Autonomous Surface Vehicles

Design, build of an ASV and autopilot integration

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Abstract

The University of Western Australia has pursued a marine robotics project aimed at producing a solar autonomous unmanned surface vehicle (USV), later known as SPAR, Solar Powered Autonomous Raft, or SPAB, Solar Powered Autonomous Boat.
This project aimed at replicating results obtained by Darren McMillan, who successfully managed to build an autonomous USV, which crossed the Pacific Ocean from California to Hawaii in 2016, and later sailed through the South Pacific Ocean.

The UWA's USV project initiated in 2017 with the production of a rudimentary first hull, based on three PVC tubes and a solar panel mounted a frame[1]. It nonetheless was functional and allowed to obtain significant results, notably in terms of navigation and energetic management.
The project then evolved over the following years with the addition of client sensors , communications and online reporting capability [2].
The stated objective was to build up a seagoing capability such that the SPAB was able to autonomously sail to Rottnest Island and back [1]. While this ultimate benchmark has not yet been achieved, it was noted that the project made a certain headway, extensive testing was carried out and the progress was accurately reported upon.

The previous year thesis reports identify several leads for improvement of the design, and the a number of issues were retained as estimated actionable within the given time-frame.

The proposed methodology to address some of the above issues was to integrate some of the author's previous work in that field, reproduce the previous results and improve where possible. Several tasks were identified to improve the process:

- Review of the long range communication systems.
- Migration of the system to an improved design, whilst retaining the propulsion ensemble and base electronics.
- Analysis of the new power requirements, adaptation of the solar system and battery capacity.
- Establishment of a reliable reporting system both for navigational and client data.
- Generally ensuring reliability and durability of the system through review of the construction and wiring.
- Production/update of the documentation of the system, including engineering and electronic/ electrical drawings.

The construction of the previous USV was solid, however lacked marine features, which makes the hull inefficient, and increases the power required for the propulsion, and therefore limits the autonomy. The watertight integrity of the hull also has to be breached to access the internals, and the non -permanent sealing represents a risk for the asset..

A complete review of the hull was deemed necessary and led to the abandoning of the PVC pipe design.

The new hull was adapted from a catamaran designed and produced previously by the author, and required finalisation works to receive the components from the older design.

The catamaran was originally produced for a similar purpose and is based on a modular concept, which addresses a number of suggestions made in the literature [1] , and opens up the way for future upgrades, most notably in terms of sensor arrays [3].

It is made of two fibreglass laminated expanded polystyrene foam cores with hydrodynamic properties and six multipurpose wells. The floats are connected by a CNC cut aluminium structure supporting a rugged control box and a solar awning.

Generally speaking the electronics of the propulsion system were either found suitable and so retained, or upgraded by more recent components.
The old SPAB thrusters were adapted and mounted onto the new hull in a detachable manner to both improve the ease of deployment and eliminate the vulnerability of the equipment during transport. The mountings of the thrusters are upgradable and alternative propulsion configurations have been explored.
The wiring loom has been replaced, simplified where possible and tidied up; the connectors for power and data are now standardised.

The control box higher level electronics (autopilot and companion computer) were mostly kept or upgraded with compatible equivalent, but relocated to an elevated rugged enclosure which allows for access without affecting the watertight integrity of the vessel.

This document also aims at presenting the setup and basic functioning of the control system onto a bare hull and how it is configured to match the propulsion configuration.

Finally some of the functions offered by the MAVLink protocol are presented and show the potential utilisation scenarios for an ASV.

As this document is being presented as an admission requirement for a future HDR cycle, it was found relevant to present a number of potential upgrades to establish a road map for future activities within this context.

1 Introduction

The University of Western Australia has pursued a marine robotics project aimedg at producing a solar autonomous surface vehicle (ASV), later known as SPAR, Solar Powered Autonomous Raft.

This project aimed at replicating results obtained by Darren McMillan who successfully managed to build an ASV which crossed the Pacific Ocean from California to Hawaii in 2016, and later sailed through the South Pacific Ocean[1].

The UWA's ASV project was initiated in 2017 with the production of a rudimentary first hull, based on three PVC tubes and a solar panel mounted a frame [1]. It proved functional and allowed to obtain significant results, notably in terms of navigation and energetic management.

The project then evolved over years with the addition of client sensors [3], communications and online reporting capability [2].

The stated objective was to build a seagoing capability such that the SPAB is able to autonomously sail from Fremantle to Rottnest Island and back [1]. While this ultimate benchmark was not achieved, it was noted that the project made a certain headway, extensive testing was carried out and the progress was accurately reported upon.

Illustration 1: SPAB earlier hull (Credit: Hodge - 2017)

1 www.seacharger.com

1.1 Project status and internal literature review

A review of the SPAB project was conducted in August 2019 and a discussion was held with the author's tutor, Pr. Thomas Braunl with the view to improve the design of the ASV.

The defined task list was to review the previously produced relevant literature, assess the design, identify the issues with the SPAB (at the construction, performance and communication levels), to propose and implement solutions, and finally to implement and test these solutions.

