Unmanned Surface Vessel Development for Robot-X 2022 - Prawnie

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***Abstract*—Unmanned Surface Vessels (USV) continue to be at the forefront of marine operations combined with the surge in interest of robotics and autonomy has led to high demand for young engineers with the skills to develop this technology. Team Mantis a student-based team from The University of Queensland aim to develop a fully autonomous USV for the Robot-X competition in 2022. Competing for the first time, planning, designing and constructing the vessel to record, process and interpret environmental surroundings and navigate through a variety of courses and tasks. This paper outlines the vessel design and explores the rationale for design selection.**

I. Introduction

Automation of systems and processing continues to be advancing at a rapid pace with small businesses and industries turning to autonomy to bridge skill and human resource shortages. Teaching the next generation of engineers and programmers to construct these systems is critical to ensure growth in autonomous industries, Team Mantis aims to aid this process by supporting young engineers in development and implementation of their ideas in novel and exciting environments. Part of this aim is the ability not just for development of an autonomous unmanned surface vessel (USV) but also for team members to develop the skills to work autonomously and within a team environment encouraging collaboration and communication.

Team Mantis from The University of Queensland will be competing in Robot X 2022 for the first time, beginning work in early 2022 a rapid development was required. Team members come from a broad engineering background with varying degrees of existing knowledge from first year to post-graduate studies, with unique sets of knowledge leveraged to design, build, test and present a new approach to Robot X in 2022.

Figure 1, Team Mantis unmanned surface vessel, Prawnie, undergoing pretest checks.

The vessel presented within has been affectionately named *Prawnie* due to the positioning of cameras above on the port and starboard side resembling a mantis shrimp (Figure 1). This is a good example of the team attitude we try to embrace not just looking to the natural environment to develop different approaches but also a lighthearted and supporting environment providing positive support for team members.

II. Design Strategy

Development of Prawnie has focused on rapidly designing, prototyping and revising potential solutions while minimising complexity. Team Mantis has tried to focus on achieving fit for task solutions while allowing for future expansion where required. Balance in design is always an important component, within this project understanding where sub-systems lie on a quality, time, and cost triangle is important to understand how to prioritise where budget or human resources are allocated, or cost associated with purchasing a part locally compared to extended shipping times direct from the manufacturer.

For these reasons, Team Mantis decided to focus efforts on key areas of competition which formed an underlying basis for future work or tasks team members showed interest in and wished to pursue. Due to the complexity, it was decided that unmanned aerial vehicles (UAV) tasks would be out of scope, while significant interest in development of a UAV was present team members agreed focusing on a rigorous USV would provide better project outcomes. Proceeding, the identification of six tasks was planned based on similarity between tasks and the ability to be developed in parallel, which were.

- Task 1 – Situational awareness & reporting
- Task 2 – Entrance and exit gates
- Task 3 – Follow the path
- Task 5 – Scan the code
- Task 6 – Detect and dock
- Task 7 – Find and fling

While these tasks formed the design basis of Prawnie in its current state, allowing for future adaption has been at the forefront of design. This can be observed in the minimisation of permanent fixtures on the vessel and clustering of instrumentation to allow for upgrading to perform future tasks.

III. System Design

System planning began with simple network diagrams (Figure 2) focusing on equipment required to undertake the primary task of identification and navigation. During this phase, a subsystem-based approach was adopted where individual sensors would operate as separate computation nodes and provide information to a centralised node for decision making. Decentralised processing provides the benefit of redundancy within the network if a computation node is to fail an alternate is still operational and providing information. Drawbacks to this approach is the need for additional power supply within a limited power system, excess heat generation, and increased cost which was evaluated and deemed to be worth the redundancy provided.

