RobotX 2024 Technical Design Paper

Aw Han Wei, Balajee Viswanath Akshay Narayanan, Chan Wei Hua, Chang Yu Wei, Chew Chern Jin Aegan, Fu Yingjie, Ho Ky Trung, Howe Felix, Kang Zihan, Lai Wenxin, Li Tz Lung, Li Tz Yuan, Lim Zachariah, Pang Wentao, Seow Frentzen Ziheng, Shandilya Mayank, Shi Wenjie, Song Jieni, Suen Wei Jie Darren, Benjamin Tai Joe Yew, Song Ziyi, Wang Zheng Liang, Weng Shi Zhuo, Wong Rui Yue, Yan Zhenqi, Yang Siyang, Zhang Qile, Zhang Yan and Zhao Jiayan

***Abstract*— Archimedes Autonomous Vehicles persevered through logistical challenges to develop our Autonomous Maritime System (AMS) for RobotX 2024. Reflecting on our shortcomings in 2022, we redesigned every subsystem for an improved Unmanned Surface Vehicle (USV) and Unmanned Aerial Vehicle (UAV). While this ambitious overhaul may not yield immediate competitive success for our young team, our bold endeavour comes from is part of a long-term strategy to use RobotX 2024 as the ultimate testbed to explore ideas, gather insights, and refine solutions for future competitions. This paper outlines our strategies, improvements and future plans.**

I. Competition Strategy

Archimedes Autonomous Vehicles

As a young multinational team, we developed our strategy based on our circumstances. Our team is mainly composed of final-year undergraduates and international dissertation students who commit to RobotX as a year-long project. Despite our school's participation since RobotX's inception, we are relatively new due to the project handover occurring three months prior to the competition. Our multinational makeup also made for challenging work dynamics as members were geographically dispersed, limiting time for in-person collaboration and integrated testing.

Goal 1: Attempt all tasks; Make valuable mistakes

After weighing the trade-offs between tackling all tasks or focusing on specific ones, we chose the all-out approach. Given our competitive disadvantage of having three months to prepare, we decided to strategise for the long-term and use RobotX 2024 to explore ideas, gather valuable feedback and lay the foundation for stronger developments for subsequent years. Though a targeted approach for reliable results would be ideal, our limited time for water testing made it impractical. We believe we would gain more from the mistakes made when exploring all tasks despite the added complexity of integrating multiple ideas.

Goal 2: Go through every task from start to end

During RobotX 2022, technical shortcomings such as maneuverability issues often forced the AMS to terminate task attempts mid-way. This resulted in grey areas on our solutions' effectiveness for unattempted task requirements. To get comprehensive feedback for passing down, we are determined to see every task through from start to finish. Our design strategy will emphasise on key functionalities and contingency planning.

Goal 3: Execution over accuracy

To maximise our score, we allocated more resources towards subsystems with most task relevance and prioritised scoring execution points first before aiming for accuracy points.

USV

Subsystems	Relevant Tasks	Priority
Propulsion	Necessary for all tasks	+++
Communications	Task 1 and bonus points in all tasks	++
GPS	Relevant to all tasks	++
Vision	Tasks 2, 3, 4, 5, 6	++
Planning	Tasks 2, 3, 4, 6	++
Hydrophone	Task 2	+
Ball Launcher	Task 6	+

UAV

Subsystems	Relevant Tasks	Priority
Control	Necessary for all tasks	+++
Vision	Tasks 7, 8	++
Navigation	Tasks 7, 8	++
Robotic arm	Task 7	+

Tables 1a, b: USV, UAV subsystem priorities

II. Design Strategy

Objective 1: Upgrade technologies for critical subsystems

We determined the following subsystems to be essential for Goal 2.

1. Propulsion and Control – maneuverability through the courses in good control
2. Vision – detection of the visual inputs

necessary to progress in the tasks

3. Planning – contingencies to proceed to the next step of the course even if insufficient data is received to complete prior tasks

Upgrading our key subsystems is necessary for Goal 2 and our long-term plan. Future members can develop better solutions by leveraging the competencies of the latest technologies and avoid unnecessary work from bridging technological gaps of outdated hardware. The Minn Kota motors that struggled to propel our USV in 2022 and the low resolution 2014 camera are examples of weaker or outdated hardware that can be upgraded.

Objective 2: Incorporate new capabilities

Reflecting on RobotX 2022, our team identified areas with potential for new solutions and aim to gather new insights during the competition. While some of these ideas may not be fully realized in time, such as our racquetball launcher that has yet have a trajectory planning module for accurate tossing, we shall focus on execution first before improving on accuracy as per Goal 3.

Objective 3: Improve troubleshooting capabilities at Ground Control Station (GCS)

To better monitor our AMS performance in real-time and easily pinpoint issues in our subsystems, we shall establish a robust GCS. A new, intuitive Graphic User Interface (GUI) that summarises all vehicular statuses and supplementary data for troubleshooting helps us to adapt faster to attempt more task requirements and maximise our score.

III. USV Design

A. *Propulsion and Control System*

During RobotX 2022, our two Minn Kota RT80 thrusters struggled to manoeuvre the USV. We thus replaced them with the Navy 3.0 Evo propeller, each providing 60 kg (133 lbs.) of thrust for sufficient propulsion power. [1] They are powered independently by an E60 lithium battery each, which has a high 60Ah capacity and steady 48V voltage for continuous power. [2] Both propellers are mounted in parallel along the USV keel for a differential drive propulsion system.

