extremely low cost of PVC and the amount of rigidity they offered for the smaller scale of our frame made them the optimal choice.

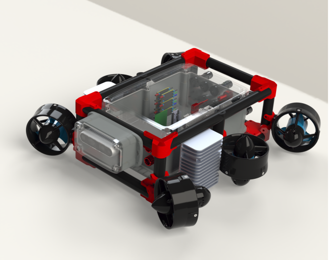

Figure 2: The CAD model of the AUV designed in Solidworks

Thrusters: The choice to utilize Blue Robotics T200 thrusters went by similar logic as our enclosures, wanting to minimize possible points of failure by choosing a reliable but slightly more expensive off the shelf component. Positioning them and the final number of thrusters was decided with the competition strategy in mind. To perform the gate task linear movement in the xyz axes and rotational yaw movement were deemed necessary at a minimum. This led us to choose a popular configuration of four angled horizontal thrusters for xy movement plus yaw rotation, and two vertical thrusters that perform movement along the z axis as well as roll rotation if needed.

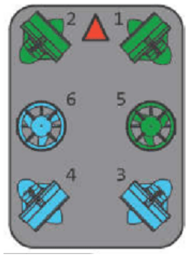

Figure 3: Top view of thruster configuration

B. Electrical Design

The design goals for the Electrical team are outlined below:

- Determining the appropriate onboard computers, sensors, and actuators to enable the AUV to autonomously navigate, in light of the design choices of the mechanical and software subteams.
- Determining an appropriate power supply to accommodate the voltages and max current draw required for all internal and external devices. As well as distributing the proper voltages required and implementing proper protections for both the power supply and all devices on the AUV
- Creating the proper signal and power connections between the onboard computers, sensors, and actuators in a compact form factor

With these design goals in mind, the team decided that buying off the shelf modules for the battery (LIPO), onboard computer (Jetson Nano), microcontrollers, and sensors while custom designing PCBs for them to interface with would result in a reliable design going forward for future years. Further, the responsibilities for the PCBs could be grouped into two boards: the power distribution board and the Microcontroller/sensor board.

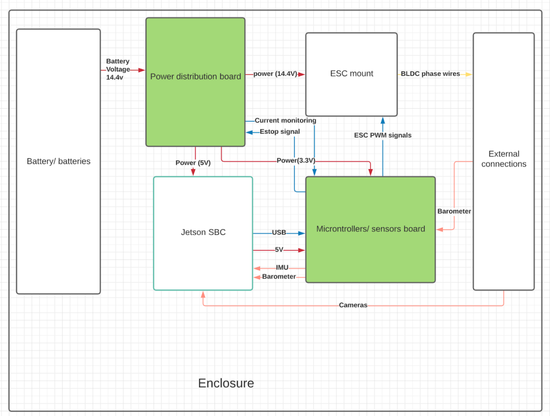

Figure 4: Overview of the internal electronics

Power Distribution Board (PDB): The PDB takes the input power from the battery and distributes the regulated voltages to the Jetson Nano and the Microcontroller/sensor board, while also sending the battery voltage in parallel to the thrusters.

A second responsibility is providing undervoltage and overcurrent protection for the battery and the microcontrollers, sensors, and onboard computer. This is done through buck converters which power the onboard devices, overcurrent protection is accounted for with individually fused ESCs, and the battery is protected against undervoltage with one of the microcontrollers monitoring the LIPO battery balance connector pins and controlling a MOSFET that acts as our thruster shutoff.

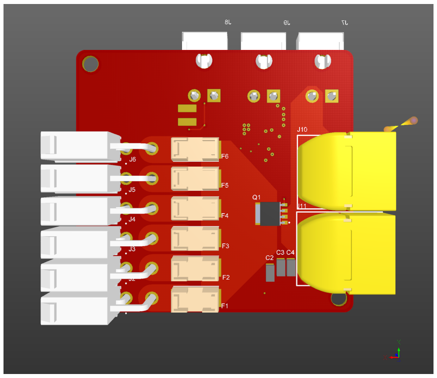

Figure 5: The power distribution board designed in Altium

Microcontroller/Sensor Board: The Microcontroller/sensor board is equipped with two Teensy 4.0 microcontrollers and interfaces with an IMU, Barometer, Leak sensor, and Hall effect sensor to monitor the external magnet killswitch. The Teensys are split into two main functions: one acts as the flight controller, handling the input from the Barometer and the IMU and interfaces with the Jetson Nano to enable navigation. While the system manager monitors the rest of the sensors to communicate any critical failures to the rest of the system and handle the shutdown of the thrusters on the AUV if required.