The previous year thesis reports identify several leads for improvement of the design, and the following were retained as estimated actionable within the given time-frame:

- The reportedly unreliable long range communication has also been recurrently mentioned [1][4][3], and whilst the vessel was able to navigate in confined waters, it was unable to report to the ground control station beyond a certain range.
- The autonomy was deemed insufficient for multiple day operations and that the couple battery capacity and solar production should be reviewed [4]. The battery system should be managed and closely monitored to avoid complete depletion of the batteries [1][3].
- The construction presents a level of risk for third parties, as the profile of the SPAB is very low on the water, and the vessel lacks of visual signalisation such as navigation lights [1] or radar beacons [4]. The risk of collision with other vessels is therefore hard to mitigate, and the potential liability is substantial. Communications with relevant safety authorities were not conclusive as to which legal framework was applicable for such vessels [4] .
- The corrosive marine environment affected the fasteners rapidly, degrading the aesthetics and fragilising the assembly [4] .
- Finally the documentation related to the project was deemed informal and while the general engineering documentation was done, the wiring drawings should be produced [4]. A certain effort was produced in that direction [3].

In a more general manner, the concept and construction of the SPAB was questioned. The design was undoubtedly solid, however the lack of marine features made the hull inefficient, and increased the power required for the propulsion, and therefore limiting autonomy.

The watertight integrity of the SPAB's hull also has to be breached to access the internals, and the non -permanent sealing represent a risk for the floatability and the electronics.

These issues being essentially conceptual, it was deemed easier to abandon the raft design and port the system to a newer hull.

1.2 Additional literature and state of the art

Beyond the continuation of the in-house project, the review of the literature from other institutions allowed for a general overview of the research carried out on ASVs in the world.

While there is a plethora of projects related to the marine environment at various scales, the selection below is given in an effort to position the SPAB project in the current state of the technological achievement elsewhere, and to provide an outlook of the potential further development leads.

As opposed to a land-based robotic configuration, the peculiarity of a sea-going asset is to move along with the water surface movement, current, waves and wind, and, that, regardless of the ground referential. Marine controllers, which are used both for manned and unmanned marine assets require a certain flexibility to be able to cope efficiently with the complex dynamics of the marine environment.

Within an industrial marine context, a marine controller (or a set of) ideally needs to be able to provide two principal functions : course-keeping and station-keeping, being respectively the capability to navigate to an accurate and globally referred position, and the capability to maintain precisely the current attitude with reference to the ground.

1.2.1 Motion control theory and simulation.

Throughout the review of the selected literature, it would appear that the work of Thor I. Fossen, “Handbook of Marine Craft Hydrodynamics and Motion Control” [5] is consistently cited as an authority book, and was therefore consulted in priority to the study of other articles.

This book is given as main reference for the two articles mentioned below, related to the simulations of solids in marine environments.

For instance, the article by A. G. S. Júnior, M. V. A. Silva, A. P. D. Araújo, R. V. Aroca, L. M. G. Gonçalves at Federal University of Rio Grande do Norte [6] in 2013 describes the simulation of the kinematics of a sailboat in view of producing a navigation controller taking into consideration the wind direction.

Similarly, the 2017 paper by Ya Huang and Ze Ji at University of Portsmouth [7] describes a method for simulating marine environments and assets, and how the simulation may assist in the early decision making process necessary to design an ASV.

While, the intent of the research described in these two articles is to reduce design and production cost (either at a pre-design stage to optimise the type and position of thrusters or by modelling an asset in view of producing its control system before manufacture) it is nonetheless noted that the dynamic simulation of a marine environment is seemingly a very complex matter and may offer only partial results due to its relative accuracy.

Further to this, the complexity of the controller is likely to either increase as the model becomes itself more complex, or to push the flexibility envelope by encompassing a bigger scope and requiring the use of self-adaptive parameters.

1.2.2 Marine controllers and small scale projects.

Of the substantial number of other marine autonomous projects and papers, cited below is only a small selection aiming to position the SPAB project in the global research context, based on the type of the controller, from simplest to most advanced.

At University of Qatar, M. Noorizadeh & N. Meskin [8] outfitted in 2017 a commercial RC boat with a course keeping controller based on cascade PIDs, and presented the results of their tests in comparison to a simulated model. While the asset is indeed simple, the focus of the project was, at the time of publication, course-keeping only, based on a cascade of linear controllers.

The Institut Teknologi Sepuluh Nopember developed in 2018 [9] an ASV capable of deploying a remotely operated underwater vehicle. The autopilot based control method as described is understood to have been be achieved with similar equipment as used on the SPAB, and also uses linear controllers on the effector side, although it is noted that the asset attitude is estimated via a nonlinear controller based on an extended Kalman filter, as part of the autopilot software framework.

Further to the simulated results obtained at Federal University of Rio Grande do Norte, the School of Naval Architecture and Ocean Engineering, Huazhong UST, China, implemented in 2018 a course controller for a rigid wing 1m sail boat model [10] using a fuzzy logic controller to generate the rudder orders. A velocity polar prediction diagram is used to allow for waypoint navigation, upwind sailing, and automated tacking. The fuzzy logic allows a situational control type, depending on the attitude of the boat in relation to the wind (the tack). In this study, the wind is no more considered as a pure disturbance but part of the propulsive ensemble, and therefore the controller needs to react not only based on its internal parameters but also within the constraints of an environmentally dependent propulsion system to reach its geographic goal .

Departing from deterministic controllers, AI technologies are also introduced and the Department of Electrical Engineering Universitas Indonesia Depok, Indonesia [11] published a paper in 2017 describing an approach to controlling a boat model using a back propagation neural network based on self-learning the effect of “unknown” effectors prior to being able to perform course-keeping.

The above papers are presented to outline the various type of controllers used for marine applications within the research domain, as likely to find their way in an industrial context.

1.2.3 Dynamic positioning of vessels

The control of unmanned sea-going units is derivated from manned units, and the offshore and marine industry has benefited from very active research, with strong financial support.