Figure 1: Navy 3.0 propellers on engine pods

A CubeOrangePlus MCU writes driver files to control the propellers. It is equipped with a M9N GPS module, allowing us to retain positional control if the USV's main GPS module fails. PID controllers control yaw rate and velocity. The output goes into the control allocation section to determine each motor's velocity. In manual control, the control input is determined by the pilot's joystick. Whereas for our waypoint-based planning, an L1 controller is used to calculate the control input from the origin and the destination.

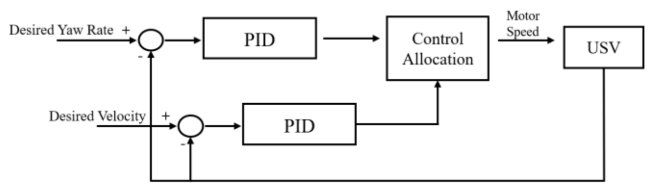


Figure 2: Controller Diagram

B. *Perception Systems*

1) *Binocular Vision*

The previous Axis m2014-e network digital camera is replaced with the ZED2i camera – a powerful stereo camera built for spatial analytics and powered by Neural Depth Engine 2. This provides new capabilities like depth perception and better supports AI applications like object detection and three-dimensional point cloud information capture. Since vision is our primary perception module to handle all the tasks, this upgrade is necessary to provide our planning algorithms accurate, precise input. [3]

A YOLO model is used to detect target objects and derive positional data from the point cloud data. For reliability, we used confidence thresholds that our detection frame counts must satisfy before passing data to the planning module. [4, 5]

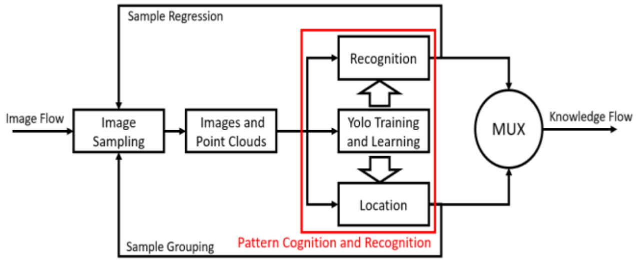


Figure 3: Process of recognition and localisation

2) GPS

We retained the previous GPS module since they provided reliable, precise results and were compatible for marine use. We kept the Hemisphere R632 GNSS Receiver for its multi-satellite system support, RTK capability and high accuracy of up to 4cm positioning and 0.01° heading. [6] We kept the Hemisphere A25 Antenna for its millimetre accuracy, superior multi-path mitigation, stable phase centre and strong SNRs at low elevations. Its aluminum housing is pretreated for marine use to withstand salt, fog and spray. [7]

Figure 4: Connection diagram and testing of GPS hardware.

3) Hydrophone

The Teledyne Reson TC4013 was kept for its high sensitivity, oomnidirectionality, broad band and O-ring sealed mounting. It receives digital data of acoustic signals and outputs their frequency and the presence of the sound emitter.

C. Planning and Control

We obtained the code base that our school placed 3rd with during RobotX 2022 VRX. While some VRX tasks can be adapted to RobotX 2024, we had to account for the hardware differences between the code and what we actually had. Since we use a waypoint planner for navigation, we also had to adapt the code to output waypoints instead of command velocity. Below is an overview of how we adapted the code for each task:

Task 2 – Entrance and Exit Gates

There is no equivalent task in the VRX competition. However, we adapted an existing mission planner which uses Dubin's path to plot a pathway between the boat and a point between the two buoys marking the appropriate gate.

Task 3 – Follow the Path

The VRX equivalent task is the "gymkhana" challenge. However, the obstacle avoidance was previously done based on command velocity. Instead, we used A* algorithm on a graph where edges are weighted based on a repulsion field around each obstacle for obstacle avoidance.

Task 4 – Wildlife Encounter

We improved the VRX code by streamlining the logic for manoeuvring around the wildlife. Instead of a smooth circular path around the wildlife which requires complex calculations of the USV's turning angle in real time, we opted for a simpler manoeuvre of four straight 90° turns.

Task 6 – Dock and Deliver

The VRX code used a LiDAR to locate parallel edges via point cloud data. As we do not have a LiDAR, our approach is to determine a panel plane from all three docking bay panels (in red below) and send waypoints (in green) that are perpendicular to but sufficiently far from the panel plane to avoid colliding into the dock.

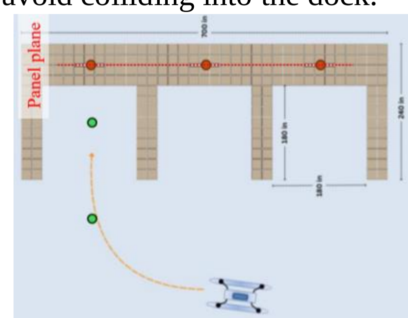


Figure 5: Illustration of strategy for task 6

D. Power System

A new power distribution network was designed for our new hardware. The two E60 batteries act as the USV's main power supply. They directly supply 48V power to the Navy 3.0 Evo propellers through solid-state relays. Multiple DC converters are used to step the power down to 24V, 12V and

7V to power the other subsystems.