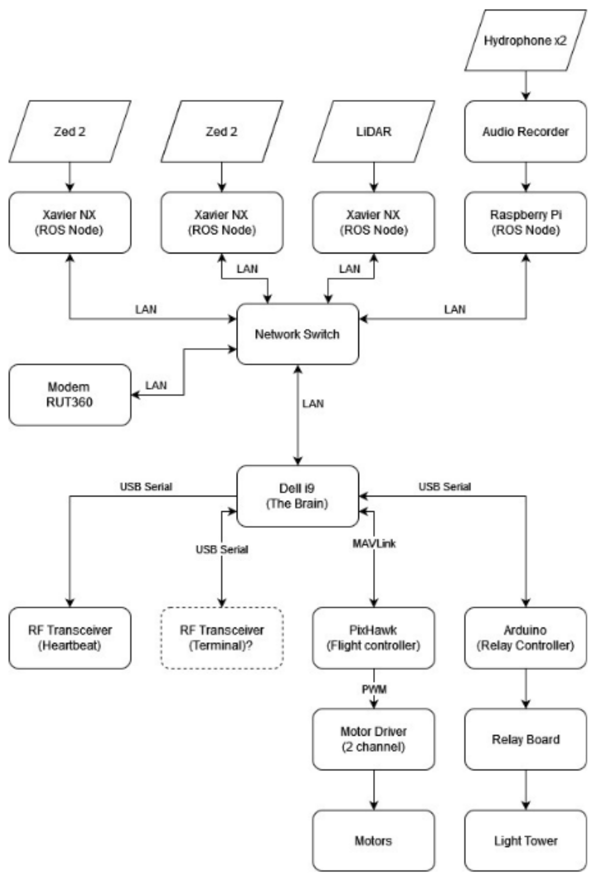

Figure 2, System network overview diagram of the computation network

A. Land to Sea Communication

Reliable communication between Prawnie and the shore is paramount to building public confidence in USV's, for this reason, Team Mantis has implemented multiple methods of communication. In simplest form is the emergency stop protocol, which utilizes 2.4 GHz to control power to the motors with an open state fail safe. Additional communication is through the 2.4 GHz H16 smart controller, two RFD 900x modems (915-928 MHz) (RF Designs, Archerfield, QLD, Aus), WIFI connection to a Rut360 (Teltonika, Kaunas, Lithuania), and finally a 4G mobile network connection through the Rut360.

These communication pathways provide a stepped approach to reliability and transfer rates dependent on the need, combined they accomplish the goal of the ability to hold continuous communication. Future designs plan to implement an indicator to the general public of vessels intentions, currently navigation of public waterways by autonomous vessels is in its infancy and as waterways have minimal restrictions upon movements unlike roadways it is important for USV designers to communicate motions to other waterway users to build confidence and operate safely.

B. Vessel Layout

Location of instrumentation was placed as a high priority in the initial planning of the vessel, an alteration to the centre of mass could destabilise the vessel leading to decreased performance or in extreme cases capsizing. Addressing this was a focus to keep the weight as low as possible above the centre of buoyancy, reducing the lever arm in rough conditions thereby minimising destabilising moments. For this reason, two aluminium storage containers were affixed to the underside of the payload tray, with the heaviest component being the batteries located toward the aft (closer to the centre on buoyancy), also within these storage containers are additional computation nodes, flight controller, network switch and most electrical hardware. These containers present both opportunities and challenges with the ability to affix instruments to the container to be used as a large heat sink which is shaded by the payload reducing internal temperatures. However, this also presents the need for power systems to be well shielded due to the potential of a short circuit through the container as well as the enclosed nature acting as a faraday cage which requires all antennas to be run externally for signal strength.

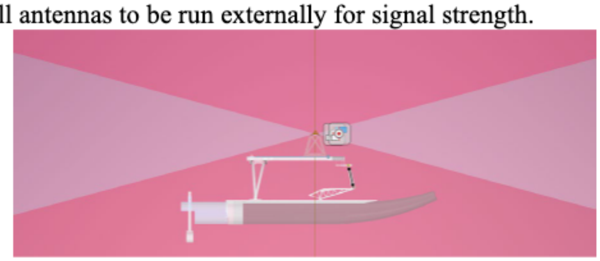

Figure 3, Field of view of the LiDAR sensor with raised sensor frame.

Instrumentation on top of the payload tray such as antennas, light towers, and sensor frame was considered. The final positioning of these was toward the aft of the payload tray allowing a clear area at the front for future development of UAV landing or other tasks. This area is also the location the find and fling sub-system is mounted when required. Concerned were raised about obstruction to the field of view of sensors however, by raising the sensor frame ~ 500 mm (Figure 3) no obstruction to LiDAR was present, while cameras were mounted overhanging the sides of the payload tray to allow unobstructed views of the sponsons.

