Design of the Minion Research Platform for the 2022 Maritime RobotX Challenge

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***Abstract*— For the 2022 Maritime RobotX Challenge Embry-Riddle Aeronautical University (ERAU) has made significant improvements to their fully autonomous research platform, Minion. To complete mission tasks, Minion uses sophisticated sensory and perception algorithms fusing data from a suite consisting of multi-beam LiDARs, multi-modal imagery sensors, and a high precision GPS/INS. This data feeds decision-making algorithms that include neural network visual detection, long-range LiDAR-based object detection, and dynamic path planning. These processes are all tied together using a unique tasking system designed to initiate tasks when perception queues are received and select a task order to maximum time usage. The research team has also developed an autonomous drone platform, for completing the tasks that require aerial reconnaissance.**

All of Minion's systems are rated and tested to survive operations in adverse weather conditions, including high temperature, high humidity, and heavy precipitation. In the course of development, Minion was thoroughly tested using simulations, recorded data, and dozens of hours of in-water testing. The result of this is an advanced platform that is robust, reliable, and readily upgradable.

I. Introduction

Embry-Riddle Aeronautical University's (ERAU) Team Minion includes students ranging from undergraduates to Ph.D. candidates with backgrounds in Unmanned Systems, Software, Electrical, Aerospace, and Mechanical Engineering. The team has drawn from experiences learned in the three previous Maritime RobotX competitions and the 2022 Virtual RobotX (VRX). The Minion autonomous surface vessel is an award-winning platform, as it was recently recognized as the 2021 AUVSI Xcellence award winner in the category of Hardware & Systems Design [1]. This award recognizes companies, organizations, and individuals that achieved significant accomplishments across the unmanned systems community.

C. Vehicle Overview

From its inception in 2014, Team Minion has worked to create a platform that is rugged, customizable, and easily upgradable to meet emerging research and competition requirements. All components are designed to withstand harsh environmental conditions including precipitation, humidity, and heat. In 2018, the primary upgrade to the Minion autonomous surface vessel (ASV) was adding holonomic maneuverability to allow Minion to control position and heading simultaneously.

In 2022, Team Minion further worked to improve the performance of the ASV by upgrading the ASV power and perception systems. The team also performed a complete overhaul of the system software to comply with industry standards and compete in the VRX challenge. These upgrades allowed for significantly higher endurance and increase simulation testing, which was particularly important during the COVID-19 pandemic when the team could not assemble in person. The team's software improvements have also significantly improved system robustness, which should lead to improved performance in the 2022 competition.

D. Software Overview

The software architecture on Minion has been migrated to Robot Operating System (ROS) which is a set of software libraries and tools designed for use in robotic applications. Using ROS allows development and execution of software to be divided into individual nodes that can be developed and executed in parallel and operate on a publisher-subscriber messaging architecture. Fig. 1 shows the software architecture used in competition.

Sensing capabilities on Minion were designed to handle object detection, classification, and mapping with improved robustness over prior competition cycles through upgraded sensing hardware and algorithms. To do so, the software architecture leverages a GPS/IMU-based localization module and separate LiDAR and camera-based object detection and classification modules. These modules allow Minion to leverage the strengths of individual sensing modalities, which are then fused into a global map where each object is tagged with global positioning, classification, and color for autonomous tasking.