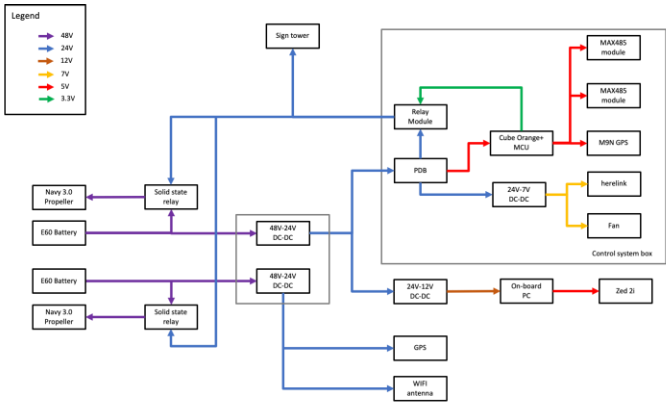


Figure 6: Power distribution of USV

The CubeOrangePlus MCU controls a 4-channel relay module to manage the sign tower lighting and the switching of solid-state relays. The relay module is connected in series with the control input of the two solid-state relays. When the relay module is open, the solid-state relays lose control voltage and shut off the power, providing remote control of the propulsion system's power supply.

E. Racquetball Launcher

Our team was passed down a base structure that was designed for yaw and pitch manipulation of the barrel. While structurally complete, the launcher was missing the hardware to actuate and control the barrel. To save time, we worked on retrofitting the missing mechanisms onto this build, including the flywheel launching actuation and the new drum reloading mechanism. With Goal 3 in mind, we prioritized the launching mechanism over the control modules to score the easier points for execution.

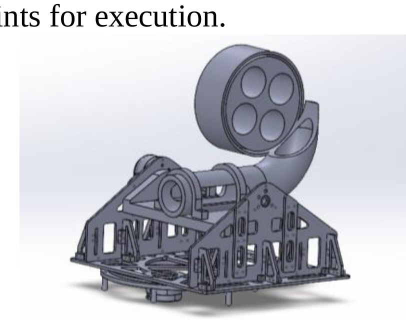


Figure 7: Racquetball launcher

F. UAV Landing Dock

To secure the UAV onto the USV during operations on the uneven sea terrain, a new UAV Landing Dock was designed. Conceptually based on the Heisha Drone Docking Station, our dock consists of 4 stepper motors that linearly actuate rods towards each other to clamp the UAV's legs.

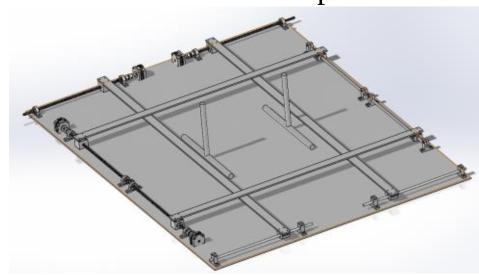


Figure 8: UAV Landing Dock

G. Mechanical Integration and Waterproofing

Integrating all subsystems onto the WAM-V was challenging due to the positional requirements different components had. The new UAV Landing Dock also meant that all hardware that was housed on the WAM-V payload tray previously had to be relocated for the UAV's safe launch and recovery.

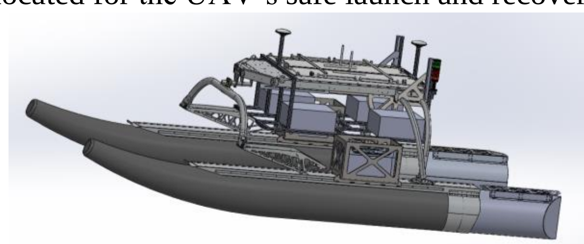


Figure 9: RobotX 2024 USV

Our redesign puts the UAV Dock and sensors atop the payload tray while the rest will be waterproofed and stored underneath on a custom shelf. Engine pods as per WAM-V's design were manufactured to replace the smaller buoys at the rear bulkheads. This creates stronger mounting points for the heavier Navy 3.0 Evo Propellers and stabilises the USV's pitch against the waves for the camera to remain forward-facing.

IV. UAV Design

Having faced maneuvering difficulties during RobotX 2022 due to incompatible hardware, we redesigned our UAV, ensuring that the mechanical and electrical specifications of our chosen hardware safely meet the necessary thrust and power requirements for operations.

Figure 10: RobotX 2024 UAV Internal build

A. Mechanical design

We estimated our UAV to weigh 6–7kg. To achieve the recommended 2:1 thrust-to-weight ratio, we selected TMotors' MN4014 400kv motors, each providing 1.530kg thrust at 50% throttle when paired with 17-inch propellers. [8] To prioritize preparation for tasks instead of the UAV build, we chose the HolyBro X650 frame. Its carbon fibre frame provides sufficient structural strength to handle the payload requirements. [9]

B. Electrical system

We aim to have >20 minutes of flight for sufficient time to conduct multiple task attempts. From calculations, a 6S 22000mAh 25C LiPo battery would provide >40 minutes of hover, comfortably giving the desired endurance even after accounting for power draw from dynamic movements and efficiency loss.