The automated course-keeping capability of marine vessels has long been assumed by auto-pilots, the first one being used on the vessel ”MV Standard Oil” in 1920[2]. The automated station keeping capability first appeared in the offshore industry with the drill ship “MV Cuss 1” in 1961[3].

Nowadays, dynamic positioning of industrial marine assets is ubiquitous in the offshore and marine industry and relies on so-called DP systems, consisting of networks of marine controllers, and a high degree of redundancy both on the control and on the effector side.

2 Autopilot - Wikipedia link
3 Dynamic positioning - Wikipedia Link

This technology now has access to an ecosystem of reference peripherals, an expectable if not standard signal set from effector manufacturers, support by industry leaders in human machine interfaces and an extended compliance and testing protocol.

A push in this research field is noticeable in Asia, and especially China's striving shipbuilding industries of the early 2010's, in a move seemingly emancipating from the traditional Western industry leaders[4].

The Harbin Engineering University, China report on a vigorous push [12][13][14] in 2011-2012 in the field of non linear controllers for DP vessels.

The College of Information Science and Engineering, Northeastern University, Shenyang China was also experimenting in 2016 with fuzzy logic controllers [15], using adaptive controller to obtained a faster response on large size dynamically positioned vessels.

Efforts led by the School of Marine Engineering, Jimei University, Xiamen, China, in 2018 reported in article [16] on the design and construction of a joystick system for a DP simulator, but also introducing the regulatory bodies and texts relevant to the design of marine dynamic positioning systems. This reflect on the maturity of the technology, through the training of operators in a simulated environment (assuming already a standard interface and function set) and compliance with international texts (notably the International Maritime Organisation's legal framework, its associated Classification society implementation, and professional associations such as IMCA[5]).

Fundamentally, the technologies evocated for marine controllers are the same on large size manned units as those being worked on for ASVs.

1.2.4 Active heave compensation control for suspended loads.

Active heave compensation of marine cranes of large capacity (50-100t SWL)[6] appeared in the 1990s on offshore construction vessels, and is a complementary technology to the dynamic positioning of vessels, although operating in the vertical domain rather than the horizontal one.

By measuring the motion of the vessel and building a vectorial construct of the segments of the crane through forward kinematics, an AHC system deduces the vertical movement of the tip of a crane mounted a ship, itself subject to sea disturbances. The system will operate the crane's winch and adjust dynamically the length of wire, allowing a very precise landing of heavy subsea modules on the seabed, despite variable sea conditions. The system effectively compensates for variation in altitude of the vessel (heave) and pitch and roll movements resulting from the action on the waves and swell on the vessel.

The currently accepted performance benchmark in the offshore industry is to be able to stabilise a load of approximately 75 tonnes within as few centimetres while perturbed by an 8m (±4m) swell.

In 2011, the College of Mechanical Engineering Tongji University Shanghai, China [17] devised an electronically assisted AHC hydraulic control system, and a comparison of two approaches : passive and active compensations modes. The cascade of a PID and fuzzy PID are reported to yield the better simulated results.

4 Global Dynamic Positioning Systems (DPS) Market 2015-2020 - Equipment Type, Sub-system, Application, and Region Analysis and Forecasts for the $1.48 Billion Industry - PR Newswire 26-06-2015

5 International Marine Contractors Association - Website link

6 Active heave compensation - Wikipedia link

The 2016 paper [18] produced by the College of Mechanical and Electrical Engineering, Harbin Engineering University, China, reviews several approaches for the correctors used in the AHC systems, and describes a heave compensation system based on an estimate of the heave velocity determined by an IMU mounted close to the sheave of a crane. It also presents experimental results obtained at a specifically made facility.

The problem of heave compensation was revised in 2018 by the Dept. of Ship Power and Automatics, Far Eastern Federal University, Vladivostok, Russia [19] by actuating the boom of a crane (instead of the wire length), in such a way that the load is stabilised in relation to the calm sea state plane. The motion analysis approach is reminiscent of the approach used in the dynamic positioning papers previously evocated, the objective being to reduce the number of costly effectors on the winch of a crane.

In the industrial context, the peripherals and equipment used for the vertical motion compensation are virtually the same as for a dynamic positioning system acting on the horizontal plane.

One logic development for an ASV project is to be able to deliver payloads (active such as ROVs or passive such as sensors or camera arrays...) to the seabed, or at a stabilised depth, therefore heave compensation is likely to find relevance in future research.

1.2.5 Higher level functionalities (collision avoidance, multiple unit management)

So far this non exhaustive review was based mostly on the marine controller and motion analysis technology,although more advanced achievements in terms of higher level functionalities are reported upon elsewhere.

The Korea Research Institute of Ships and Ocean Engineering (KRISO), Daejeon, South Korea, has a very advanced medium size ASV, outfitted with a number of traditional integrated marine instruments (Radar, Automated Identification system and complemented by RTK GPS, LIDAR, and multiple spectrum cameras). The article [20] describes how the authors have implemented and tested an automated navigation and collision avoidance system for a large size ASV, taking into consideration the traditional sea rules (COLREG[7]) and geographic environment. The described collision avoidance strategy uses algorithms such as A* within a changeable action space created from the instrumentation.

While this last project focuses on a single unit, a core focus of the industry is to be able to manage a fleet of ASVs. In its simplest form, each assets would have a specific mission and the control would be centralised. A collaborative aspect of multiple units management appears to be trending.

As early as 2008, the Robotics System Lab, Santa Clara University, California USA [21] was implementing a control system based on cluster space for 2 or 3 autonomous boats in order to develop cohesive movements of a fleet of floating robots.

