JAMES COOK UNIVERSITY AUSTRALIA

2021

Robot-X Application

Technical Contact

Dr Shou-Han Zhou, Lecturer, Electrical Engineering
Email: shouhan.zhou@jcu.edu.au
Phone: (07) 4781 4789

Administrative Contacts

Ethan Waters, JCU Robotics Club President
Email: ethan.waters@my.jcu.edu.au
Phone: (+61) 0435 626 685

Ross Siddins, JCU Robotics Club Secretary
Email: ross.siddins1@my.jcu.edu.au
Phone: (+61) 0467 258 646

1.0 Introduction

James Cook University prides itself in being the leading institution in education in the field of marine science and biology. Recently, the Department of Engineering at James Cook University is looking to extend its education and research strength to the field of marine robotics. Marine robotics is well-aligned not only with the research and education strength of the university but also its location within Tropical Queensland. Research and engineering design of automated marine robotics that can robustly operate within the tropical region can provide novel opportunities for research in tropical marine life and the conservation of the Great Barrier Reef. The Robotics Club and the Head of Engineering at James Cook University believe that the Robot-X competition presents an unprecedented opportunity to engage student interest in the field of marine robotics. The College of Science and Engineering will be committed to the current and future Maritime Robot-X competition because it is an ideal competition for James Cook University students. The competition can provide students with an opportunity to apply their knowledge to real-world challenges, as well as bringing novel ideas and design concepts to the robotics field. The Robot-X competition will be open to students from all year levels with the College of Science and Engineering at James Cook University and will become the primary interuniversity competition for the School. Final year students will have the opportunity to take this challenge for their thesis. For this reason, the Robotics Club is taking the initiative to apply for entry into the competition with the intent of being awarded a WAM-V platform. This competition will strengthen the collaboration with the Trusted Autonomous System and Queensland Artificial Intelligence Hub at the Australian Institute of Marine Science, making Townsville the leading city in tropical marine robotics within regional Australia. An overview of the Autonomous Marine System proposed by James Cook University is presented below:

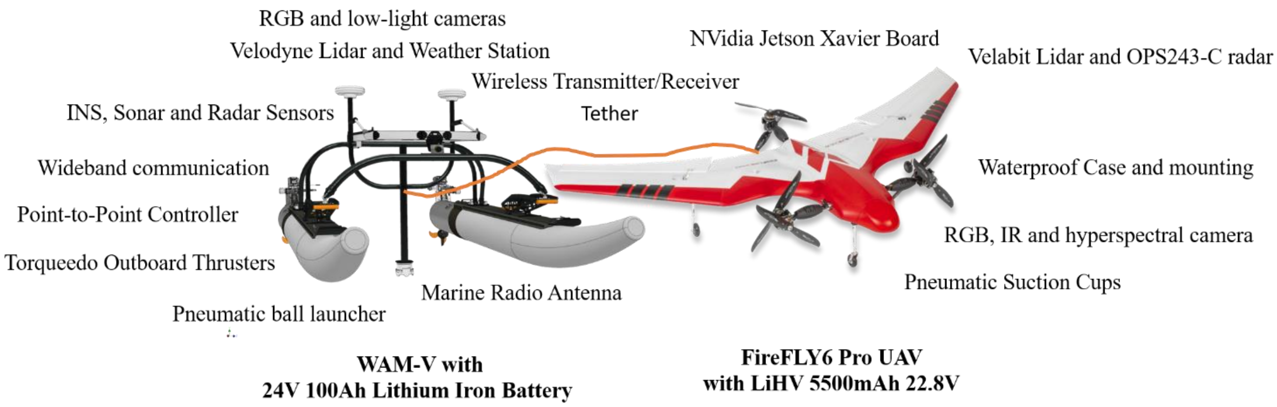

Figure 1: Overview of the Autonomous Marine System proposed by James Cook University

2.0 Technical Approach and Justification

The autonomous marine system proposed by JCU for the 2022 competition will involve two systems: the UAV and the WAM-V. The technical summary below uses the 2018 competition rules and requirements. Further design considerations will be reviewed upon release of the 2022 information.

2.1 UAV Technical Summary

The UAV provides vital information and data to the WAM-V in addition to other responsibilities (Figure 1). The UAV will be an already acquired FireFLY6 Pro, equipped with an RGB, infrared and hyperspectral camera to capture visual information about the UAV and WAM-Vs surroundings, as well as the objects and hazards relevant to the challenges. It will utilise the LiHV 5500mAh 22.8V batteries to allow for an hour of flight time per battery under full load.