C. Control system

The Pixhawk 6X Flight Controller controls the UAV. It uses a PX4 autopilot, allowing us to use MAVLink protocol for vital functions like precise landing using Arcuo marker apriltags and survey path planning when paired with a M9N GPS module. For emergencies, manual control can be instantly taken using a separate handheld radio controller or ground controller software that communicates directly with the flight controller.

D. Perception system

The previous outdated, discontinued stereo camera is replaced with the Arducam 64MP Autofocus Camera. This gives us a greater field of view, higher resolution and better documentation support. Since we eliminated the stereo camera, we compensated for the lack of depth perception by using an ultrasonic sensor. Python packages like OpenCV and TensorFlow are used for image processing on the Raspberry Pi Model 4B for object and colour detection.

E. Robotic Arm Manipulation

We kept the previous robotic arm and 16-channel Servo Controller Board. We modified the gripper to better grasp the tin cans in Task 7 and adjusted the inverse kinematics of the arm to suit the new spatial constraints of our new UAV frame.

F. Waterproofing and Floatation

Waterproof enclosures are designed to house the electronics in case of water landings. Additionally, we installed DroneRetriever's Floatation Devices, which automatically inflate buoys upon water contact to keep the UAV afloat for retrieval. Each device sufficiently provides 6.4kg lift. [10]

Figure 11: Testing of UAV floatation device

V. AMS Communications Network

Ubiquiti Rocket transceivers and airMAX antennae on the USV and in the GCS provide long-range wireless communications suitable for maritime use and give us control of the onboard computers. MAVLink protocol is used to communicate between the onboard ROS system and the GCS PC. A new GUI was designed to clearly display all statuses on a single frame clearly. Supplementary modules like the UAV video transmitter displays the Raspberry Pi's runtime screen for faster troubleshooting as per Objective 3. During emergencies, autonomous missions can be terminated and positive control of vehicles can taken via handheld radio controllers.

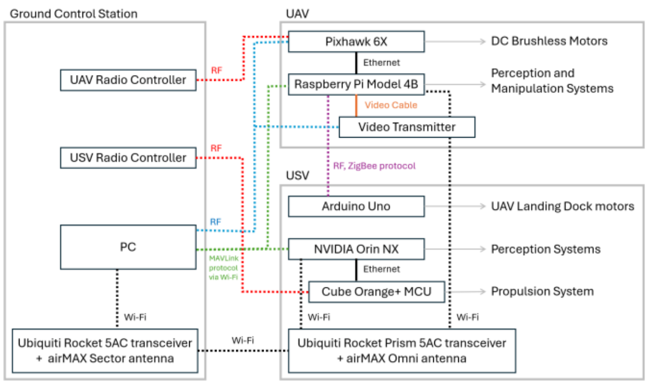


Figure 12: Communications network of AMS

VI. Testing Strategy

Given the three months our team had to prepare for RobotX 2024, we planned our tests in 3 phases.

Phase 1 (Aug – Sep): Individual Subsystem Testing

Since the team was geographically dispersed, we worked remotely, focusing on developing solutions and testing them via simulation or bench testing. Our goal is to ensure that each subsystem can function independently.

The biggest challenge came for our planning team, who could only simulate their path planning algorithms based on ideal maneuvering controls and optimal sensor inputs. Nevertheless, the team used this period to ensure the theoretical execution of their algorithms and to plan for contingencies.

Phase 2 (Sep – Oct): Water testing

During Phase 2, we had most of the team back in Singapore. With a month left till our vehicles' shipment, we aimed to repeatedly conduct water tests, focusing on system integration and prioritising the key subsystems from Objective 2.

Unfortunately, structural issues with the engine pods and delayed shipment of the batteries postponed our trials, reducing our opportunities for water testing. Despite these challenges, we managed to verify our propulsion and control module's effectiveness to manoeuvre the USV in good control, marking a progress towards Goal 2.

Phase 3 (Oct – Nov): Inter-subsystem tests

With the vehicles been shipped, the team will continue to test intersystem integration with our peripherals without the WAM-V structure.

VII. Future Work

Strategic changes

1) Team Organisation and Handover Structure

Our current team handover cycle will leave future members the same issues of limited time and resources for competition preparation. We aim to establish a permanent team with proper handover procedures to provide future members ample time and foundation to perform better.

2) Targeted Strategy

With more preparation time, a targeted approach to dedicate more time for repeated water tests is preferred to get more consistent, reliable results.

Technical developments

1) Incorporating LiDAR

A LiDAR would provide 360° awareness, a vast improvement from our current sole forward-facing camera on the USV. Using it to develop a SLAM localisation approach helps with obstacle avoidance and path planning.

2) Ball launcher control and trajectory planning

Additional capabilities such as pitch and yaw control and a trajectory planning module will improve the accuracy of our ball launcher.

VIII. Acknowledgements

The completion of our AMS would not have been possible without the aid of our academic mentors in Nanyang Technological University:

Associate Professor Xie Ming – for his supervision of the team and technical advice on autonomous systems and machine vision.

Professor Ng Heong Wah – for his keen guidance with mechanical integration matters.

Lab Technician Sa'Don Bin Ahmad – for his unwavering assistance in technical support.