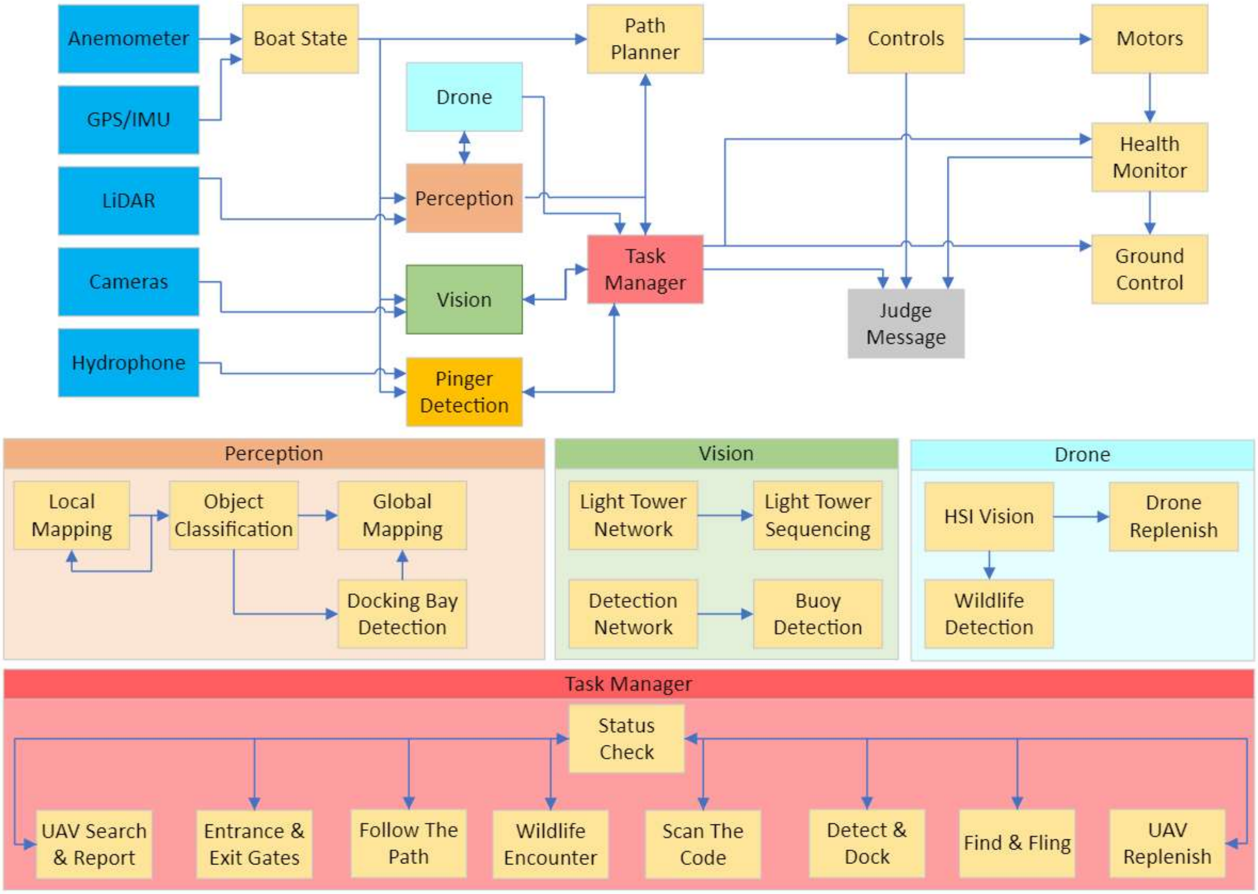

Fig. 1 - Minion ASV Software Architecture.

Task allocation and execution has been condensed into a Task Manager module that uses a bidding system to allocate which task should be given permission to control the boat. With this system, each individual task checks if Minion has enough information from the sensors to execute its task and continuously submits bids to the Task Manager for control of the platform. Once a task is given priority by Task Manager, that task module is permitted to send commands to Path Planner, Controls, and any other module used in the task's execution. Task Manager continuously communicates the bid and status of each task, so all parties are aware of who has active control of the boat and the status of each task.

Integration of capabilities within ROS allows for the modules to be run for the competition through minimal inputs from the team members, in fact the entire mission is configured in a single file and executed using two commands from the ground controller. The design and function of key software modules is further discussed in Sec. III – Vehicle Design and the relevant Appendices.

II. Design Strategy

At the 2018 competition, Minion performed well from a hardware standpoint but did not execute the autonomous missions as well as desired. The team lacked sufficient simulation testing capabilities and was unable to achieve enough on-water test time prior to competition. Most of the competition testing time was spent solving basic software problems in path planning and controls.

A primary goal for the 2022 competition was to enable more system testing on-water and in simulation before competition. To test on the water a manned support vessel (MSV) is required by Embry-Riddle risk management. The team previously relied on a faculty advisor's personal boat or renting a boat to serve as an MSV, significantly limiting when the team could test. On test days, the team was also limited by battery capacity, which was quickly depleted during strenuous motor testing. The team's reliance on a LabVIEW software base also prevented the team from competing in the VRX challenge, and meant the team had to generate and maintain its own toolset for simulation testing.

In addition to a primary goal of more testing, the team identified three focus areas that would contribute most to 2022 success. First, a drone is needed for multiple tasks, unlike the acoustic pinger detection and racquetball delivery systems, which each affect only one task. Secondly, while the perception and deep learning algorithms implemented in 2018 were highly effective at short range, the sensors themselves did not provide sufficient pixel and LiDAR return density to detect and classify objects at the desired range of 25-50m. Additionally, ambient lighting proved challenging to the cameras due to over- or under-saturation of the images. Thus, new sensing solutions were needed to address these issues. Lastly, the path planning and controls modules from 2018 were ineffective. After testing them further in the lead-up to the cancelled 2020 competition, the team determined they had fundamental issues and targeted these modules for replacement in 2022.

A. *Increase Testing Capabilities*

The single biggest key to success at competition is the testing that occurs before and at competition. As such, Team Minion identified increasing the quantity and quality of testing that occurs as a major strategy for competition success. The goals Team Minion identified to achieve this objective are:

1. Establish a robust simulation-based testing environment to prove systems before on-water testing
2. Store enough energy on Minion to test 8 hours/day
3. Remove reliance on volunteer and rented MSVs so testing can occur when needed
4. Ensure ground support systems are waterproof, so tests can occur during mild precipitation

B. *UAS Development*

The UAS platform's design was carefully considered to maximize the payload capacity while maintaining a manageable form factor. To achieve this, some of the characteristics of the UAS were defined at the onset of development. These include:

1. UAS should be a quadcopter to reduce design complexity and cost.
2. UAS must have a footprint smaller than 1m x 1m
3. UAS must be able to carry a payload of up to 2kg
4. UAS payload must include a visible camera to meet the requirements outlined in Tasks 8 and 9 of the RobotX handbook.

C. *Robust Sensing*

Autonomous surface vessels can only be as effective as their ability to perceive and interact with the environment. So, while perception has always been a strength of Team Minion, the team identified several key areas where improvement would lead to better competition and research performance. As such, the team's perception goals were:

1. Ensure object color is consistent in obtained imagery
2. Ensure camera pixels and LiDAR returns are dense enough to identify objects at least 25m and 50m from ASV respectively
3. Maintain a 180° forward FOV for camera imagery
4. Utilize state of the art deep learning algorithms and sensor fusion techniques
5. Maintain a global map that updates at 5Hz or faster
6. Classify objects with 90% accuracy

D. *Path Planning & Controls*

The path planning and controls processes collectively dictate Minion's ability to navigate effectively. At the 2018 competition, these modules were less effective than desired due to their complex nature and lack of robustness to the Hawaiian surf. When further testing did not improve performance, the team decided to fully re-design these modules with the following path planning and control goals in mind:

1. Planned paths shall typically stay over 4 meters from objects to be robust to uncertainties (control, sensing, etc.), but allow maneuvering close to objects when necessary (docking)
2. Ensure ASV can follow the path based on platform dynamics
3. Plan paths within one second so that paths can be used for obstacle avoidance
4. Use controllers that are easy to tune to the environment
5. Create holonomic, azimuth thrust, and differential thrust steering modes

III. VEHICLE DESIGN

A. *Design Process*

The design process for Minion incorporates techniques from AGILE [1] for both hardware and software development. A 2-week sprint cycle was adopted, with a weekly zoom meeting during the COVID-19 pandemic and a weekly stand-up meeting once the COVID restrictions were lifted. These meetings require every member of the team to present their progress in a fast-paced manner with few technical details. This permits every member of the team to be versed in the progress of the entire project. A 2-week sprint cycle concludes with testing on the final day. This provides a visible metric of progress for all team members, as well as incentive to accomplish all goals within a sprint cycle. Any developments to the system that require funding in excess of $500, or can't be completed in a 2-week window, undergo a critical design review before any funding is committed. Such reviews are scheduled on an as-needed basis and are conducted at the conclusion of the weekly stand-up meeting. All team documentation is version controlled through a SharePoint site for general documents, an SVN for CAD files, and a Git repository for code.