Prior to the event, the visual, spectral and infrared data will be gathered and sent to a high-performance computer accessible by JCU students to train neural networks and machine learning algorithms such as

Node-RED nodes for IBM's Watson. Once developed, the algorithms and scripts will run on an Nvidia Jetson Xavier Board to process the visual information in real-time during the event.

Whilst the UAV can itself be autonomous and will be capable of conducting untethered tasks, it will transfer information to the WAM-V for the majority of the tasks through tethered data transmission via custom made waterproof steel-reinforced ethernet data tether cables. Tethering the UAV to the WAM-V provides a significantly larger data transfer rate than the available wireless counterparts and will also eliminate the need to constantly monitor and charge the UAVs battery.

The flight plan and trajectory of the UAV will utilise a fluid motion planner during flight to increase reliability, efficiency and reduce the task completion time [1]. This will be implemented in combination with a controller that will utilise a PID feedback loop to ensure the UAV hasn't deviated from the desired trajectory or position. GPS, IMU and altitude sensors onboard the UAV will be fused together via an extended Kalman Filter to provide the required information for UAV location.

Contingency plans have been considered and accounted for to ensure the UAV correctly performs its required tasks in different environments while maintaining safety. To account for adverse weather conditions which can impact accurate visual information from the cameras, the newly available Velabit LIDAR and radar will fuse with existing sensors to ensure that accurate information is gathered.

The UAV and cameras must also be able to withstand the marine environment and rain without incurring damage to the electronics. Appropriate waterproofing and chemical treatment will be applied to the electronics and the UAV materials. Electrical components will also be stored in waterproof casings, utilising waterproof cables and connectors between the various electronics containers. The containment of the electrical subsystems will also enable fast replacement of any faults during the event, with multiple backups will be kept on hand.

In the scenario that the UAVs tether breaks unexpectedly, the UAV will utilise wireless communication capabilities and backup batteries to complete the task. For this reason, multiple ESP32 microcontrollers running the ESP-NOW protocol will also be mounted on the UAV. Wideband support with channel-switching will be considered to account for possible on-site interference. However, if wireless communication between the UAV and WAM-V is unable to be established, then the UAV will be programmed to return to shore. In the case of an emergency, the UAV will have manual override capabilities, allowing a pilot to manually manoeuvre the UAV to safety or immediately stop the UAV.

2.2 WAM-V Technical Summary

The WAM-V will utilise a point-to-point feedforward controller that predicts the craft dynamics in the marine environment [3] (Figure 1). Environment information gathered from an onboard weather station will be integrated with a wave dynamics model to predict the WAM-V's travel dynamics and the optimal path to the target while avoiding challenge constraints. Model errors will be corrected by feedback controllers using the WAM-V location, as determined from sensor fusion of onboard inertial navigation systems with differential GPS, compass, a LIDAR, a radar and RGB cameras.

A wireless ESP32 microcontroller will be added to the WAM-V. Along with the tether, wireless communication via the ESP-Now protocol will be made with the UAV to ensure robust communication. Collision detection will be implemented via RGB camera, ultrasonics, LIDAR and radar to keep the WAM-V from running into the vessels of other teams and course objects.

The WAM-V will be fitted with dual independent outboard electric motors for accurate velocity control, high efficiency and additional redundancies in case of engine failure. The outboard electric motors will be controlled directly by a central module, which also receives positional, target and obstacle information from the sensors on the WAM-V and the UAV.

Other contingencies have also been placed to negate the effects of subsystem failure or adverse weather. Much like the UAV, the electrical subsystems of the WAM-V will be water-treated and be contained within modular waterproof containers, accessible by waterproof connectors and cables. To ensure correct colour detection in low light conditions, a low light security camera will be fused with the RGB cameras to detect objects. Machine learning training in different operating conditions such as low light will enable the colours to be detected during the event. In the event of major communication failure between the two systems, the WAM-V would rely upon its own onboard sensors for situational awareness and obstacle avoidance.

An emergency stop system is also built. The stop system can be triggered from Robot Operating System software and a custom-built wireless emergency stop unit developed by the team. The wireless emergency stop operates using the ESP-NOW protocol and will enable the vessel to be shut down safely from over 480m away.