Lab Technician Ng Tian Seng – for providing support to the UAV team.

We would also like to express our appreciation to our sponsors (Refer to Appendix C), including Platinum Sponsor – Future Systems and Technology Directorate (FSTD) for their continuous support.

IX. References

[1] “Navy 3.0 Evo - ePropulsion outboard motor,” *Camper and Marine Ltd*. https://camperandmarine.com/products/navy-3-0-evo-3kw?srsltid=AfmBOopO1Zcp9px_M88tjbaKpzpo_W5tkxGQQLgdxNRxqEiA1QIBBRZg

[2] “Marine Lithium Batteries|E-Series|ePropulsion,” *ePropulsion*. https://www.epropulsion.com/e-series-batteries/

[3] R. Blake and H. Wilson, “Binocular vision,” *Vision research (Oxford)*, vol. 51, no. 7, pp. 754–770, 2011, doi: 10.1016/j.visres.2010.10.009.

[4] Z. Yin, X. Ren, Y. Du, F. Yuan, X. He, and F. Yang, “Binocular camera calibration based on timing correction,” *Applied optics (2004)*, vol. 61, no. 6, pp. 1475–1481, 2022, doi: 10.1364/AO.450271.

[5] L. Cao, “Improved genetic algorithm for fast path planning of USV,” in *MIPPR 2015: REMOTE SENSING IMAGE PROCESSING, GEOGRAPHIC INFORMATION SYSTEMS, AND OTHER APPLICATIONS*, BELLINGHAM: SPIE, 2015, pp. 981529-981529–6. doi: 10.1117/12.2210736.

[6] NavtechGPS, “R632 GNSS Receiver - NavTechGPS,” *NavtechGPS*, May 04, 2022. https://www.navtechgps.com/r632-gnss-receiver/

[7] NavtechGPS, “A25 GNSS antenna - NavTechGPS,” *NavtechGPS*, Dec. 22, 2021. https://www.navtechgps.com/hemisphere_a25_gnss_antenna/

[8] “MN4014 Navigator Type UAV Multi-Motor KV400_Navigator Type_Motors_Multi-rotor UAV Power_T-MOTOR Official Store-Multi-rotor UAV,Fixed Wing,VTOL,FPV and Robot Power.” https://store.tmotor.com/product/mn4014-kv400-motor-navigator-type.html

[9] “X650 Kits,” *Holybro Store*. https://holybro.com/products/x650-kits?srsltid=AfmBOoqBbL29Re1gtQUZ9iYb8KAUjuycX1CwZ_3OMPQBVYLRFbJB5y3T

[10] Drone-retriever.com, “DRONE-RETRIEVER (Lifting Capacity/Unit Weight: DR9 - Lifts: 9 lbs - 4 kg, SHIPPING: OUTSIDE USA/International -In order to provide the lowest cost shipping we ONLY process orders manually. Send to sales@drone-retriever.com - exactly what you want to purchase–Your complete shipping address–email address–destination phone number),” *Drone-retriever.com*. https://drone-retriever.com/shop/ols/products/drone-retriever-usa-free-usa-ground-shipping/v/DR9-I

APPENDIX A

USV Components List

Component	Vendor	Model/Type	Specs	Custom / Purchased	Cost	Year of Purchase	Reasoning
Power System (battery)	ePropulsion	E60	https://www.epropulsion.com/e-series-batteries/	Purchased	USD $1999	2024	Light weight, sufficient power supply
CPU	NVIDIA	Orin NX	https://www.seeedstudio.com/reComputer-J4012-p-5586.html?srsltid=AfmBOoo8HDU_pEK8RvNf2f8NwnowMYt2EqohYFwerepeQg9tZkd6MEEy	Purchased	USD $899	2024	USV PC, NVIDIA GPU for CUDA dependencies of Zed2i
Propellers	ePropulsion	Navy 3.0 Evo	https://www.epropulsion.com/navy/	Purchased	USD $3130	2023	Providing sufficient thrusts, can moniter the battery and propeller status via RS485 communication
USV Controller	Hexsoon	CubeOrangePlus	https://docs.px4.io/main/en/flight_controller/cubepilot_cube_orangeplus.html	Purchased	SGD $508	2024	For USV Control
Telemetry / Joystick	Hexsoon	Herelink	https://docs.cubepilot.org/user-guides/herelink/herelink-overview	Purchased	SGD $1460	2024	
Power Distribution Board	Hexsoon	Hexsoon Power Distribution Board	http://www.hexsoon.com/en/product/product-52-363.html	Purchased	USD $14	2024	
Relay	kuriosity	Relay Module 4 Channel 3.3V	https://kuriosity.sg/products/relay-module-4-channel-3-3v-5v-12v-24v?variant=49918221254969&currency=SGD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gad_source=1&gclid=Cj0KCQjw6oi4BhD1ARIsAL6pox1Pb34-uoi_49QX64XeLnFRl-xBorBsS0yJ-tRztE3dGekQUKh9_Q4aAnjVEALw_wcB	Purchased	SGD $9.20	2024	For emergency stop and signal tower
Camera(s)	Stereolabs	Zed 2i	https://www.stereolabs.com/en-sg/store/products/zed-2i	Purchased	USD $549	2024	High resolution and complete recognition algorithm
Hydrophones	RESON	TC4013	https://www.teledynemarine.com/brands/reson/tc-4013	Purchased	USD $199	2022	Making absolute sound measurements and calibrations within a broad frequency range
GPS Receiver	NavtechGPS	R632	https://www.navtechgps.com/r632-gnss-receiver/	Purchased	Unknown	Unknown	To receive GPS data of USV
GPS Antenna	NavtechGPS	A25	https://www.navtechgps.com/hemisphere_a25_gnss_antenna/	Purchased	Unknown	Unknown	To receive GPS data of USV