B. *Propulsion*

Minion's utilizes two VM thrusters from Copenhagen Subsea with asymmetric nozzles for main propulsion, which give up to 600N of forward thrust and 360N in reverse. The propulsion system is configured to allow Minion to azimuth and beach both thrusters. Allowing the thrusters to rotate, or azimuth, improves maneuverability because it allows control over the direction of force from each thruster, rather than just magnitude. Independent azimuth control also improves robustness as it allows the platform to operate and maneuver even if only one thruster is functional. The azimuth thrusters can be mechanically locked, returning the platform to differential thrust without consuming energy to hold the thrust direction constant. Azimuth control is achieved with Volz DA-36 Low Profile servos, which produce 97.4 lbf-in of torque and allow the thrusters to rotate ± 85°. These servos are a 200% increase in torque over the DA-26 servos used in 2018, eliminating a previous issue with holding strength. The DA-36 servos are environmentally rated like the DA-26 servos, but have a different footprint, leading to minor changes to the propulsion assembly geometry.

The thrusters can also be retracted from the water using Linak LA-36 linear actuators, reducing the human intervention required when launching, retrieving, and beaching the ASV. Due to their worm drive, these actuators lock in position when not powered. Retraction and deployment each take under 10 seconds. *Appendix H* further details the design and analysis behind the propulsion system. The final propulsion system is shown in Fig. 2.

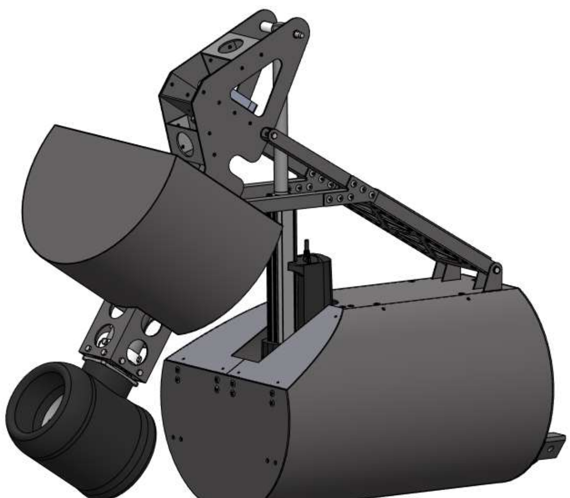

Fig. 2: Minion's propulsion system, which enables thrust, thrust direction, and beaching control. Thrusters are VM thrusters from Copenhagen Subsea.

C. Power Systems

A major testing roadblock of the team has been the onboard batteries, which are depleted in 2-6 hours of on-water testing. Fig. 3 depicts how the run time is shortened as the motor changes speed and as Atlas, the onboard computing systems, consumer more energy. Given the typical Atlas load of 500W and operating speed of 3 knots, this analysis proves Minion can only be expected to run for around 4 hours using its on-board batteries.

To address the limited testing time, the team took a short-term and a long-term approach. The short-term solution was to upgrade the existing Torqeedo Power 26-104 batteries to the new Torqeedo Power 24-3500 batteries. The new batteries have a capacity of 3500Wh each, yielding a 30% improvement in run-time which meets the 8-hour goal if the operating speeds are limited to 2-2.5 knots.

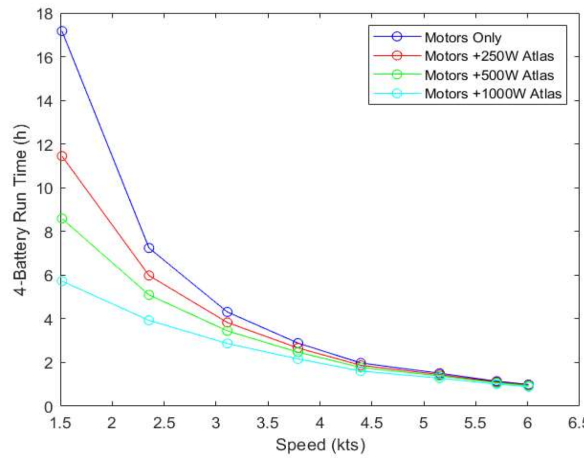

Fig. 3: Operating time based on electronics load and motor speed

As a long-term solution, the team is working to convert the ASV from a fully electric vehicle into a vehicle that could be optionally used in a hybrid vehicle configuration using an on-board generator to the power system. The team chose a Honda propane generator with a 2.2kW generating capacity, since the base load is typically 500W and the average load in testing is typically 1500-2000W. The generator would operate to offset this average load while using batteries as a buffer Under an average 2kW load, the team will be able to run Minion for 18.4 hours using just a 20lb propane tank. The generator power unit is meant for tests in the Halifax River only and will not be brought to competition since it does not meet the competition rules.

D. Unmanned Aerial Vehicle

As the UAS is used in multiple tasks, its development was prioritized over the underwater acoustic and racquetball delivery systems. Following the constraints the team outlined at the beginning of the UAS development process, a 650 mm quadcopter frame, the Tarot 650, was selected as the base of the UAS platform. Following this, diligent considerations were given to motor, electronic speed control (ESC), and propeller selections in order to maximize lifting capabilities. Motors with low KV values were prioritized to maximize the potential thrust at the expense of energy efficiency. Coupled with these motors were large propellers capable of producing the thrust necessary for the 2kg payload. The camera system was designed to maximize the FOV while flying over the water while maintaining compatibility with the platform's onboard computer (OBC), a Raspberry Pi 4. Further discussion on the UAS can be found in *Appendix B*. The camera system aboard the UAV was designed to support the development of an image detection network to support the competition tasks which require the UAV. More information on these systems can be found in *Appendix B*.