2.3 Individual Challenge Summary

The following sections details how the WAM-V and the UAV will be integrated to successfully complete the 2022 RobotX challenge:

Dynamic safety inspections require the AMS to autonomously complete launch and recovery tasks. The autonomous UAV will use telemetry and communications information described above (i.e. in the form of inertial sensing, image processing etc.). For the WAM-V to pass dynamic inspection, a similar operating procedure will need to take place utilising onboard RGB cameras and sensors.

Challenge task 4.1 requires the UAV to pass through a gate based on buoy colour and an active beacon and to circle a black buoy. The UAV will apply multi-image detection using RGB/infrared/low-light cameras to detect possible buoy/entry gate locations, the black buoy as well as the no-go and lockout zones. The UAV will then transmit the gate positions/ lockout zones to the WAM-V. The WAM-V will then sweep across the gates to detect the underwater beacon using a waterproof marine radio antenna. Upon detecting the correct gate, the UAV and the WAM-V will circle the black buoy by entering and exiting the gate.

Challenge task 4.2 requires the WAM-V will follow a path between red and green buoys. The UAV will detect, classify and identify the locations of the buoys and the obstacles using the cameras. After transmitting the object's GPS coordinates to the WAM-V, the WAM-V will navigate across the course using information from the RGB camera, the weather station, inertial navigation system, LIDAR and radar, ensuring that the heading is maintained within the buoys at all times while avoiding obstacles.

Challenge task 4.3 requires the WAM-V to circumnavigate objects of interests depending on their hyperspectral signatures. The RGB/infrared/low light and hyperspectral camera on the UAV will detect the objects and field boundary using trained machine learning algorithms. The object locations and field boundary will be transmitted to the WAM-V, which will then circumnavigate the objects according to their identified hyperspectral signature while avoiding the field boundary

Challenge Task 4.4 requires the reporting of a colour pattern displayed by an RGB buoy. The RGB/low light cameras will identify the colour sequence using previously trained machine learning models that are robust to weather, and lighting conditions will be applied during the event.

Challenge Task 4.5 requires the WAM-V to dock in a bay displaying the correct coloured light and launch a Penn Ultra-Blue Racquetball through either a 0.5m or a 0.25m hole. The correct coloured light will be detected by the RGB/low light camera as in Challenge Task 4.4. The cameras on the UAV will then detect the location of the target hole. Once the correct hole location is identified, the racquetball will be launched from a custom launcher developed from a pneumatic speargun.

Challenge Task 4.6 requires the UAV to launch from the WAM-V, recover a 200mm Diameter, 3mm Thick disc and transfer to a helipad corresponding to one of three coloured disks. The UAV will be fitted with a pneumatic suction cup. Once launched from the WAM-V, it will use RGB/low light cameras to identify the appropriate disc, approach the disc target and pick it up using the pneumatic suction cup. Finally, the UAV proceeds to the helipad location using RGB and infrared cameras.

Challenge Task 5.1 requires the UAV to process to a target while avoiding obstacles. The UAV will detect the obstacles positions in real-time and provide the information to the WAM-V. Using multisensor integration similar to that of Challenge 4.2, the WAM-V will proceed through the course while avoiding the obstacles.

Challenge Task 5.2 requires teams to implement a visual feedback system and a heartbeat broadcast system. This will be communicated from the WAM-V to the Ground Control Station (GCS) via ESP32 microcontrollers running the ESP-NOW protocol. The GCS will then communicate with the Technical Director Server (TDS) via a wired RJ45 connector.

2.4 Applicant's Capacity and System Development and Testing Timeline/Milestone

Being members of the robotics club, the applicants have extensive experience in imaging processing, control system design, hardware implementation and robotics construction. The project will consist of three teams and four milestones as follows:

Teams

Software team is responsible for imaging recognition and multisensor integration. They will ensure all relevant images are recognised. They are also responsible for ensuring the WAM-V and UAV localisation through sensor fusion.

Propulsion team is responsible for the mountings, waterproof casings and electronic boards for the UAV and the WAM-V craft. They will ensure all the electronics and UAV are suitable for the marine environment under different weather conditions. They are also responsible for ensuring modularity between the different systems and correct communications between the different systems.

Control system team is responsible for the control and dynamics of the UAV and the WAM-V craft. They are responsible for designing the control system and ensure that it can integrate with all the different systems. They are also responsible for ensuring all Challenges can be done in the Virtual Maritime RobotX Challenge simulation [2].

