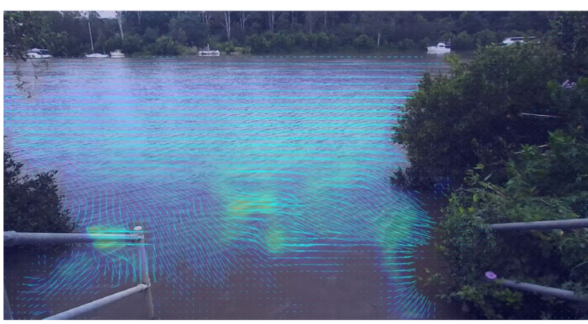
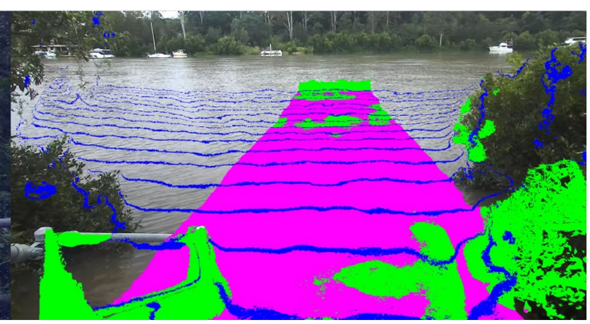



UQ Robot-X

Building a trans-disciplinary autonomous systems team to solve challenges for a better world

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1. Technical Approach and Justification

The University of Queensland seeks to participate in RobotX to expand their innovative work applying autonomy and machine learning to environmental challenges. Across all challenges the UQ team will be motivated by using bio-inspired approaches to sensing, analytics, decision making and actions. The influences of the marine environment on optical and acoustic systems are significant. Through a solid foundation in biology and physics the team has developed approaches to optical and acoustic sensing that is derived from the evolutionary adaptations of marine fauna that have superior acoustic and vision systems. The multidisciplinary nature of this team with strengths across autonomy, mechatronics, data science, remote sensing, cloud computing, oceanography and biology will introduce some fresh approaches to the challenges.

1.1 Examples of student-led innovation at UQ

Students within the team have recently developed a leading-edge stereo camera-based water velocity monitoring system using a combination of edge and cloud computing to yield novel machine learning approaches. The team has also developed a UAV based profiling water quality system that has been licenced to water technology company Xylem. Using a lightweight winch to deliver power and data to a multi-parameter water quality sonde to depths of up to 30 m the system is able to transmit water quality data in real-time from water bodies inaccessible by surface vessel. Our team has also developed a novel approach of using predictive hydrodynamic, meteorological and bio-geochemical modelling approaches to provide autonomy inputs to low-cost autonomous surface vessels. This concept enables USV systems to predict the environment rather than simply react to it from in-situ sensors.
The team is also at the forefront of remote sensing technology using both optical and object-based approaches to derive large scale spatial information from multi and hyperspectral airborne and satellite-based sensors. Opportunities exist to provide real-time feedback between in-situ sensors onboard the USV, airborne sensors onboard a UAV and satellite-based sensors that can be tasked directly by onboard computing. Whilst satellite-based systems may be beyond the scope of the 2022 competition our team is interested in pursuing these linkages between AUV, USV, UAV and satellite systems for future challenges. We are a highly motivated group from diverse backgrounds that seeks to use the 2022 RobotX competition to draw together the initiatives outlined above to drive innovation and collaboration in marine robotics.

1.2 Achieving Platform Autonomy

High level platform autonomy will be achieved using the ROS (Robot Operating System) backseat driver, which draws on a modular decision-making framework specific to the task at hand. The modularity of the proposed approach enables student developers working within the UQ RobotX team to rapidly develop system modules independently without impacting workflow within the software stack. The open-source operating system and intended modularity also facilitate module development in future years, allowing student developers to share advancements with the broader robotic community and receive feedback regarding implementation of their systems in a host of real-world environments.