E. ROS Transition

Since team Minion began in 2014, the team has developed an expansive and sophisticated codebase. But this codebase had a large problem, it was developed in

LabVIEW. By spring 2021 it had become evident the team was spending too much time fixing issues related to its use of LabVIEW and developing its own simulation tools since none of the open-source tools were compatible with LabVIEW. Additionally, the team could not compete in the VRX competition, which is the simulation version of RobotX because this competition requires compatibility with ROS.

Given the team's stated focus on testing in the 2022 competition cycle, the team made the difficult decision to port its entire codebase to ROS between Spring 2021 and Summer of 2022. This ultimately meant that every process the team had written in almost 7 years had to be rewritten in a span of 16 months. However, development occurred during the COVID-19 pandemic when the team was not allowed to meet in person. So ironically, the team made this transition during a time where on-water testing was not allowed anyway due to public health concerns.

The move to ROS was partially completed in time to compete in the VRX competition in Spring 2022, and fully completed in summer 2022. With the move to ROS the team has begun to use the Gazebo and the VRX supported simulation of the WAM-V to test all of its perception and decision-making processes. Along with Gazebo simulation testing, ROS bag files now provide valuable data logging. Bag files are used by the team to collect all its sensor data and messages between algorithms during a real-world test. New ROS nodes can also be implemented and executed with the recorded data to test how the program would operate with empirical data. So, while the shift to ROS was a significant undertaking, the transition enabled the team to develop its process this summer/fall at a faster rate than ever before.

F. Robust Sensing

One way that the team intended to achieve their robust sensing goals was with the creation of a new custom sensor suite to mount to the top of the Minion ASV. The custom sensor suite was developed in the lead-up to the 2020 RobotX Challenge and has since been integrated onto Minion. The new custom sensor suite includes: one High Dynamic Range (HDR) camera, three high resolution visual cameras, two infrared thermal imaging cameras, and three forward-facing high-density LiDAR. In-depth reasoning and explanation behind sensor selection and integration into the Minion ASV can be found in *Appendix C.*

Similarly, the team's sensing strategy incorporates cameras that operate in different spectra. These modalities include visible 4k, infrared, and HDR (high dynamic range) cameras. Using different spectra helps the team achieve its goal of detecting objects in different weather and lighting conditions. The team uses object detection bounding boxes as well as semantic neural networks to detect objects in the obtained imagery. The HDR camera is used to help guarantee color consistency, even in the presence of varying ambient lighting and viewing angles. To accomplish the FOV requirements, an array of 4k visual cameras have been included on the platform. Lastly, the thermal imaging cameras are used mainly for research purposes, but aide in nighttime navigation.

The addition of the three Livox LiDAR sensors in the front of the vessel extended the range of our LiDAR detection and classification algorithms to 50m and 75m respectively for objects as small as a 0.5m tall buoy. However, adding the addition of significantly more LiDAR returns slowed these algorithms from a rate of around 10Hz to 0.3-0.5Hz, which did not meet the objectives noted in Section II. The team investigated other clustering and concave hull boundary extraction techniques, which all failed to be fast or reliable. The team then devised a new scheme, called Grid-Based Clustering and Concave Hull Extraction (GB-CACHE), whose timing and resolution performance exceeded anything found in the literature. This method also allows for use of classification features and object mapping in the same manner as [3], which was previously developed by team Minion and found to be effective at the 2018 competition. The details of GB-CACHE are found in *Appendix F.*

G. Path Planning & Controls

Minion's path planning solution is a custom approach developed by the team and published in [4]. The method is based on a graph search construction method for visibility-Voronoi diagrams which allow users to tune path optimality and path safety while considering vehicle dynamics and model uncertainty. The vehicle state is defined as both a 2D location and heading. While Minion is capable of holonomic control, its primary operating steering modes are to use differential and azimuth motor thrust, which are more efficient. This results in an underactuated system, leading to an assumption that only paths that satisfy a minimum turn radius are considered feasible. Thus, the roadmap generated from a Visibility-Voronoi diagram uses motion curves and path smoothing to ensure path feasibility. The roadmap is then searched using the A* graph-search algorithm to return optimal paths subject to a minimum distance-based cost. Paths are generated as an anytime algorithm, meaning a feasible path is found quickly and any remaining time allotted is used to improve path quality. The method and analysis of the method are further explained in *Appendix D* with example competition results found in Section II.

The 2018 iteration of the Minion ASV used an optimization routine to determine actuator inputs needed to follow vehicle paths. This was largely due to the desire to use holonomic control to minimize error, but it also led to high energy consumption and an inability to tune the system to environmental disturbances. The new controls module has been simplified to apply independent PID controllers on surge, sway, and heading with unique gains for each of the three steering modes (holonomic, azimuth thrust, differential thrust). The job of the controls module is also simplified by the path planner, which returns paths composed of straight line and arc segments of a pre-defined turn radius. As such, the PID controllers only need to be tuned to follow straight lines and circles of this radius.

When operating in azimuth and differential thrust modes, sway control is suppressed due to the underactuated nature of the ASV in these modes. This leads to a small increase in cross-track error, but a significant reduction in energy usage, which increases testing time.

H. Tasking

It was clear from the 2022 RobotX task descriptions that completing tasks requires the ASV to take keys from its environment and other tasks. MinionTask, was developed to address this need. MinionTask is an auction-based structure where each task bids for control of the boat based on the number of points it projects to be able to score and the time it will take to complete its task. Among the list of tasks that are ready to be undertaken, MinionTask uses the A* with bounded costs (ABC*) methodology [5], [6] to determine the pareto optimal order in which tasks should be undertaken. The first task to be initiated is then given control to navigate the boat as needed. This method is discussed further in *Appendix G*.