Further to this study, GRASP Lab. and Dept. of Mechanical Engineering and Applied Mechanics, Univ. of Pennsylvania, Philadelphia, PA, USA has produced two papers [22][23] to present the development of multiple unit management in a particularly innovative field. The project aimed to use a swarm of self interlocking marine units to build up large assemblies of floating structures.

A correlation is drawn between global fixed and local changeable point of interest for a mobile robot application in a traffic area, where more than one, controlled or not, mobiles are interacting.

7 International Regulations for Preventing Collisions at Sea - Wikipedia link

Multiple autonomous unit management in a collaborative environment is seen as a promising field for commercial applications, multiplying in a cost effective manner the capability of a human operator.

Illustration 2: ASV Aragon II (Credit: KRISO 2018)

1.3 Research methods

The SPAB project is indeed a modest asset compared to some other institutions projects, although it does not lack potential, due to the environmentally friendly solar powered propulsion, and ambition, through its proposed goal.

Achieveing the ultimate objective of navigating autonomously for 30 nautical miles in oceanic conditions is already a serious enterprise.

The proposed methodology to address some of the issues seen as critical for the success of the endeavour was to integrate some of the author's previous work in that field, reproduce the previous results obtained at the UWA's Mobile Robot Lab and improve where possible.

Several tasks were identified to achieve the objective:

- Migration of the system to a more performant and durable asset, whilst retaining the propulsion ensemble and base electronics.
- Retain a compatibility with earlier works, notably the existing student made software (notably the web server).
- Review the long range communication systems.
- Analysis of the new power requirements, adaptation of the solar system and battery capacity.
- Establishment of a reliable reporting system both for navigational and client data.
- Generally ensuring reliability and durability of the system through review of the construction and wiring.
- Production/update of the documentation of the system, including engineering and electronic/electrical drawings.
- Operational testing
- Additional long term improvements.

As the scope of work was substantial, where objectives could not fully achieved, provisions were to be made and methodology devised for ease of future implementation.

2 Design and construction of a sea-going ASV

2.1 Hull and structure

2.1.1 General concept and documentation

As discussed earlier the need for a better build asset was identified, and the decision was made to port the system to a partly completed unit, originally drafted by the author in September 2017. The design consists of a sturdy medium size catamaran, with hydrodynamic features below the waterline, and several mounting options from the main deck up.

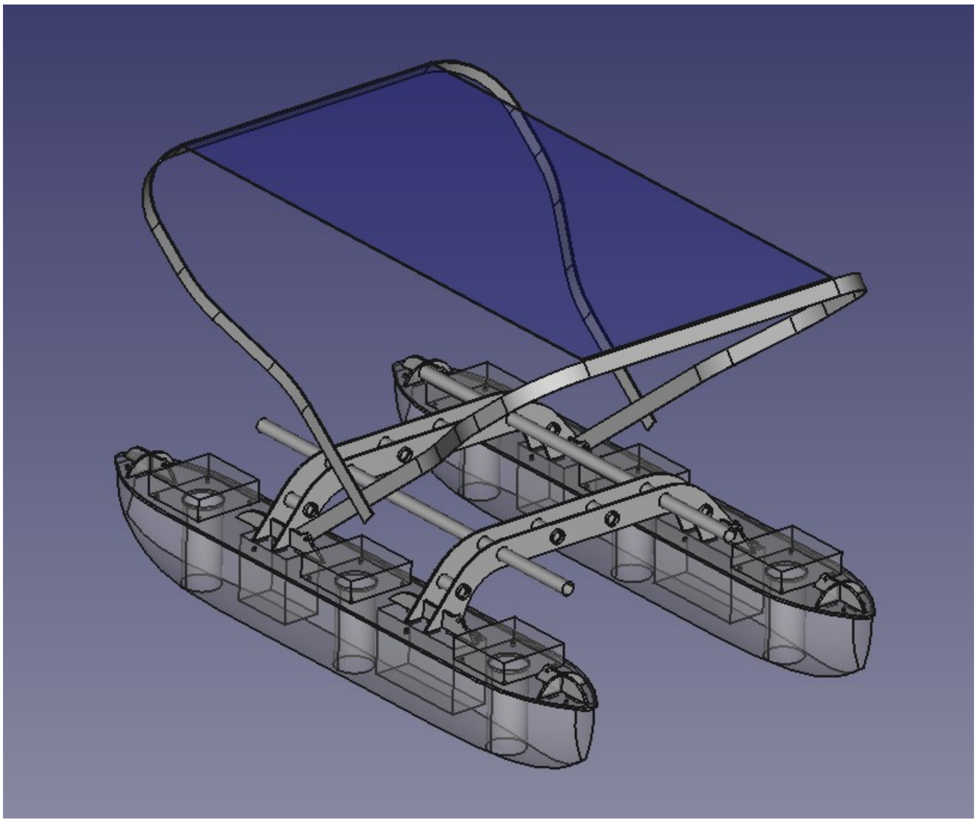


Illustration 3: Isometric view of the catamaran as per CAD design

The twin hull configuration is inherently stable and does not require extensive stability calculations. It allows for a limited wet surface and minimal drag, and a wide deck surface to maximise the carrying capacity.

The floats provide the interface with the water and are connected rigidly by an aluminium frame.

The overall dimensions are illustrated below as extracts of the dimensional drawings presented in annexure.