A mast-mounted stabilised stereo camera system with integrated IMU rotating consistently to provide 360-degree awareness of the vessel's surroundings will be implemented. The 3D data provided to the computer vision GPU processing system (up to 30 m in all directions) will be directly indexed to the associated imagery produced, with a projected plane of the water surface computed beyond 30 m towards any potential objects of interest identified in the distance assisting in path finding and distance estimations. The 360-degree scanning operation of the stereo camera system will provide the foundational data stream for immediate object avoidance and close-quarters manoeuvrability operations. Adverse conditions, such as glare and water on the lens will be minimised through weather resistant design and error identification analysis flagging unreliable data produced from the system. The output of this stereo vision system will be fused with LiDAR data in order to augment confidence maps relating to the area around the vessel, and replace erroneous artefact signals returned by each sensory system. Standard autonomous operating task sets built into the decision support structure for situational awareness will activate sets of sub-routines analysing sensory information and translating this data into actions towards the currently identified goal with priorities maintained for obstacle avoidance and other necessary consistent operational sub-routines.

Autonomous navigation will be achieved through the development of communication protocols responsible for relaying information between the high-level autonomous system and low-level dynamic control system. Sensory inputs including the Inertial Measurement Unit (IMU), Ground Positioning System (GPS), Acoustic Dead Reckoning System and computer vision aided environmental awareness transmit key navigational data directly to the high-level autonomous system responsible for determining and prioritising vessel waypoint actions. This high-level autonomy aims to provide simplified navigational commands to the low-level dynamic control system in the form of dynamic control outputs (i.e. vessel speed and heading). These dynamic control outputs are then translated to desired propeller thrust and azimuth orientation according to a custom inbuilt control library developed as part of extensive hydrodynamic modelling, dynamic vessel simulation and in-field testing under a range of varying sea-states. The operation of linear actuators responsible for controlling the wave-adaptive pontoons and heave compensation systems facilitating UAV docking in unfavourable sea-states are to be considered auxiliary navigational systems. While these systems provide improved navigational and operational performance, they are not considered essential meaning the vessel may still perform navigational tasks in the unlikely event of system failure. Similarly, systems involving the operation of winches, mechanical grabs and payload transfer devices will be integrated independently.

1.3 Capacity to Achieve Selected Tasks

We will utilise the Gazebo simulation environment for both single and integrated testing of algorithms and dynamic responses. A core focus of our testing will be fortnightly full-team simulations to ensure the critical linkages between components are robust. To ensure rapid feedback from field trials to testing we will host monthly field trials in a marine environment to provide regular opportunities for testing and refinement in real-world conditions. We believe a common mistake is to leave field trials to late in the development pathway, our team will place field testing as the highest priority.

Challenge Task 1 Entrance and Exit Gates: The key challenge in task 1 will be the localisation of the underwater beacon to determine the entrance gate. We propose to use two hull mounted underwater hydrophones (DolphinEar DE600, DolphinEar Hydrophones) fixed at a set position and Pinger localisation will be based on the Time Difference of Arrival (TDA) method. As the ASV transits towards the pinger, the beacon location will be determined with increasing confidence as the TDA is minimised until successful localisation occurs. After the active beacon is detected, the WAM-V will transit the gate where the active beacon is located and then target the middle of two buoys. After it transits these two buoys, the developed decision algorithm will plan to turn right/left to circle one of two buoys. In the last step, the active beacon is detected and localized as described in the first step, and then the WAM-V will transit the gate again.

Challenge Task 2 Follow the Path: In challenge Task 2, a UAV will be deployed to detect red/green coloured buoys. An RGB camera as a sensor and OpenCV Python are used to detect these coloured buoys. After detection, the middle points of each red and green buoys will be determined, which will be used as waypoints to define a path. The defined path will be given to the WAM-V as a reference trajectory, and WAM-V will follow this reference trajectory precisely. As obstacles may be included within and around the path, we will use a LiDAR to detect the obstacle and run our obstacle avoidance algorithm. Here the challenge is to generate an alternative reference trajectory to avoid obstacle and guide the WAM-V through the defined path. Our team's experience with autonomous driving will be a good starting point to avoid obstacles and to generate new reference trajectories. Therefore, there might be a need for developing a path planning algorithm in which the yaw angle of the marine vehicle will be changing when the WAM-V is avoiding obstacles.