The task themselves are broken into three key aspects. First, there is a "ready check" function that determines if any part of the task can be completed with current knowledge. Second, a "bid" function is used to report the task status (searching, ready, active, or complete), along with the expected score if initiated now, max possible score, minimum and maximum time to score points on the task. If the task is given control of the boat by the Task Manager (which is running MinionTask), then the third function is initiated which runs the Autonomy of the task. To ensure there is always a valid task to undertake, a search task is used to cover the operating area while looking for the task elements.

I. Support Systems

To enable more testing, the team also sought to acquire its own MSV. To this end, team Minion quickly identified a desire to use electric propulsion on the MSV, due to already owning multiple sets of Torqeedo batteries and the limited maintenance of electric thrusters compared to internal combustion engines. To this end, the team was able to acquire a Torqeedo Cruise 4.0 thruster, which had the necessary horsepower (8hp) to ensure the MSV could chase down Minion in an emergency. Furthermore, the team modified Minion's trailer to house both Minion and the MSV, further simplifying support needs.

Aside from the MSV, the remote controls used by safety drivers to operate the boat were not waterproof. To ensure we could operate regardless of rainy weather, the team developed its own, waterproof, remote-control system to communicate to the boat, which is shown in Fig. 4 and is a drop-in replacement for prior remote-control system. Furthermore, this system enables the safety operator to see everything Minion sees, providing greater situational awareness to the operator.

IV. TEST PROCEDURES

As testing is so important to Team Minion's success, the team defined a testing process which is detailed below:

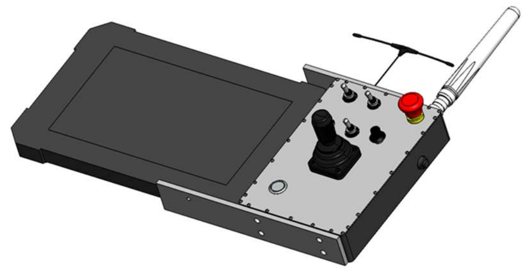

Fig. 4: Custom-built remote control for Minion

A. Simulation & Playback

In between tests, the software team uses simulation and ROS bag playback tools to develop and improve algorithms. The simulations are mainly performed in Gazebo's virtual environment using the VRX toolset. All software is tested in Gazebo before it is moved onto the ASV, allowing the team to iron out major issues before test day. This also allows on-water testing to be mainly spent on tuning real-world performance.

B. Vehicle Shakedown

A vehicle shakedown takes place the day before a test to verify changes and ensure compatibility between modified code throughout the past sprint. This procedure helps ensure that time is not wasted during a test debugging incompatibility between the software modules. The shake downs include various checks like ensuring the code compiles, dependencies are downloaded in the ASV, the propulsion system is responsive, and checking the sensors' networking is correct.

C. Test Days

A test day occurs the final day of each 2-week sprint. In a standard AGILE method, this would be the member demo. During a test, the platform is deployed in the river with a chase boat and may be run in tele-operated or autonomous modes. These tests may be used to find discrepancies between Gazebo simulation and the real-world environment. Similarly, it offers a good opportunity for logging data from the sensors to improve algorithms in the next sprint. Nearing competition the sprints might occur every week or multiple times per week if needed.

D. Logging

The Minion platform has two primary methods of logging. First, ROS bag files are used to record all messages, or a subset of messages published by Minion's software modules. This enables all software modules to be tested in the lab as if they were receiving these messages live. Second, for algorithm training, camera data is stored locally on the Jetson within the camera enclosure. This data is not streamed using ROS due to the heavy network load it would require.

E. Test Debrief & Sprint Planning

After a test, there is a debrief for all team members. This debrief covers everything that was accomplished during the test, as well as anything that needs to be accomplished for the next test. These debriefs are used to begin planning for the next 2-week sprint cycle.

V. EXPERIMENTAL RESULTS

A. Calibration

The LiDAR and camera sensors were calibrated using [7], and then manual corrections were made to reduce errors introduced by the procedure. The resulting calibrations are shown to be highly accurate, as shown in Fig. 5.

Fig. 5 - One second of LiDAR points (blue) overlayed on thermal (top left, top right), HDR (top middle), and visible imagery (bottom row).

B. LiDAR Perception

To stress test GB-CACHE, Team Minion identified a local marina as representative of the most cluttered environment the ASV could encounter with a large number of close proximity marine objects. The timing results of the method are summarized in Table 1 using a 10cm object resolution. The results show that so long as the clustering distance does not exceed 15 times greater than the desired resolution, the 5Hz target for real-time use can be ensured. In general, the system will perform much faster than shown in Table 1, as the system rarely operates this close to so many objects.

A sample segmentation result of this environment is shown in Fig. 6 using a 10cm object resolution and a clustering distance of 0.5m. The accuracy of GB-CACHE and the and mapping system was found to be approximately 20cm, with ranges of 40m, and 70m respectively for detection and classification. GB-CACHE is further explained in *Appendix E*.

Table 1: GB-CACHE Timing Results at Cluttered Marina

Clustering Distance (m)	Total Rate (Hz)	Total Time (sec)	Objects Segmented
0.15	10.0	0.100	2582
0.2	12.1	0.083	1798
0.3	17.8	0.056	924
0.5	17.5	0.057	529
0.75	13.1	0.076	362
1	9.3	0.108	269
1.25	6.9	0.145	220
1.5	5.0	0.200	181
1.75	3.7	0.267	153
2	2.9	0.340	133

F. Vision

The vision module is responsible for identifying the color of objects and patterns used in competition. Color classification is required to complete Scan the Code, while pattern detection is required for UAV Replenishment, Search and Report, and Wildlife Encounter. The team uses the HDR imaging camera as the main camera for most vision tasking. The HDR imaging camera allows for the unique capability to capture data even in bright daylight conditions that would wash-out the image on a visual camera. This is clearly shown in Fig. 7, which shows the washed-out nature of the visible camera when looking into the sun compared to the HDR camera used by Minion in 2022.