Transceiver	Ubiquiti	airMAX Rocket Prism 5AC	https://store.ui.com/us/en/products/rocket-5ac-prism	Purchased	USD $249	Unknown	To establish Wi-Fi connection from USV
Transceiver	Ubiquiti	Rocket 5AC	https://www.networkhardwares.com/en-sg/products/rocket-ac-r5ac-lite-wireless-bridge-r5ac-lite-us?variant=41019568193741&utm_source=google-ads&utm_campaign=&utm_agid=&utm_term=&creative=&device=c&placement=&gad_source=1&gclid=Cj0KCQjw6oi4BhD1ARIsAL6pox3LGIIDXuba5SH2Qkc4lOXyo6zAGNW2LIQfweHWeYalfpYzHAdECJwaAnFjEALw_wcB	Purchased	USD $135	Unknown	To establish Wi-Fi connection from GCS
Antenna	Ubiquiti	airMAX Omni	https://store.ui.com/us/en/products/amo-5g13	Purchased	USD $165	Unknown	To establish Wi-Fi connection from USV
Antenna	Ubiquiti	airMAX Sector	https://dl.ubnt.com/datasheets/airmaxsector/airMAX_Sector_Antennas_DS.pdf	Purchased	USD $139	Unknown	To establish Wi-Fi connection from GCS
Waterproof Connectors	DigiKey	PTR-28483	https://www.digikey.sg/en/products/detail/bud-industries/PTR-28483/17765877?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_SG_Lower%20Performing%20Prodcuts&utm_term=&productid=17765877&utm_content=&utm_id=go_cmp-20140428177_adg-_ad-__dev-c_ext-_prd-17765877_sig-Cj0KCQjw6oi4BhD1ARIsAL6pox0oDT03Iwl46s8B36vm2WnRJeMou7VabL5AzQyMpxQCNBwOQDp4B68aAnJ9EALw_wcB&gad_source=1&gclid=Cj0KCQjw6oi4BhD1ARIsAL6pox0oDT03Iwl46s8B36vm2WnRJeMou7VabL5AzQyMpxQCNBwOQDp4B68aAnJ9EALw_wcB	Purchased	SGD $19.09	2024	To waterproof electronics

UAV Components List

Component	Vendor	Model/Type	Specs	Custom / Purchased	Cost	Year of Purchase	Reasoning
UAV Frame	Holybro	X650 Holybro Frame	https://holybro.com/collections/x650-kits/products/x650-kits?variant=43994378272957	Purchased	USD$199.00	2024	Main structural frame that needs to support estimates weight of 6-7kg
Brushless DC Motors	Tmotor	MN4014 Navigator Type UAV Multi-Motor KV400	https://store.tmotor.com/product/mn4014-kv400-motor-navigator-type.html	Purchased	USD$96.90	2024	Sufficient for 2:1 thurst-to-weight ratio
Propellers NS17*5.8 Prop-2PCS/PAIR	Tmotor	Propellers NS17*5.8 Prop-2PCS/PAIR	https://store.tmotor.com/product/ns17x5_8-prop-uav-carbon-fiber.html?srsltid=AfmBOopcDEza	Purchased	USD72.99	2024	Sufficient for 2:1 thurst-to-weight ratio