C. Power Supply

Providing adequate power to components on the vessel was placed as a high priority and with extended lead times shipping high-capacity batteries, it was agreed that conservative power consumption would be adopted allowing for additions in the future if required. Two 24v LiFePo 150AH batteries (AT-LFP-24-150BTC02A, Amptron, Port Kennedy, WA, Aus) with a 200A peak discharge and 100A continuous were selected, one battery to power the motors and propulsion systems with the second powering computation nodes. Due to requirements by some equipment a 12v rail is also present within the vessel, supplied by a 1kW dc-dc converter (SD-1000L-12, Mean Well Enterprises Co., Ltd., New Taipei City, Taiwan) in additional to a 5.1v rail for microprocessors.

D. Sensor selection and mounting

A combination of stereo cameras and LiDAR were selected for navigation sensors, as a combined approach to high detail within the field of interest (~ 110° in front of the vessel) with cameras and 360° coarse data surrounding the vessel. The stereo camera selected is Zed 2i's (Stereolabs Inc., San Fransisco, CA, USA) these are an off the shelf stereo vision solution with an additional temperature sensor, gyroscope, accelerometer, magnetometer, and barometer. These additional sensors in conjunction with dual cameras, inbuilt calibrations and software generate x,y,z point cloud corresponding to the camera position simplifying the process of object detection. The maximum distance of point cloud is approximately 20 m which limits these to the near for point cloud generation however image-based detection is possible at greater distances.

Supporting the stereo cameras is a Velodyne Puck (VLP-16, Velodyne lidar, San Jose, CA, USA) while having limited vertical resolution due to 1.875° band separation provides data when image-based approaches struggle such as in poor visibility conditions due to sun glare, rain etc. this provides redundancy within the object detection sensors.

Additional to the primary navigation sensors are hydrophones for the location of subsurface pinger outlined in Task 2 – Entrance and Exit Gates, two AS-1 Hydrophones (Aquarian Audio & Scientific, Anacortes, WA, USA) connected to a Zoom UAC-2 (Zoom, Hauppauge, NY, USA) provide dual channel audio feed for signal processing.

E. Propulsion

Thrust for Prawnie is provided by two Striker 90lb brushed trolling motors which are readily available through many drop shipping companies and combined provide sufficient thrust for speeds up to 1 m/s. While brushless motors provide efficiency benefits the cost, lead time and added complexity led to the low cost brushed motors being selected. Motors are controlled by a Cube Orange with ADS-B carrier board (Hex Technology, Austin, TX, USA) flight controller configured to rover mode with tank steering providing a PWM signal to a RoboClaw 2x60A motor controller (Basicmicro Motion Control, Temecula, CA, USA) regulating the voltage provided by batteries and therefore trust produced by motors.

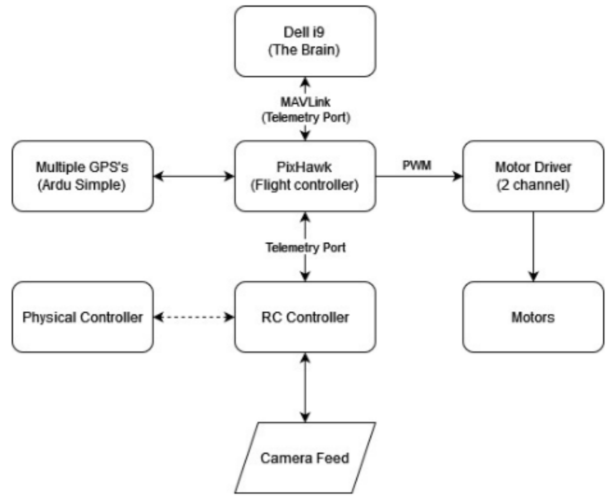

Figure 4, Overview of flight control sub-system network and associated components.

In addition to providing control of the motors, the Cube Orange also receives instruction from the decision-making machine (The Brain), in regard to propulsion operations to perform over MAVlink (Figure 4). These commands can range from simplistic move forward with the current heading or more complex task as performing turns or navigation to waypoints.

F. Object Classification

Detection of objects is completed within the image space as well as point cloud detection, within the image domain video from the Zed 2i recording at 15 fps will be used for object detection by machine learning and neural networking. Upon identification of objects, this is matched with the corresponding location within the image point cloud provided by stereo imagery. Furthermore, to increase accuracy this location is locally mapped and compared to the alternate Zed 2i, providing confidence in object detection but locality compared to the vessel. This approach was considered from early development and led to the sensor frame being located toward the aft of the payload tray allowing for the sponson to be in the frame for detection of where the vessel is within the point cloud domain.