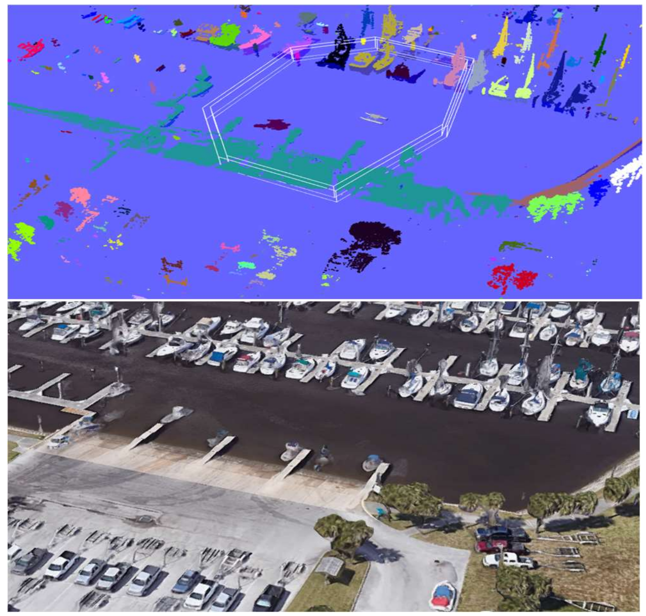

Fig. 6: Satellite view of the Halifax Marina compared to the GB-CACHE segmented point cloud captured by Minion. Each segmented object is colored uniquely. Boundaries drawn by GB-CACHE are not shown.

Fig. 7 - 5MP Visual (left) and 5MP HDR (right) Camera Data for the Light Tower Task.

Deep learning methods of classification, detection, and segmentation are used by the team to perform vision tasks, so having reliable and consistent data is imperative. These techniques require the team to collect data, label the objects in the images, and then train the neural network offline. For efficient labeling and training, the team uses the Supervisely online service. This is a labeling tool that works across different platforms and allows members to label at the same time. Moreover, Supervisely allows users to train several neural networks, store the results online, and even evaluate their performance. Fig. 8 shows a detection network recently trained by the team performaning on a live video stream of the HDR cameras.

Fig. 8 - Compressed Image with R-CNN Classifications Streaming from the Minion ASV to Ground Station.

Fig. 9: Segmentation results showing original Image (left), true mask (center), and predicted mask (right).

The segmentation results can provide the most detailed information since the classification is pixel-wise, which the team desires, although this method adds to the complexity of the data preparation and training processes. Fig. 9 shows a successful segmentation result in which the trained objects were focused on water-borne and shoreline objects.

To ensure the team could select an effective neural network architecture, the team turned to TensorFlow's model garden and their training tools. Parsing tools were programmed to convert Supervisely labels into formats that could be used to train any of the networks in TensorFlow's model garden. This gave the team access to R-CNNs, SSDs, Mobilenet and more. The team is also able to train segmentation networks, which label the class of individual pixels as shown in Fig. 9.

G. Path Planning & Controls

Here, the path planner is applied to data stored from the 2018 competition to prove the validity of the path planning solution. These results use a minimum turn radius of 2.5m, a minimum safety distance of 1.5m and a desire to stay 5m from all obstacles. The resulting paths are shown in Fig. 10 and Fig. 11.

Fig. 10 and Fig. 11 show the advantages of the path planning solution. First, the planner can plan safely near objects when needed, such as into a docking bay or a narrow set of gates. It does this by equalizing the distance to the port and starboard sides of the ASV. Second, all paths are composed of straight line and 2.5m radius arc segments, as seen in the lawn mower patter through the obstacle field. As previously noted, this ensures feasibility and makes it easier for controls to follow the path. Lastly, the roadmap is only generated around objects that are close to the distance optimal trajectory, which reduces computations and allow paths to be returned quickly. Further analysis of the timing benefits of the path planner are given in *Appendix D*.

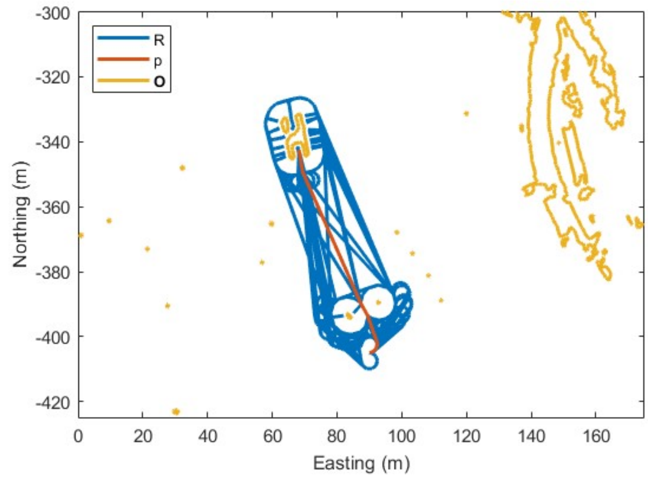

Fig. 10: Sample path planning result for docking task from 2018 competition. The object boundaries are yellow, the roadmap blue, and the final path red.

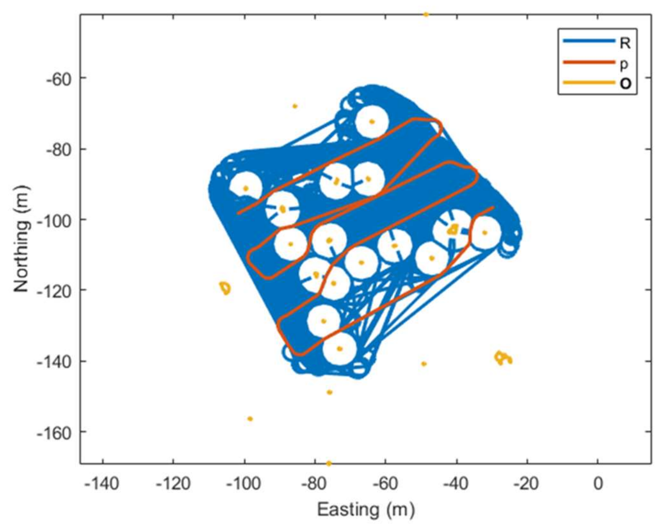

Fig. 11: Sample path planning result for obstacle field task from 2018 competition. The object boundaries are yellow, the roadmap blue, and the final path red.