Challenge Task 3 Wildlife Encounter and Avoid: The key challenge in task 3 will be the localisation of each wildlife object within the search area by the UAV. We propose to use a commercial UAV platform (DJI Matrice 600 PRO) and hyperspectral sensor (Corning microHSI 410 Hyperspectral Sensor) to exploit the flight control system and sensor integration capabilities of this UAV. In addition, our team has long-term experience in operating this UAV platform from mobile surface platforms under challenging wave and wind conditions. The UAV will undertake a standard lawnmower path across the whole survey area and ensure 80% coverage between image lines. Realtime transmission of imagery to the WAM-V for processing and object detection will be based both on spectral signature and object shape. WAM-V path planning will then occur based on the process outlined in Task 2.

Challenge Task 4 Scan the Code: In this challenge task, a LiDAR will be used to find the location of the floating platform within the search area of approximately 40x40 meters. LiDAR data will be fused with stereo camera point cloud information in the nearfield. The computer vision algorithm will be developed to detect the coloured light. We will use similar software and hardware as in Task 2.

Challenge Task 5 Dock and Deliver: In this task, the system needs to achieve colour detection to be able to perform the docking task. After the colour detection, the computer vision-based navigation algorithm will be used to guide the WAM-V to the correct dock. The LiDAR can also be used not to hit the sides of the docking station. Moreover, we will need a system to launch the balls into one of the two targets on the upper part of the floating platform. The design of this system will be determined after specifications are defined.

Challenge Task 6 UAV Replenishment: For Challenge Task 6, we will develop a lightweight manipulator, which will be mounted on the UAV, to pick up an item from the dock and deliver it to a helipad ashore. To be able to find the correct dock, as in Challenge Task 2, an RGB camera will be used to detect the correct coloured disk. A computer vision algorithm will be developed to navigate the UAV to the correct dock. The manipulator will pick up the item, and then the UAV will navigate to the helipad identified by a HELIOS light beacon to deliver the item.

Table 1: Basic hardware requirements to complete all Challenge Tasks.

Hardware	Manufacturer	Indicative Cost (AUD)	Platform Relevance
IMU	Ship Motion Control 108-30	In-Kind	WAM-V
Lidar	Hypack Velodyne VLP-16	Sponsor provided	UAV
Stereo Camera	Stereolabs Zed2 (4 units)	In-kind	WAM-V
GPS	Hemisphere VS330 @20hz	In-kind	WAM-V
Propulsion	Torqeedo Cruise 2.0, BlueROV T200 (2 units)	$12,000	WAM-V
GPU	Nvidia Jetson NX (4 units)	$8,000	WAM-V
CPU	Intel i7-9700K	$750	WAM-V
Batteries	Torqeedo 26-104, 12v LiFePO4 for Aux	$5,000	WAM-V
Hydrophones	DolphinEar DE600 (2 units)	$1,000	WAM-V
Hyper-Spectral Camera	Corning microHSI 410 Hyperspectral Sensor	$14,000	UAV
Field consumables	Various items	$3,500	WAM-V & UAV
Payload enclosures	Raw materials and fabrication	$2,900	WAM-V
UAV	Depending on further clarification of task details – the team has access to several off the shelf platforms and custom made UAVs		UAV

1.4 Troubleshooting Technical Issues

Perceptive sensors (i.e. LiDAR, Zed2 and hydrophones) critical to achieving platform situational awareness through sensor fusion, will also provide standalone data inputs to the high-level autonomous systems in the event of sensor malfunction. For example, in the case of Zed2 malfunction, the autonomous system will rely on the 3D point cloud generated by the LiDAR and redundant cameras (i.e. GoPro) to perform obstacle avoidance and computer vision aided image recognition. While performance is likely to be suboptimal, integrated system redundancy will be sufficient to achieve all tasks in a safe and timely manner. Forward and aft azimuth thrusters will also operate independently in the case of overheating or collision with submerged obstacles. Vessel navigational performance and dynamic control outputs will be designed and tested in numerous configurations consistent with as many as two inoperative thrusters.

1.5 System Development Timeline

Whilst system development, testing, and optimisation is to be ongoing throughout the development timeline, key phases have been identified for focus during the time period leading up to Team UQ's first competition in Sydney 2022.