A supplementary method of object detection used is the maximum sum of evidence approach [1], this method focuses on the point cloud domain mapping data to existing libraries of objects of interest and allows for object detection in noisy environments. While this method is more computationally demanding it provides the ability to use LiDAR data when image processing is not possible due to lighting conditions.

G. Find and Fling

The find and fling assembly has been designed in a parallel stream to Prawnie allowing for operation when it is not installed. This approach was adopted to allow for design to begin before main computing loops and while task assignment was being finalised. Due to this separation from the main system multiple prototypes have been developed for the launcher, initially made from low cost readily available plywood before being scaled to permanent and computed aided design solutions (Figure 5).

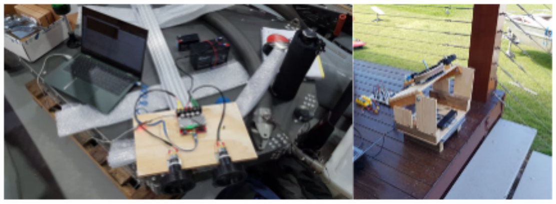

Figure 5, Prototypes of find and fling launcher. Left hand panel, first prototyping testing flywheel launching technique. Right hand panel, stage 2 prototype of the system with Zed 2i implementation and addition mass flywheels

The launcher consists of two main components, the vision and targeting aspect, and the physical ball launcher module. The launcher module is a custom pan-tilt design, driven by Nema 17 stepper motors. It also uses a pair of ESCs to run the brushless dc flywheel motors. These use a friction interface to in turn drive the flywheels, which are used to propel the racquetballs. These are all controlled using a stm32 microcontroller, which receives position and launch commands from the vision processing module (Figure 6).

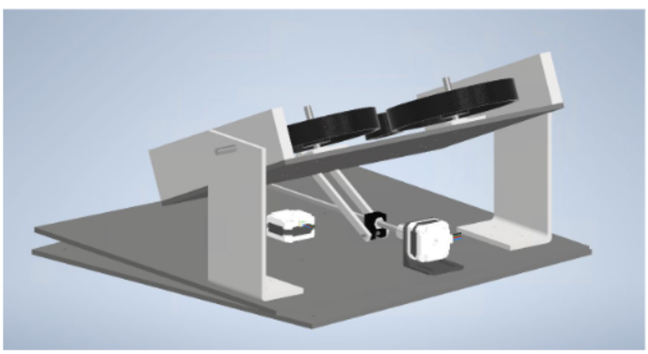

Figure 6, Final design for find and flight launcher with pan-tilt implementation.

The vision processing is done using a Jetson Xavier NX board, which receives depth images from a Zed 2i stereo camera. This is used to as the input for target detection, and then trajectory calculation. This trajectory is then used to back calculate the required launch angles for the launcher module, closing the control loop and providing the visual servoing. The Zed 2i is being used to explore an alternate way to complete stereography and improve the positional detection of the target and hence the performance accuracy of the subsystem.

The modular approach of the design means that while not actively searching for a find and fling target, the resources can be repurposed and utilised for other tasks with a simple connection to the main LAN network and power.

H. Entrance and Exit Gates

Task 2 will draw upon existing data from Zed cameras supported by two hydrophones for identification of the location of a subsurface pinger. Team Mantis has decided to locate the hydrophones toward to bow of vessel on the port and starboard, this separation will allow for the localisation of the pinger. Identification of pinger location will be completed using a Time Difference of Arrival (TDOA) method [2]. While ideally, a third microphone would provide the final point needed for triangulation it was concluded that this would incur additional costs which could be avoided by monitoring in a second location or by the synthesis with existing imaged based sensors.

Initial mounting brackets were designed for hydrophones (Figure 7), while future work aims to use a rotating bracket to remove hydrophones from the water and thereby reducing drag. However, due to project time and cost constraints, this was deemed to be not critical for the task and added complexity which could fail.

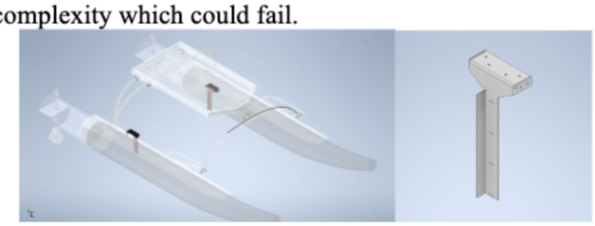

Figure 7, Hydrophone mounting bracket design. Left hand panel, original planned location of brackets however moved towards bow to avoid motor noise. Right hand panel, bracket design made from 3 mm 5050 Aluminum.