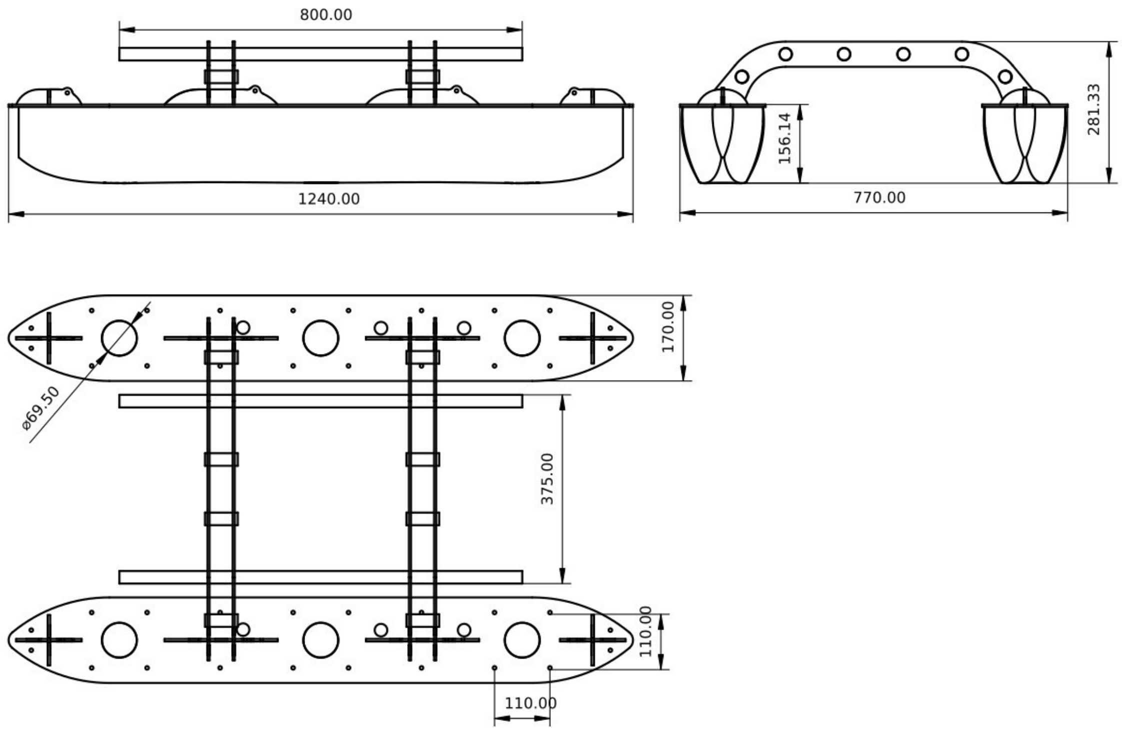


Illustration 4: General dimensions of the catamaran

All the CAD source files for the various parts are available for consultation/modification and released along with this document.

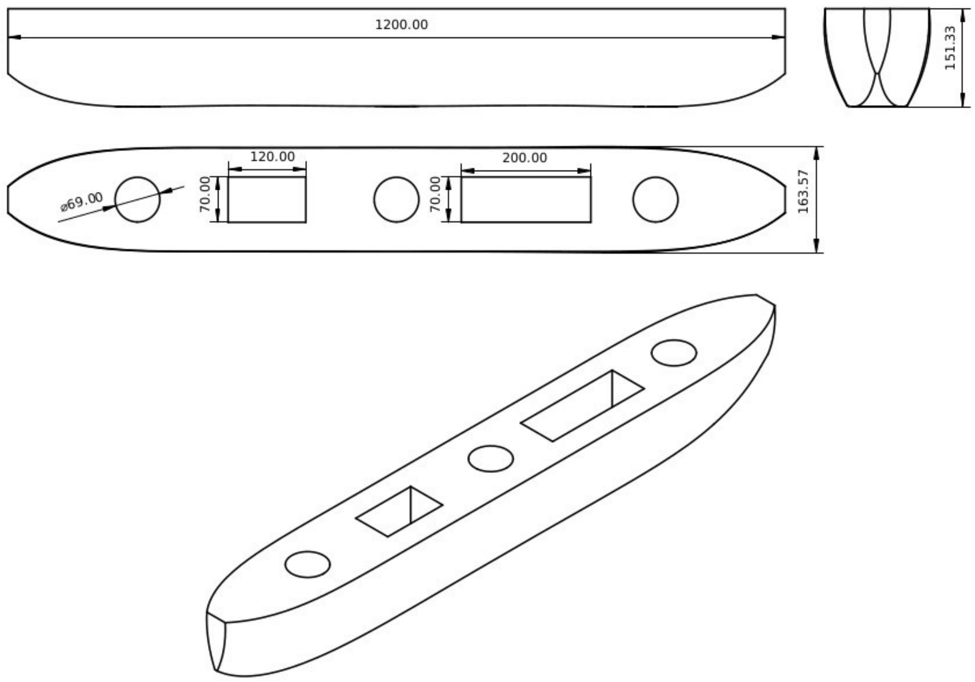


Illustration 5: EPS Foam cores dimensions

2.1.2 Hull and structural bridge design

2.1.2.1 Hulls

Both hulls are identical and made of CNC machined expanded polystyrene foam lined with epoxy fibreglass, in a similar way to surfboard's construction. Some Kevlar reinforcement was inserted in exposed critical areas.

This type of construction has the following advantages:

- Relatively inexpensive.
- Easy to shape and modify prior to glassing.
- Solid, rigid, lightweight construction.
- Not affected by UV and seawater.
- The floatability of the hull is not critically affected if the outer fibreglass layer is compromised.
- Can be repaired fairly easily.
- Good aesthetics.