			76AP6Yh-mb3LXrXwYOR-ZYO9TfInbI60QYxH2pKaE6HY				
ESC	Tmotor	AIR 40A 2-6S Multi-Rotor UAV Drone ESC	https://store.tmotor.com/product/air-40a-6s-esc.html	Purchased	USD$39.99	2024	Sufficient current rating for motors
Control	Holybro	Pixhawk 6X (ICM-45686) V2A	https://holybro.com/products/pixhawk-6x-rev3?srsltid=AfmBOopibQO4RBzhAApEHb1FAt25m4RcJ61eFHhWY7-lDdavs1qHhX80	Purchased	USD$268.99	2024	Flight controller
GPS	Holybro	M9N GPS	https://holybro.com/collections/standard-gps-module/products/m9n-gps	Purchased	USD$54.99	2024	Provide GPS location of UAV
Telemetry	Holybro	SiK Telemetry Radio V3	https://holybro.com/collections/telemetry-radios/products/sik-telemetry-radio-v3?variant=42801818239165	Purchased	USD$62.99	2024	Communication with radio controller/PC
Battery	Hobbysquare	6S 22000mAh 25C LiPo Tattu battery	https://genstattu.com/tattu-plus-25c-22000mah-6s1p-xt90-smart-lipo-battery.html	Purchased	SGD$420.00	2024	Power supply of UAV
Battery	Hobbysquare	Elements 6200mAh 35C 3S Lipo Battery	https://hobbysquare.com.sg/collections/battery-3s-11-1v/products/elements-6200mah-35c-3s-lipo-battery	Purchased	SGD$70.00	2024	Power supply of UAV Payload
Power Distribution Board	Holybro	PM02D Power Module	https://holybro.com/collections/multicopter-kit/products/spare-parts-x650-kit?variant=44351077220541	Purchased	USD$24.99	2024	Distribute power from LiPo battery
RadioMaster TX16S Mark II Radio Controller (Mode 2) , ELRS	Holybro	RadioMaster TX16S Mark II Radio Controller (Mode 2) , ELRS	https://holybro.com/products/radiomaster-tx16s?variant=42712982192317	Purchased	USD$209.99	2024	Handheld controller
ELRS Receiver (RP1)	Holybro	ELRS Receiver (RP1)	https://holybro.com/products/elrs-receivers-series?variant=42829115982013	Purchased	USD$19.99	2024	Handheld controller
Video Transmitter	Hobbysquare	RUSH Solo Tank 5.8G VTX Video Transmitter CNC shell 1.6W High Power Built-in Microphone Heat Dissipation Structure For RC FPV	https://hobbysquare.com.sg/products/rush-solo-tank-5-8g-vtx-video-transmitter-cnc-shell-1-6w-high-power-built-in-microphone-heat-dissipation-structure-for-rc-fpv	Purchased	SGD$58.00	2024	Video transmitter to GCS
Secondary Camera	Hobbysquare	Foxeer Mini Predator 5 Racing FPV Camera 4ms Latency Super WDR	https://hobbysquare.com.sg/products/foxeer-mini-predator-5-racing-fpv-camera-4ms-latency-super-wdr	Purchased	SGD$55.00	2024	Camera for video transmission
Secondary GCS Screen for UAV	Hobbysquare	Hawkeye Little Pilot Captain 10 inch IPS 1280x720 1000lux 5.8G 48CH Diversity DVR FPV Monitor 3S-6S for RC FPV Racing	https://hobbysquare.com.sg/collections/fpv-diy-drones-fpv-monitors-goggles/products/copy-of-lcd5802s-5802-40ch-raceband-5-8g-7-inch-diversity-receiver-monitor-with-build-in-battery	Purchased	SGD$280.00	2024	GCS Screen to receive video input

Floatation Device	Droneretriever	Drone Retriever (CO2 Cartridge, Trigger Bobbin and Mounting Hardware)	https://drone-retriever.com/shop/ols/products/drone-retriever-usa-free-usa-ground-shipping/v/DR9-l	Purchased	USD$85.00	2024	Floatation device
Ultrasonic Sensor	element14	DFROBOT SEN0001 ULTRASONIC SENSOR	https://sg.element14.com/dfrobot/sen0001/ultrasonic-sensor-arduino-raspberry/dp/3517887?&CMP=KNC-GSG-SHOPPING-PMAX-TOP-AOV-CATEGORY&mckv=_dc%7Cpcrid%7C%7Cpkw%7C%7Cpmt%7C%7Cslid%7C%7Cproduct%7C3517887%7Cpgrid%7C%7Cptaid%7C%7C&gad_source=1&gclid=CjwKCAjw59q2BhBOEiwAKc0ijQm0nzphvZ3EmYFayGZim7lt3JvGrSRIeARby8VklTeuSJsQ0M-8whoCxmEQAvD_BwE	Purchased	SGD$19.88	2024	Depth perception
Robotic Arm	DFRobot	DFRobot 5DOF Robotic Arm	https://www.dfrobot.com/product-227.html	Purchased	USD$149.00	2022	For task 7, picking up tin cans
Companion Computer	Raspberry Pi	Raspberry Pi Model 4B (8GB RAM)	https://sg.cytron.io/p-raspberry-pi-4-model-b-8gb	Purchased	SGD$119.99	2022	Companion computer
Camera	Arducam	64MP Autofocus Arducam	https://www.arducam.com/product/arducam-1-1-32-64mp-autofocus-camera-module-for-raspebrry-pi/	Purchased	SGD$59.99	2024	Camera for perception tasks