Milestones

Laboratory Stage [Jun-Sep, 2021] The teams will order all the parts for the RobotX 2022 competition (see Section 7). The laboratory testing stage will involve the identification of the image, the design of the mechanical components, including the pneumatic launcher, and the development of the control system in simulation.

Building Stage [Sep-Dec, 2021] The teams will work to build their individual hardware components, including mechanical and control development and sensor fusion.

Integration Stage [Dec-Feb, 2021] The teams will aim to receive the robotic component and begin to integrate them onto the WAM-V. Testing of all components is made at this time, including backup components.

Field Testing Stage [Feb-Jun, 2021] The teams will complete their integration and will test the vehicle challenges in the Marine Platform Test Facility and the Tropical Marine Test Ranges at Reefworks of the Australian Institute of Marine Science.

3.0 Team Qualifications

Ethan Waters, Timothy Yanner and Ross Siddins are the software, control systems and propulsions team leaders respectively. They are all fourth-year undergraduate, Bachelor of Engineering (Hons.)/Bachelor of Science students, with significant involvement in the JCU Robotics Club. Ethan and Ross as the current and previous president of the JCU robotics club, respectively, have experience and feel comfortable in leadership positions. Each of their involvements with JCU Robotics Club has given them the opportunity to construct, program and test Zumo robots. They all have experience in automatic controls, control systems, embedded systems and electronics. Ethan and Timothy work as professional software developers outside of their studies, providing them valuable experience with machine learning algorithms and neural networks, image recognition and a variety of programming languages.

The three teams will be directly advised and mentored by Dr Shou-Han Zhou, Associate Professor Scott Heron, Ms Valerie Cornet and Dr Melanie Olsen. **Dr. Zhou** has extensive experience and publications in robotic control systems, artificial intelligence and is an ongoing academic mentor for JCU Robotics Club. **Associate Professor Heron's** expertise in marine physics is integral to the development of the WAM-V performance within the marine environment. **Ms Valerie Cornet** has extensive expertise in hyperspectral, infrared and RGB image recognition within the marine environment. **Dr Olsen** achieved second place in the international 2014 Maritime RobotX Challenge with the Queensland University of Technology. She will provide design and development experience in marine monitoring systems, sensor communication and data fusion. Technical support will be provided by Mr Wayne Morris and Mr Russel Warburton of Area 61. They have over 30 years of experience in UAV and Marine engineering. This is in addition to the support provided by the Head of Electrical Engineering and the Head of Engineering at James Cook University. They will introduce the team to industry contacts to support this project.

4.0 Facilities

The project will be carried out in three different locations. Initially, the teams will use JCU Robotics Club's private laboratory to design, build and store prototypes of each subsystem. The team will also have access to JCU's high-performance computing system, which will be utilised to develop neural networks and machine learning algorithms. During the building and integration stage, the teams will make use of a dedicated space within Area 61which houses the WAM-V and UAV. Area 61 is ideal for this due to its direct access to electronics components and technical expertise. Finally, the team will have access to the world-leading marine testing facility, Reefworks, at the Australian Institute of Marine Science. The teams will utilise the testing facility to collect marine hyperspectral imaging data for resting and simulation purposes. Additionally, the UAV and WAM-V field testing can be performed at the Marine Platform Test Facility, as well as the Tropical Marine Test Ranges. For James Cook University, ReefWorks will become an invaluable testing stage for the 2022 and future RobotX challenge.

5.0 Sponsorships and Partnerships

The JCU Robotics Club RobotX team is proudly partnering with James Cook University, the Australian Institute of Marine Science and the IEEE Northern Australia Section. The RobotX team will receive additional support from other companies and organisations, including IBM, IEEE and DST.