The shape of the hulls is hydrodynamic through progressive lines, although not based on a standard profile. Each of the hulls has an external volume of 17.5 litres, allowing for a total deadweight of approx. 25 kg at design drafts (80-100mm).

The hulls have been designed with three PVC reinforced wells for the thrusters and instruments. Additionally two pockets for the batteries and general purpose storage have been prepared to allow for heavy equipment to be installed without raising the centre of gravity and rendering the unit top heavy/unstable.

A total of 20 M6 threaded inserts encased in the resin ensure the connection between hulls and structural bridge.

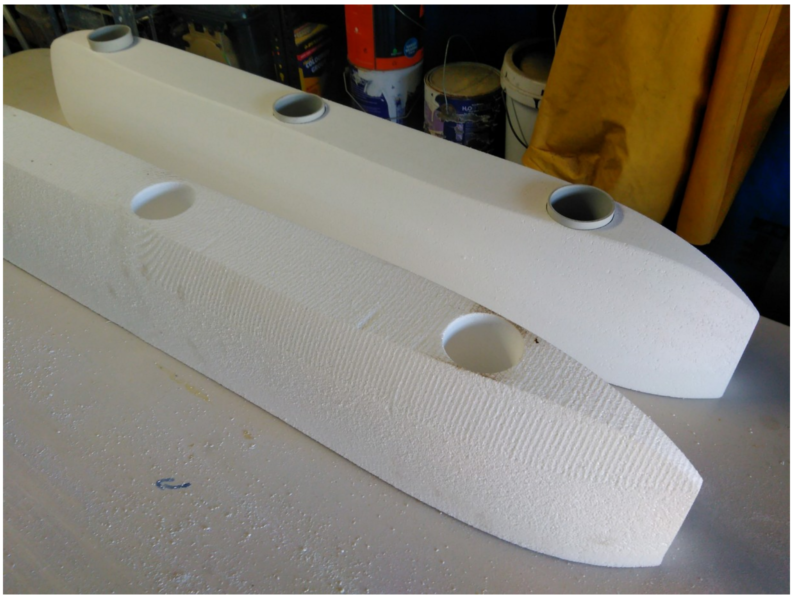


Illustration 6: CNC cut foam cores

Should the need arise, the hull design can be modified and the height increased to provide more volume without modifying the remainder of the structure.

2.1.2.2 Structural bridge

The main structure consists of a welded assembly of 5mm thick aluminium main deck plates, cross beams and hard points. Additional aluminium tubing was inserted to ensure rigidity and alignment of the vertical elements.

The parts were cut using a CNC water-jet table. The structure uses 28 parts, of only 7 different types, thus facilitating the production.

The purpose of the structure is to :

- Connect the two hulls together in a rigid and parallel manner.
- Close off the pockets for batteries and electronics.
- Support the propulsion and optional assemblies and align them with the wells.
- Provide hard points for the mounting of the awning.

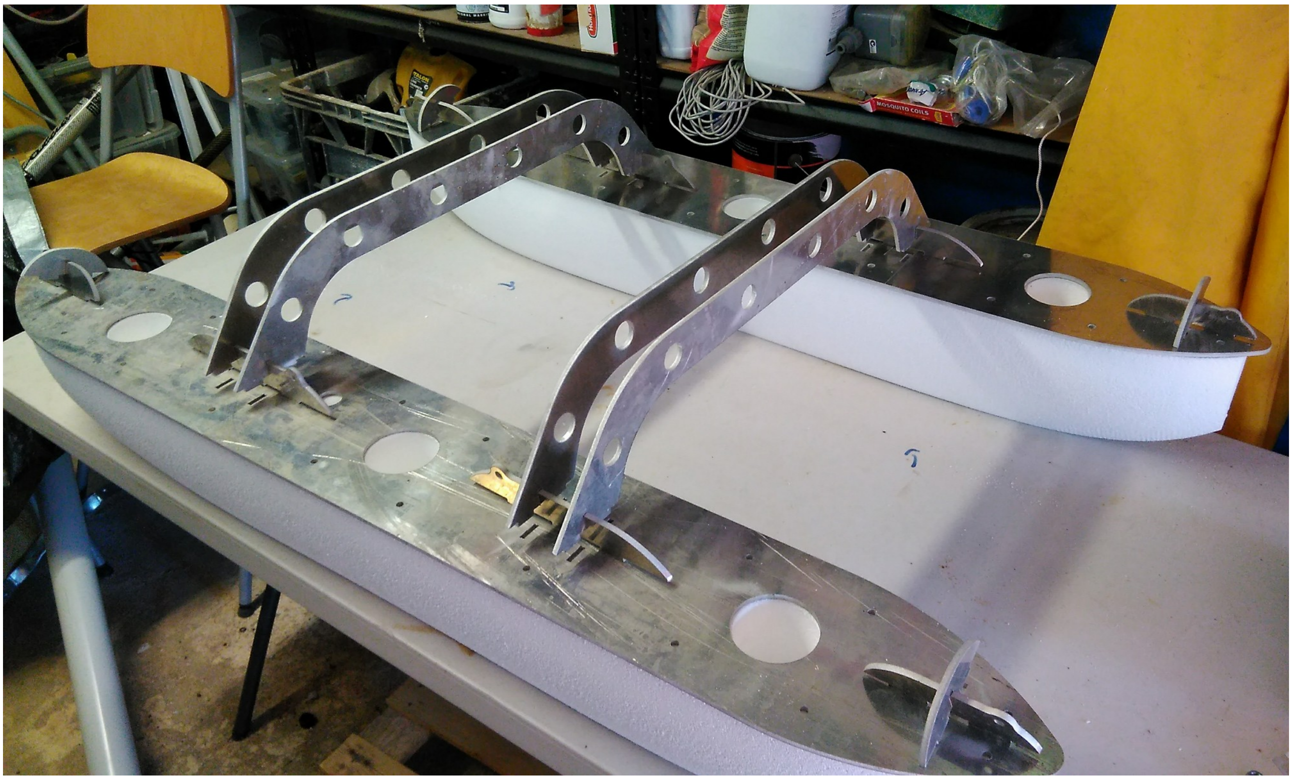


Illustration 7: Structural bridge - raw CNC cute plates pre-assembly

One of the key design feature is the two longer tubes, fitted longitudinally, in order to mount the control box and mission specific equipment. The equipment can be slid along these tubes in order to correct the trim of the vessel.