Table 2: System Development Overview

Phase	Details and Justification	Key Dates
Design	Initial design phase required to inform procurement of systems hardware	July – October
Procurement	Procurement from national and international distributors	September – November
Build	Major systems build (i.e. propulsion, linear actuators, power) and preliminary sensor integration	July – November
Autonomous Systems Development	Autonomous systems development focussed on navigation, dynamic control outputs and autonomous decision making	September – March 2022
Simulation and Laboratory Testing	Software and laboratory testing of components for initial tuning leading up to the first field testing focussed phase	March – April
Field Testing 1	Intensive field testing to determine system operation limits specific to navigation, propulsion, vessel seakeeping and obstacle avoidance	April – May
Systems Optimisation 1	Optimisation of systems for challenge tasks informed by lessons learned	May - July
Field Testing 2	Focussed field-testing campaign to fine tune autonomous systems specific to competition challenges	July- August
Systems Optimisation 2	Optimisation of autonomous sensory systems to improve performance specific to the delivery of selected tasks	September- October
Dispatch to Competition	Platform transported by road to Sydney from Brisbane	November

2. Team Qualifications

Team UQ is an inclusive multi-disciplinary team with a wide range of study background and qualification levels. Our student team is composed of undergraduate students from remote sensing, data science, mechatronic, electrical and software engineering backgrounds, students have experienced a wide range of challenges throughout their early university careers including development of autonomous land mine sweepers, articulated excavators and object detecting vehicles. These coursework projects provide students with the skills required to design, prototype and implement engineered solutions while inspired by natural systems. These undergraduate students are aided by a team of PhD students with in-depth experience in oceanography, low-cost sensor development, real-time data processing and predictive modelling. Some example projects completed by the team is development of a novel low-cost turbidity monitoring solution being award an early concept grant by The Dow Foundation.

Supporting the student lead project will be a team academics specialising in remote sensing, mechatronics, electrical and software engineering. Simon Albert and Erkan Kayacan will support the team with their diverse experience across multiple autonomous domains and scientific expertise. Prof. Stuart Phinn is a global leader in remote sensing with specific expertise in hyperspectral imaging, object-based analysis and atmospheric and water column signal corrections to achieve object detection capabilities in the marine environment. Dr. Matthew D'Souza is a Lecturer in computer engineering at the School of IT and Electrical Engineering, UQ. His expertise and interests include embedded systems, real-time operating systems, cyber physical systems, autonomous/field robotics and digital design systems. Dr Alistair Grinham is a Senior Research Fellow with over 15 years of developing aerial, surface and underwater platforms to deliver new methodologies for the use of autonomous systems for water quality and greenhouse gas monitoring in extreme sub-sea volcanic environments.

3. Facilities

The University of Queensland is home to world-class research and teaching facilities across multiple campuses in South-east Queensland, Australia. With a strong marine science program, UQ operates research stations on Stradbroke Island and Heron Island (on the Great Barrier Reef) that provide a unique testing facility to ensure systems are field ready for Sydney 2022. The team will be housed in the Advanced Engineering Building which provides a unique mixture of electrical, environmental, materials, hydrological and fabrication capabilities in an innovative open-access environment. Providing support in rapid prototyping and development will be the UQ Innovate workshop which includes commercial manufacturing tools as well as professional tradespeople able to assist in manufacturing practices. Additional marine resources will be provided by the UQ boating and diving facility, enabling the use of fleet vessels to oversee WAM-V testing.

Rigorous field testing will be a key strength of our team. Our student and academic advisors have experience conduction robotics and oceanographic expeditions in some of the most demanding environments on earth, including active submarine volcanoes in Solomon Islands to under-ice operations in Antarctica. Understanding the physical impacts of the marine environments on power, computing and electronics and the challenges associated with glare, sea spray, polarisation on sensors will be a focus for our team. The Moreton Bay Research Station on Stradbroke Island will be the primary field-testing facility to ensure the systems are ready for Sydney 2022.

4. Sponsorship and Partners

Although our team has only recently been established (April 2021) we have already secured significant support from three industry partners with strengths in robotics, vision systems, USV and oceanographic sensors. Whilst we also have indications of support from several government and defence partners these have not been formalised at the time of writing. Our team has a strong record of securing industry support. We also have ongoing collaborations with Queensland University of Technology and University of Tasmania RobotX teams who will ensure our students are quickly immersed in the collaborative culture of RobotX.