APPENDIX B

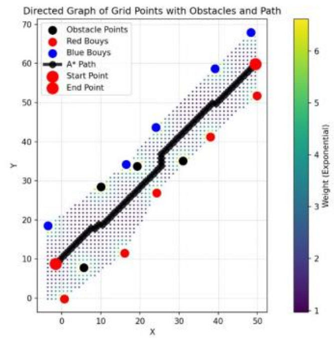
TEST STRATEGY PLANNING

Phase 1 (Aug – Sep) – Individual subsystem tests

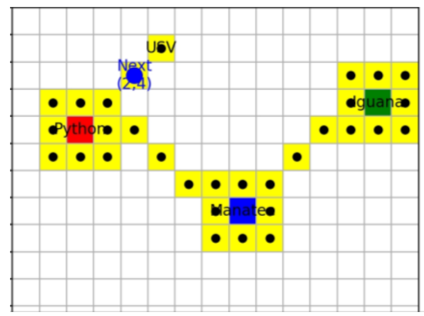
Subsystems	Test Objectives	Test Environment
Propulsion	1. Wiring of batteries to thrusters	In Lab
	2. Control of thrusters	In Lab
	3. Estop requirements	In Lab
Communications	1. GUI for GCS	Remote
	2. Communication network set-up	In Lab
GPS	1. Reading of latitude and longitude	In Lab
	2. Reading of heading	In Lab
Vision	1. Object recognition (buoy, light tower, dock panel)	Remote
	2. RGB colour detection	Remote
	3. Depth perception	
	4. Coordinates	Remote
		Remote
Planning	1. Path planning simulations for each task	Remote
Hydrophone	1. Reading of acoustic signal and derive location	In Lab
Ball Launcher	1. Launching of ball	In Lab
	2. Control of barrel	In Lab
	3. Vision module to detect target	Remote
	4. Trajectory Planning	Remote
UAV (Perception)	1. Object detection (Marker, Logos, Tincan)	Remote
	2. RGB detection	Remote
UAV (Navigation)	1. Replenishment path planning (Task 7)	Remote
	2. Survey path planning (Task 8)	Remote
UAV (Manipulation)	1. Robotic arm control	In lab

Some results from subsystem tests:

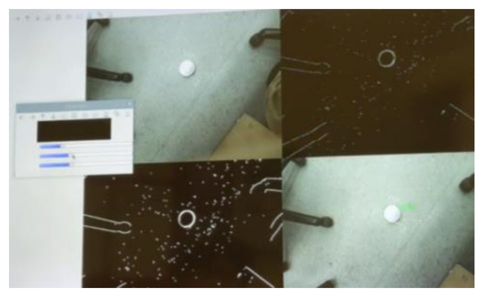
Vision: Object detection of buoy



Planning: Task 3 A algorithm path planning*



Planning: Task 4 path planning based on Wildlife Encounter



UAV Perception: Task 7 results for detecting tin cans based on Canny Noise Reduction

UAV Perception: Task 8 results for detecting objects within 4-marker boundary

Phase 2 (Sep – Oct) – Water tests

Water Tests	Test Objectives
1	1. Basic manoeuvres of USV 2. Test of waypoint control of USV position 3. E stop system test
2	1. Planning-to-propulsion integration 2. Perception calibration of sensors
3	1. Vision-to-planning integration 2. UAV Landing Dock test
4 onwards	1. Testing every task

Phase 3 (Oct - Nov) – Inter-subsystem tests and subsystem finetuning

Subsystems	Test Objectives	Test Environment
Vision	1. Improve training dataset for more accurate object detection	Pool
Hydrophone	1. Continue lab testing of hydrophone	In Lab (ater tub)
Ball Launcher	1. Calibration of ball launcher	In Lab In Lab
	2. Continue on control of barrel	Remote
	3. Continue on Vision module	Remote
	4. Continue on Trajectory Planning	Remote
Vision - Planning	1. Integration test (check image input corresponds with desired output)	Pool/In Lab
Hydrophone - Planning	1. Integration test (check signal input corresponds with desired output)	In Lab (water tub)
All - Communications	1. Updating of status for heartbeat message	In Lab

APPENDIX C

SPONSORS

A. *Title Sponsors*

Nanyang Technological University, School of Mechanical and Aerospace Engineering (MAE) – For their lab facilities to our project.

B. *Platinum Sponsors*

Future Systems Technology Directorate (FSTD), Singapore Maritime Foundation (SMF), Kim Heng, and Republic of Singapore Yacht Club (RSYC).

C. *Silver Sponsors*

Ocean Network Express (ONE) and Wilhelmsen.

D. *Bronze Sponsors*

Miclyn Express Offshore (MEO)

APPENDIX D

GPS MODULE CALCULATIONS

The input to our GPS module is satellite data, and the outputs are latitude, longitude, altitude, time and heading. The following details the process from input to output.

1. Data Acquisition:

Python was utilised to read and process NMEA sentences from the GNSS receiver. The following NMEA sentences were used to extract essential information: GPGGA(Time, latitude, longitude, and altitude), GPRMC(Course over ground and speed), GPMSS(Signal strength and signal-to-noise ratio), GPHDT(Heading), GPGSA(Horizontal, vertical, and positional dilution of precision). A Python script using the pyserial and pynmea2 libraries was implemented to extract and display this information.

2. Data Processing:

Latitude and longitude data were converted to local coordinates using the Haversine formula Eq.(1), allowing the USV to navigate accurately relative to the competition course.

$$d = 2R\sin^{-1}\left(\sqrt{\sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right)+\cos\varphi_1\cdot\cos\varphi_2\cdot\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)}\right) \quad (1)$$

3. ROS Integration:

The system was configured on Ubuntu 20.04 with ROS 1 Noetic as the middleware. The data logging and processing pipeline included: data_logging.py: Captures raw GPS data; data_slicing.py: Processes and publishes parsed GPS information; GPS_UI.py: Displays real-time GPS coordinates and vessel heading via GUI.

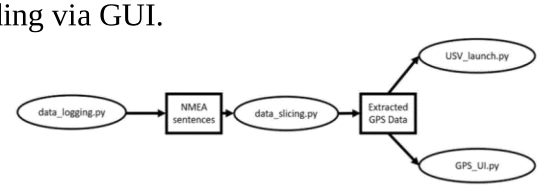


Illustration of the rqt graph