Upon completion of the welding, the structure was laid flat and submitted to a weight of 160kg without noticeable deformation.

2.1.3 Through-hull wells

As seen above, the catamaran is fitted with 6 through-hull wells, which can be equipped with different appendages (as the design aims at maximising the potential for experimentation).

2.1.3.1 Thruster assemblies and propulsion configurations

The thrusters have been attached to a tubular mount that slides into the well from the bottom of the hull and is bolted topside against the deck plates. A waterproof connector allows for a rapid electrical disconnection of the assembly.

There are two purposes for the non permanent mounting:

- The thrusters can be removed for transportation, so they do not get damaged, as their prominent location makes them quite vulnerable.
- The orientation of the thrusters can be modified later to accommodate various configurations, or receive steering assemblies, in order to improve the manoeuvrability of the vessel.

Retaining the propulsion principle of the original SPAB, the new asset is propelled by the same two Blue Robotics T200 thrusters, able to produce approx. 3.5 kgf of thrust under 12V.

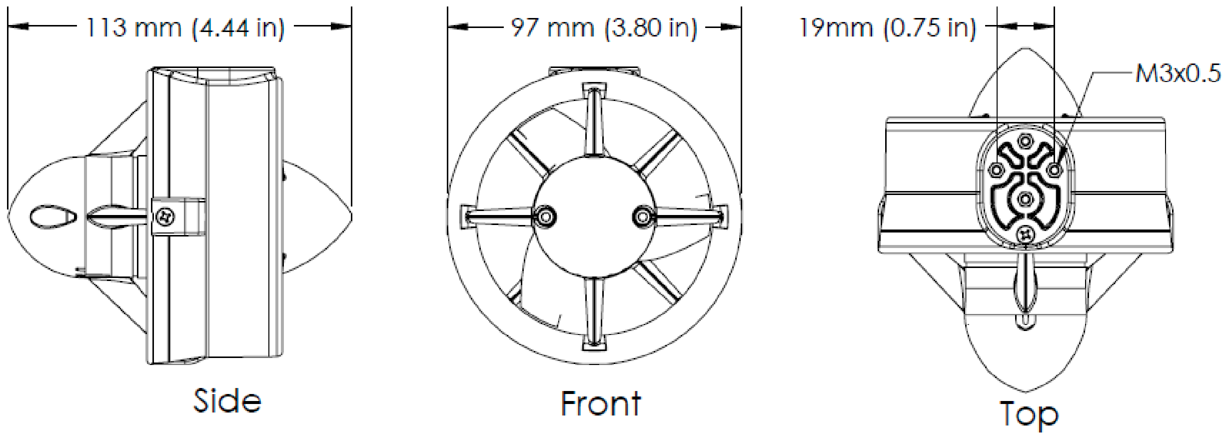


Illustration 8: Thrusters general dimensions (BlueRobotics - T200 technical specification)

The differential configuration is the easiest to setup and allows mainly two degrees of freedom (surge and yaw), which is sufficient for course keeping. The thrusters are positioned along the axis of the vessel, at the aft end to maximise the ability to control the yaw whilst underway.

This configuration is currently equipped, and has been successfully used during testing.

At a later stage it can be envisioned to alter the configuration of the propulsion on the catamaran to obtain a third degree of freedom to allow for station keeping, i.e. to move the vessel sideways, or to maintain a position and heading with a sideways perturbation, as wind and current produce.