H. UAS

The detection and localization algorithms of the UAS were evaluated using data collected from a UAV flying over different color buoys in a known configuration. The data was then processed using a YoloV5 detection neural. The image in Fig. 12 shows a collection of red, green, and black (represented by white markers) buoy locations, showing the consistency of the approach to locate the objects in a repeated nature.

Table 2 shows the actual position of the green, red, and black buoys along with the mean estimated position. From the information in Table 2, the neural network performed worst with the red buoy. The mean estimate for the green buoy was 0.4 m away from the true position. The red buoy's estimated position was 3.0 m away from its true position. The black buoy's estimated position was 1.3 m from its true position. While the 3.0m of error may seem significant, these objects were anchored and drift slightly over time. Thus, the accuracy noted here is expected to be sufficient for competition purposes.

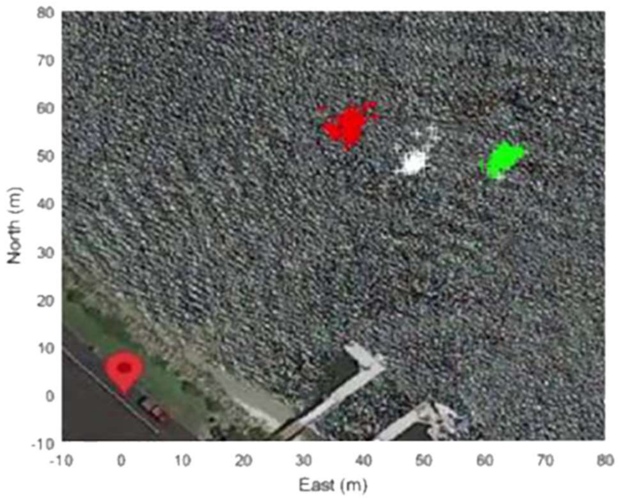

Fig. 12: Location of the red, green, and black buoys (white marker) when applying the YoloV5 algorithm and localization routine over a 5 minute flight.

Table 2: The actual position of the red, green, and black buoys during a 5-minute flight compared to the mean estimated position from Fig. 12

Object	Actual [m]	Mean Estimate [m]
Green	(63.0, 49.5)	(63.1, 49.9)
Red	(36.1, 53.3)	(37.2, 56.1)
Black	(47.9, 47.7)	(48.8, 48.7)

I. *Task Testing*

Task testing was conducted in the Virtual RobotX (VRX) simulation environment using Gazebo. A simulation course with all Maritime RobotX required tasks was designed after the layouts provided in the team handbook on page 24, Section 2.8 Finals Round [8]. This course is shown below in Fig. 13.

The team also uses RVIZ, which is a graphical tool in ROS, to visualize Minion's sensor data and decision-making. We call this ground interface MinionTab. To test Minion's ability task to find and complete tasks, the team designed plug-ins to MinionTab that allow us to manually select the operating area of Minion, and a cell-based routine to ensure each part of the operating area is searched. Fig. 14 shows the search area when initially selected, while Fig. 15 shows the search area after several tasks have been completed.

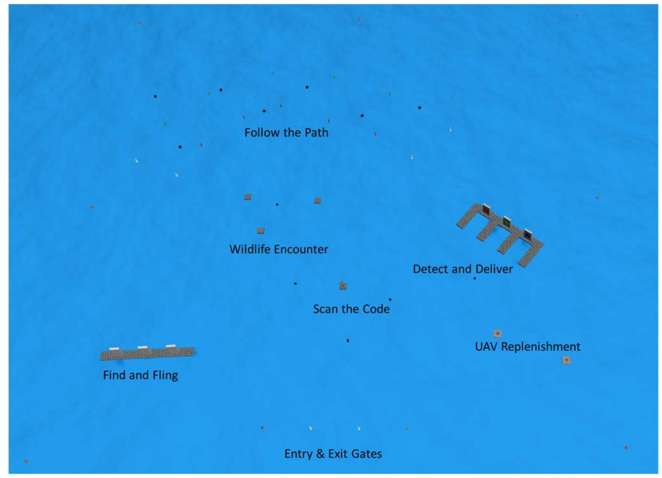

Fig. 13 - Semi/Finals Course Layout from [8].

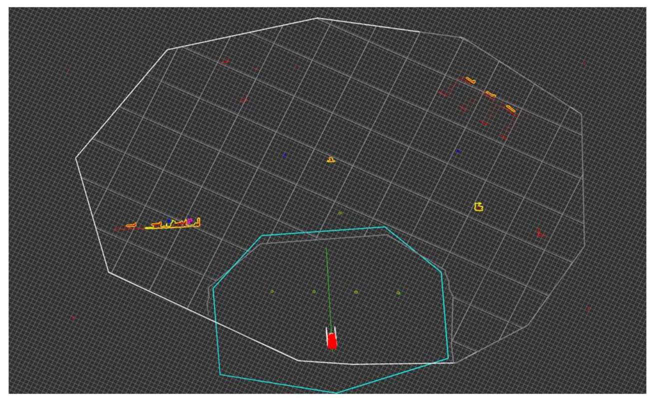

Fig. 14 - Search area around Gazebo competition course as selected in RViz.

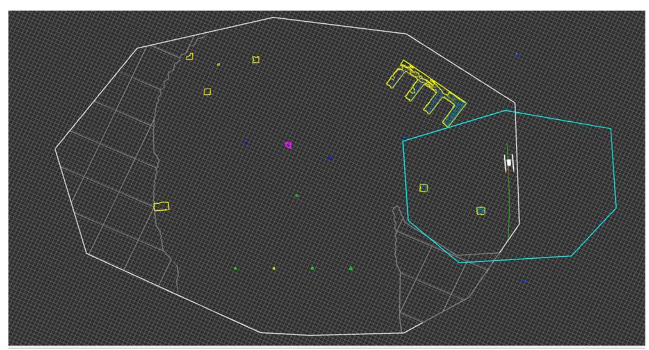

Fig. 15 - Search area after 70% coverage of the Gazebo competition course.