Firetail Robotics – Firetail robotics are an agile, innovative robotics company across multiple domains. With experience in UAV, USV, UGV and traffic systems they are well placed to provide guidance and access to equipment and prototyping capabilities. Jack Hurley CEO m: +61439333379 e: jack@firetailrobotics.com

Greenroom Robotics Pty Ltd – Greenroom robotics are experienced in machine learning and computer vision to aid system autonomy across a range of platforms including AUVs, UAVs and USVs. Given their extensive background and involvement in Maritime Defence Technology, Greenroom robotics have demonstrated an existing capacity to develop systems specific to the WAM-V. Harry Hubbert – Chief Technology Officer (E: harry@greenroomrobotics.com Ph: +61409576633)

Xylem are a large transnational water technology company with a global product portfolio across oceanography, limnology and water resource management. They have existing capability in AUV, USV and UAV based environmental monitoring systems. Steve Bird, Manager – Environmental Solutions O: +61 2 9832 6780 e: Steve.Bird@xylem.com

5. Management Approach

The structure of the UQ RobotX team will draw on the decades of experience with UQSpace (https://uqspace.com.au/) and UQRacing (https://www.uqracing.com/) teams. With over 100 members, the UQSpace team has quickly grown to be the leading student rocketry team in Australia. The UQRacing team is developing Queensland's first student led autonomous racing vehicle in 2021 and will provide an opportunity to collaborate with the UQ RobotX team. The strength of this existing student cohort and industry outreach will ensure the UQ RobotX team starts from a strong position. The team will be student led with academics and industry partners acting as advisors on technical aspects. We are also in early discussions with industry partners to develop an internship scheme that provides opportunities for students to work hands on within industry to further develop their skills. At the time of writing the team comprises of 9 undergraduate students, 6 postgraduate students, 7 academic staff and 4 industry representatives (from Firetail, GreenRoom and Xylem). With the launching of team across the institution in July 2021 through undergraduate class recruitment we anticipate the student cohort will quickly reach the target size of 30 students. We will investigate opportunities to embed RobotX challenges within 4th year mechatronics and embedded systems thesis projects. Although our team is new, we anticipate the strength drawn from existing student teams (space and racing) and our close collaboration with previous RobotX teams (QUT and UTAS) we will be in a position to rapidly progress to be competitive in 2022.

6. Proposed Budget

The UQ RobotX team has a diverse experience in securing and managing significant industry sponsorship. Senior academics within the group are currently leading >$10m of industry funded research. Furthermore, UQ student led teams such as UQ Space and UQ Racing have a strong history of leveraging industry support to compete in aerospace and racing challenges. We have already secured in-kind support for core items such as IMU, LiDAR, UAV, stereo cameras, GPS and field testing. We expect to raise a further $62,150 AUD in Q3/4 2021 to fully support the proposed budget below. We have initial indications of strategic funding from UQ and our partners to cover this amount pending successful acquisition of a WAM-V platform.

Table 3: Indicative budget to undertake 2022 RobotX challenge.

Item	Unit cost (AUD)	Total cost (AUD)
Hardware	All hardware in Table 1	$47,150
Software	Python, Matlab	Open source, In-kind
Field testing	Car hire	In-kind
	Boat hire	In-kind
Competition travel	Air travel (8 persons)	$4,000
	Hardware freight (2 way)	$5,000
	Team accommodation (5 nights)	$6,000
Total		**$62,150**

7. Summary

Our highly motivated team is comprised of students, academic and industry mentors across a diverse range of fields that are committed to competing in RobotX 2022 in Sydney. We have the resources, institutional support, expertise, student culture, industry mentors and academic advisors to not only compete but to introduce some new approaches to the challenges. Access to a WAM-V platform remains the critical barrier to our team to realise the ambitions of Team UQ. Whilst UQ have not participated in previous RoboNation competitions, we have a strong history of building internationally competitive student teams in aerospace (UQ Space) and racing (UQ Racing) fields. Furthermore, through existing collaborations with Australia's leading autonomous systems specialists at QUT (Prof. Dunbabin) and UTAS (A/Prof. Williams) we can rapidly develop a RobotX team that will contribute to the collaborative culture of innovation and excellence.