C. Software Design

The design goals of the software team are outlined below:

- Enabling the AUV to autonomously navigate from an initial position to an identified target position in the competition field in the context of each task
- Implementing a mission planner to allow the AUV to handle higher level competition task decisions and respond to low level sensor signals in emergency situations

The primary focus with our software design was to make sure the robot could complete the gate task to align with our competition strategy. To work towards our design goals within the gate task and future tasks we divided our software development into five main areas: ROS integration, mission planning, computer vision, navigation, and motor control.

ROS: The team chose ROS as the framework for the communication between the rest of our code. Although the initial research and becoming familiar with the various APIs and packages ROS offered was tedious, we decided that the payoff of being able to easily integrate, test, and troubleshoot our current and future code would be worth the effort.

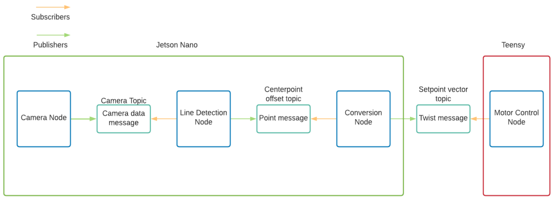

Figure 6: Practice bot line detection node map

Mission Planning: The mission planning code is still in the research phase of development, our software team is currently investigating the use of Behavior Trees or Finite State Machines in conjunction with ROS to achieve the desired functionality. This would likely manage cycling through high-level substeps of a chosen task, as well as responding to critical failures from the system manager and halting the current processes to switch into a standby state.

Computer Vision: The purpose of the computer vision code is to provide environmental information to the motor control code and to allow the robot to process its surroundings. Using OpenCV, by detecting the orange contours seen on the pillars of the gate, the robot is able to determine where it is in relation to the gate so it can send that information to the motor control code through ROS. As OpenCV works well within the gate task, for more complex image recognition with the Make the Grade task and others the use of Machine learning is being investigated.

Figure 7: Demonstrating detection of one side of the gate to pass through

Navigation: Similarly to the Mission planning code, the Navigation processes are still being researched. While the current autonomous navigational abilities of the Practice bot take a heuristic approach of reacting to narrow conditional statements based on info from the camera sensor, we aim to work towards a more optimal approach to the problem. This would most likely utilize point cloud data via an RGB-D camera sensor to create a map of the environment with SLAM where we can then localize our AUV within the created map and perform path planning based on the computer vision input which would feed direction vectors into the motor control systems.

Motor Control: Motor control is handled on the flight controller, where it uses the 9DOF IMU (gyro/mag/ accel) and barometer data in a complementary filter to acquire the pitch/roll/yaw/ depth of the AUV. Those values are set at a stable heading with PID controllers for each axis. Movement of the AUV is currently determined with outputs from the computer vision program, but as mentioned previously we aim to further develop the navigational abilities of our AUV in the future.

III. Experimental Results

As previously stated, our AUV is not fully designed/ manufactured as of writing this paper. With robust preparation done this year and planned for the following, P&E aims to be able to manufacture an AUV that meets our design goals by participating in the 2022 Robosub Competition.

IV. Acknowledgements

Palomar P&E would like to thank our Physics and Engineering faculty advisors, Dr. Patrick Nunally, Prof. Hector Garcia Villa, and Prof. Quan Nguyen for their continuous input and support of our project. We would also like to appreciate our sponsors, Dassault Systémes, Bulgin Connectors, and Mathworks, for providing resources that made development of our AUV possible. Additionally, we would also like to thank the Palomar Inter-Club Council and the Associated Student Government for providing us with outreach and funding opportunities within Palomar Community College.

Appendix A: Component Specifications

Component	**Vendor**	**Model/Type**	**Specs**	**Cost (if new)**	**Status**
Buoyancy Control	N/A	-	-	-	Not yet purchased (NYP)
Frame	Home Depot/ HatchBox	PVC pipe, ABS			NYP
Waterproof Housing	Polycase		IP68		NYP
Waterproof Connectors	Bulgin connectors		IP68		NYP
Thrusters	Blue Robotics	T200			NYP
Motor control	Blue Robotics	Basic ESC			NYP
High Level Control	PID control	Custom code			NYP
Battery	Amazon	4S 8500mAH Lipo			NYP
Regulator	Mouser				NYP
CPU	Nvidia	Jetson Nano			
Internal Comm Network	USB				
External Comm Interface	Ethernet				
Inertial Measurement Unit (IMU)	Adafruit	9DOF IMU			
Vision	Intel	Realsense 455	RGB-D camera		
Algorithms: Vision	Gaussian Blur,				

	Canny Edge Detection				
Algorithms: Localization	PID				
Open source software	ROS, OpenCV, Ubuntu				
Team Size	10				
HW/SW Ratio	1:1				
Testing Time	N/A				
Programming Language #1	Python 3				
Programming Language #2	C++				