The first competition task the team developed was the navigation challenge, which requires navigation of two sets of channel markers. Here the buoys are detected and classified using the LiDAR-based perception system, and the task is triggered when the first gate has been found. Fig. 16 shows simulation results while Fig. 17 shows Minion completing this task on the water.

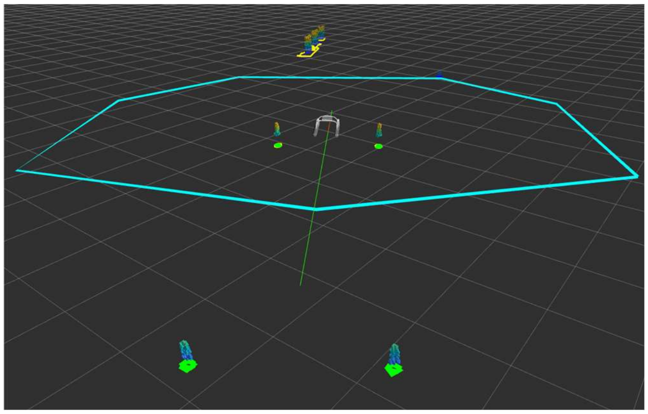

Fig. 16 - Minion completed the second gate, successfully finishing the Navigation Challenge task.

Fig. 17 - Minion successfully completing the 2nd gate on the water.

This task has been successfully completed in simulation and on-water dozens of times in the lead-up to competition. In these tests Minion's starting position, the location of the buoys, and the parallel nature of the gates were varied to ensure task robustness.

The second task team Minion tested was Follow the Path [8]. The Follow the Path task consists of white buoys to designate the start and end gates, and pairs of red and green buoys representing a path. Round black buoys are scattered along the path to represent obstacles to avoid. Minion is required to autonomously navigate through the path while avoiding the black buoy obstacles and staying within the path. The initial tests in Gazebo were conducted with just the red and green buoy gates and no black buoy obstacles, as shown in Fig. 18. These scenarios have also been tested on the water using three gates. Further on-water testing must be done in Australia since the team owns only 6 total buoys.

Additional simulation testing has also been conducted to include obstacle buoys. In these test cases Minion was able to complete three of the red/green gates but then stopped in the middle of the course after being confused about where the next gate lies. The team is currently working on improvements to the gate detection strategy to address this issue and expect the technique to be ready for the start of competition. Team Minion has also extensively tested its dock detection routine and task. For brevity, these results can be found in *Appendix I*.

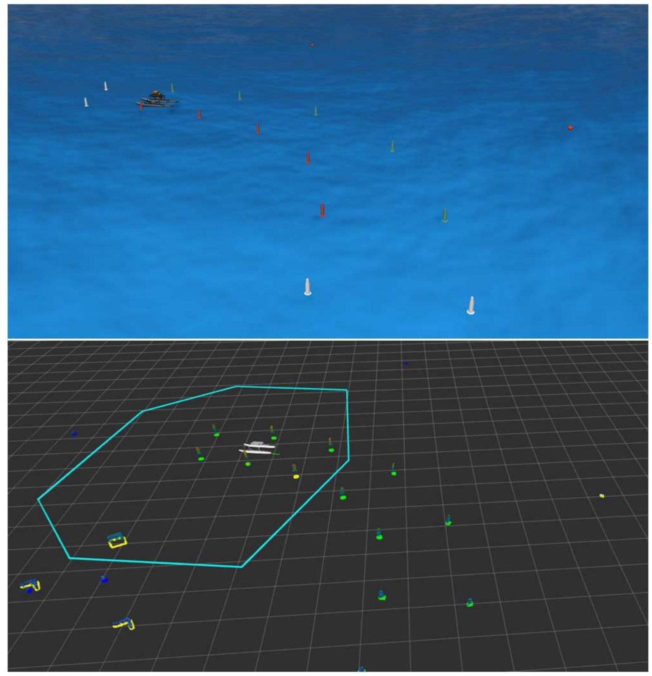

Fig. 18 - Minion completing the last gate in Follow the Path.

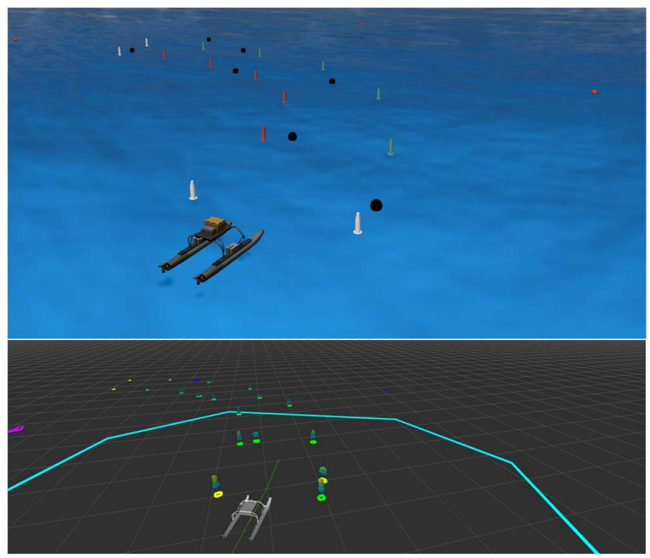

Fig. 19 - Minion completing the last gate in Follow the Path.

VI. CONCLUSIONS

ERAU Team Minion has improved on its 2018 RobotX entry through additional testing, improved sensing capabilities, and multiple new autonomy features. The 2022 iteration of Minion focuses on the core aspects of competition, which are USV and UAS autonomy rather than the supporting systems, such as racquetball delivery and acoustic pinger detection. The system has been extensively tested with thousands of hours of simulation development and close to 100 hours of in-water testing. The result is a highly capable autonomous maritime system capable of competing successfully in RobotX 2022.

VII. ACKNOWLEDGEMENTS

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