Organisation	Email	Phone
AIMS - Autonomous Systems and the Queensland Artificial Hub	molsen@aims.gov.au	(07) 4753 4249
National Instruments	info.australia@ni.com	(02) 9491 4000
IBM	anzcrt@au1.ibm.com	1300 304 292
Velodyne Lidar	N/A	(669) 275 2251
IEEE Northern Branch	molsen@aims.gov.au	(07) 4753 4249
Solex	sales@solex.com.au	(07) 4771 4211
DST	N/A	+61 417 191 881

6.0 Management Approach

The project will take advantage of the incremental developmental methodology to guide the development of the system. Each subsystems development and individual testing will be the responsibility of either the control systems, propulsion or software team. Each team will comprise up to three undergraduate students with the guidance of highly regarded academics and industry professionals. JCU Robotics Club will advertise this opportunity to undergraduate students within the College of Science and Engineering. Interested undergraduate students will be interviewed and selected by the JCU Robotics club and Dr Shou-Han Zhou. The selection criteria will take into their account academic achievements, teamwork skills and communication skills. The WAM-V will be transported to the Sydney Regatta Centre in the reusable shipping case it was obtained in. The WAM-V and other required equipment, such as the UAV, will journey to Sydney and back in a fleet of JCU owned trucks. The project will be transported ready two weeks prior to the beginning of the event, allowing ample time to complete the approximately three days drive to Sydney. Team members will be required to make their own arrangements to arrive in and return from Sydney on the 8th and 20th November 2022, respectively. This will provide the team with time to test the system within the Sydney Regatta Centre.

7.0 Summary

James Cook University Townsville is well-situated on the coast of tropical North Queensland with persistent and ever-growing ties to local maritime, marine science and defence industries. With the RobotX challenge offering the chance to strengthen these bonds further through educational experience, practical application and professional networks, any WAM-V will have a permanent home at the Bebegu Yumba campus. Even in recent weeks, JCU-AIMS relations have declared a renewed purpose in making Townsville a centre for excellence in autonomous marine science research and development. By receiving your support, James Cook University and RoboNation will be creating new opportunities locally and globally in pushing forward the field of AMV research.

8.0 Rough Order of Magnitude

JCU University will supply most project hardware, including UAV, sensors, communications equipment and the hyperspectral camera. Most items below are purposely over-estimated to show the feasibility of JCU participating in the 2022 RobotX Challenge.

Support

AIMS	$ 5,000
Industry Partners (IBM, Autoweed)	$ 9,000
Solex and Velodyne Lidar	$ 3,500
IEEE and DST	$ 7,000
Total	**$ 24,500**

Expenses

UAV

FireFLY6 Pro UAV (treatment)	$ 200
LiHV 5500mAh 22.8V(existing)	$ 0
RGB, IR and hyperspectral camera	$ 0
Waterproof cables and connectors	$ 820
NVidia Jetson Xavier Board	$ 600
Sensors (GPs, Accel, Altitude)	$ 600
Velabit LIDAR and OPS243-C radar	$ 300
Waterproof case and mounting	$ 200
Pneumatic Suction Cups x 2	$ 300
UAV Total	**$ 3020**

WAM-V

WAM-V (free from the application)	$ 0
Case, moutning and lifting hoist	$ 600
Emergency Stop Buttons	$ 100
Waterproof cables and connector	$ 350
Velodyne Lidar and Weather Station	$ 3,800
Sensors (INS, Sonar, Radar)	$ 500
Communication and control boards	$ 400
RGB and low-light cameras	$ 600
Marine Radio Antenna	$ 100
Cressi Pneumatic Spear gun x 2	$ 500
Torqueedo Outboard Thrusters	$ 6000
24V 100Ah Lithium Iron Battery x2	$ 3,000
WAM-V Total	**$ 15,950**

Personnel and Logistics

Hotel Room (Backpackers)	$ 800
WAM-V Transport (JCU Fleet Truck)	$ 1000
Food and transport (emergency)	$ 200
Logistic Total	**$ 2000**

9.0 References

[1] M. Radmanesh, K. Cohen, M. Kumar, 4 - Large-Scale UAV Trajectory Planning Using Fluid Dynamics Equations, Multi-Rotor Platform-based UAV Systems, pp. 63-86, 2020, https://doi.org/10.1016/B978-1-78548-251-9.50004-2.

[2] B. Bingham, C. Aguero, M. McCarrin, J. Klamo, J. Malia, K. Allen, T. Lum, M. Rawson, R. Waqar, *Toward Maritime Robotic Simulation in Gazebo*, Seattle, WA, October 2019, [Git Repository], https://github.com/osrf/vrx

[3] S.-H. Zhou, Y. Tan, D. Oetomo, C. Freeman, E. Burdet, and I. Mareels, "Modeling of endpoint feedback learning implemented through point-to-point learning control," *IEEE Transactions on Control Systems Technology*, vol. 25, no. 5, pp. 1576–1585, 2016.