I. Safety Systems

Providing a safe environment for team members and the general public is paramount for this reason safety measures have been implemented beginning with circuit breakers (120A) and battery isolation switches fitted to each battery. While circuit breakers are less than the peak output of the batteries they exceed of normal operating range in the vessels current form, thereby reducing the current for activation is a conservation approach.

In addition to battery protection, motor protection is critical due to the risk on impalement or a runaway vessel. Prop guards have been fitted to the vessel to reduce the risk of prop strike damage to humans or marine life. Furthermore, the emergency stop (E-stop) system has been designed to isolate batteries from the motor in the event of activation (Figure 8). The E-stop system has been designed such that all e-stop switches on the vessel must be released (in their normally closed positions) and the microcontroller is required to actively switch the MOSFET without both conditions present no current will flow through the relay, causing it to disconnect power from the motors (Figure 8). This allows for all fail conditions to be accounted for, including loss of microcontroller control without loss of power, with the external switches still able to disconnect power. Additionally, the signal from the E-stop is connected to another relay which controls the red signal light of the WAM-V whilst maintaining galvanic isolation between the main batteries and the e-stop system.

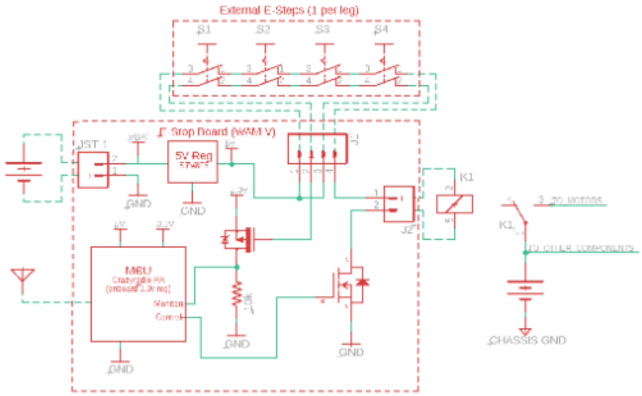

Figure 8, Schematic of the vessel side E-stop system.

The CrazyRadio PA radio module was chosen as the communication link between Prawnie and shore since it uses a NRF24L microcontroller which was able to be programmed with custom firmware. This meant that no external module would be required, and it could all be achieved using a single controller. The CrazyRadio PA module communicates at 2.4 GHz and has been set to communicate at 250 KB/s to allow for maximum range, range tested to 250m.

IV. Field Testing

Field trials and equipment testing is an important component to the development of environmental sensing technology and has been an endeavour of Team Mantis. While plans for field testing were put in place and scheduled, delays were observed due to the inability to transport Prawnie, with initial field testing occurring in August since this test regular field trips have been completed on a bi-weekly basis. Initial work focused on flight controller tuning, basic marine navigation and identification of systems not working correctly.

Initial issues were quite simple to solve such as antenna placement, loose wiring connections and reducing signal noise with shielding. As field testing has continued more complex challenges have begun to arise around networking and data collection due to the quantity of data Zed cameras generate.

While field testing data has been collected Team Mantis aims to increase this catalogue with varying weather and lighting conditions, while being in a similar weather climate to Sydney, Australia, the possibility of weather events (rain/fog) has not been investigated as much as the team would like.

V. Conclusions

The development of autonomous systems has continued to advance over the past years, while many off the shelf tools and hardware are available planning, designing and building these systems still presents challenges that require unique solutions. Team Mantis USV for the Robot X – Sydney 2022 competition has been developed to detect and navigate autonomously through six outlined tasks. The vessel will use a combination of stereo cameras, LiDAR, and hydrophones to provide environmental information for processing through various methods with the aim of completing tasks.

VI. References

[1] Phillips, T., D'Adamo, T., & McAree, P. (2021). Maximum Sum of Evidence—An Evidence-Based Solution to Object Pose Estimation in Point Cloud Data. *Sensors*, 21(19), 6473.

[2] Zhu, S., Jin, N., Wang, L., Zheng, X., Yang, S., & Zhu, M. (2016, January). A novel dual-hydrophone localization method in underwater sensor networks. In 2016 *IEEE/OES China Ocean Acoustics* (COA) (pp. 1-4). IEEE.