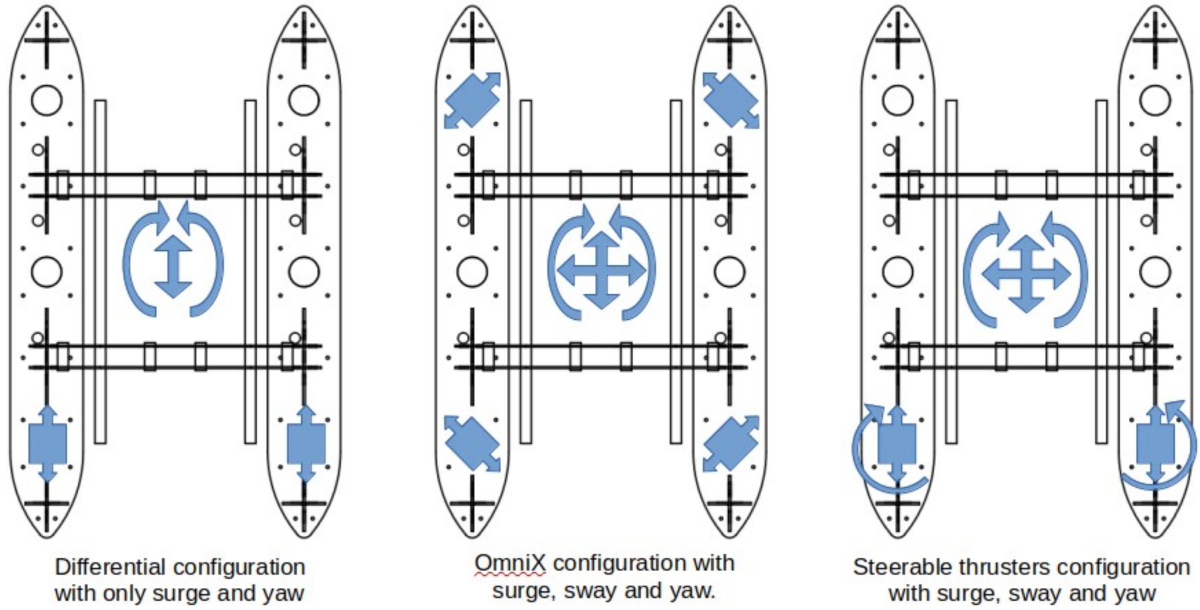


Illustration 9: Alternative propulsion configurations

As a fairly readily achievable alteration, a third degree of freedom is obtained by adding 2 more thrusters at the forward end and orienting all the thrusters at 45 degrees from the longitudinal axis. This arrangement is known by the autopilot software[8] as OmniX, and allows the thrust to be combined through matrices of factors. The resulting force is omnidirectional and allows for a holonomic behaviour.

While particularly suitable for confined waters situations such as in marinas or constrained waterways, due to the ability to deliver quickly thrust in any direction, the OmniX configuration is arguably inefficient for course-keeping and long missions, as part of the thrust is dispersed sideways and wasted.

In an hypothetically more efficient third configuration, the thrusters can be made steerable, increasing the efficiency of the thrust.

The spacing of the fasteners is by design easily reproducible, and allows for securing structurally mechanical assemblies onto the deck. As an example, a mechanical steering gear design was produced and fabricated, although has not yet been mounted on the asset.

8 Omni boat configuration - Ardupilot website link

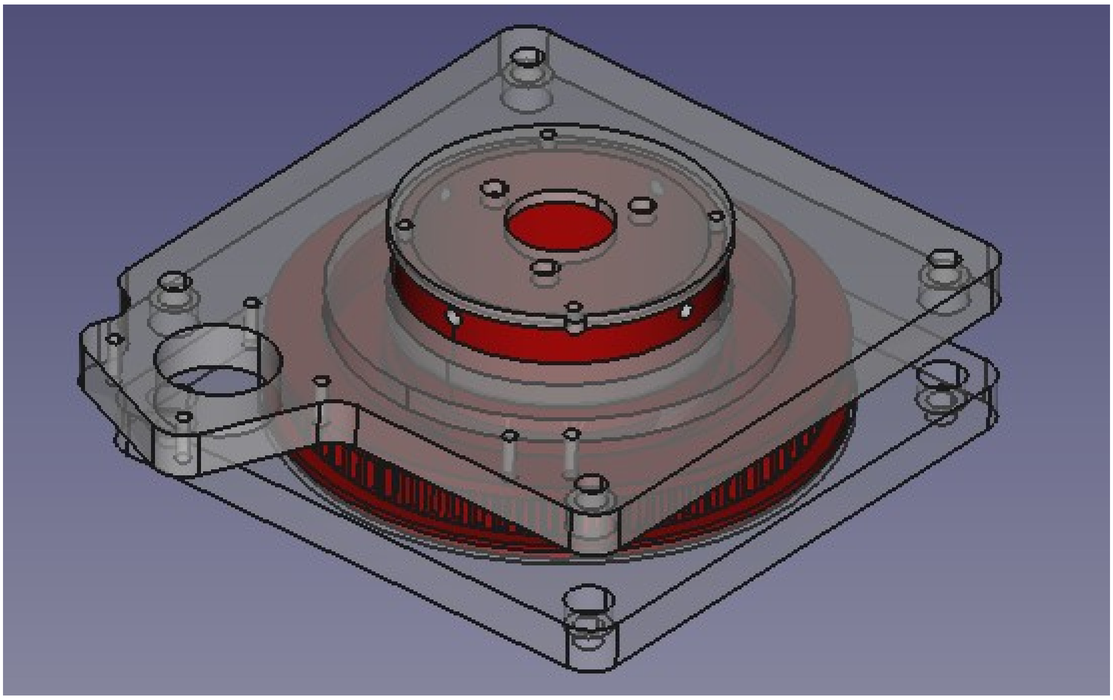


Illustration 10: Above deck belt-driven steering gear design

2.1.3.2 Instrumentation

The free wells can also be used for additional instrumentation. One of the short term objectives is to integrate consumer level instruments such as a salinity and pH meter, and a vertical underwater camera as they are already available at the UWA laboratory.

The CAD templates for the well plates are provided as part of the documentation package to facilitate future accessory fabrication.

Whilst the integration of instrumentation was planned for, no definitive progress can be reported upon it at this stage, although this will be addressed in the near future.

Liaison with other university departments in order to setup a collaborative approach to define requirements in terms of measurable parameters relevant to other research field such as marine biology or oceanography is suggested.

2.1.4 Control box and mounting

The control box exists in a modified rugged ABS instrument case, housing the electronics away from the water, and is secured onto the longitudinal structural bridge tubes by means of CNC cut polyethylene legs.

Illustration 11: Control box and mounting during construction.

The challenge was to integrate all the electronics into one single waterproof enclosure, ensuring that they are secured properly, and that the asset's motions would not affect the integrity of the wiring and components.

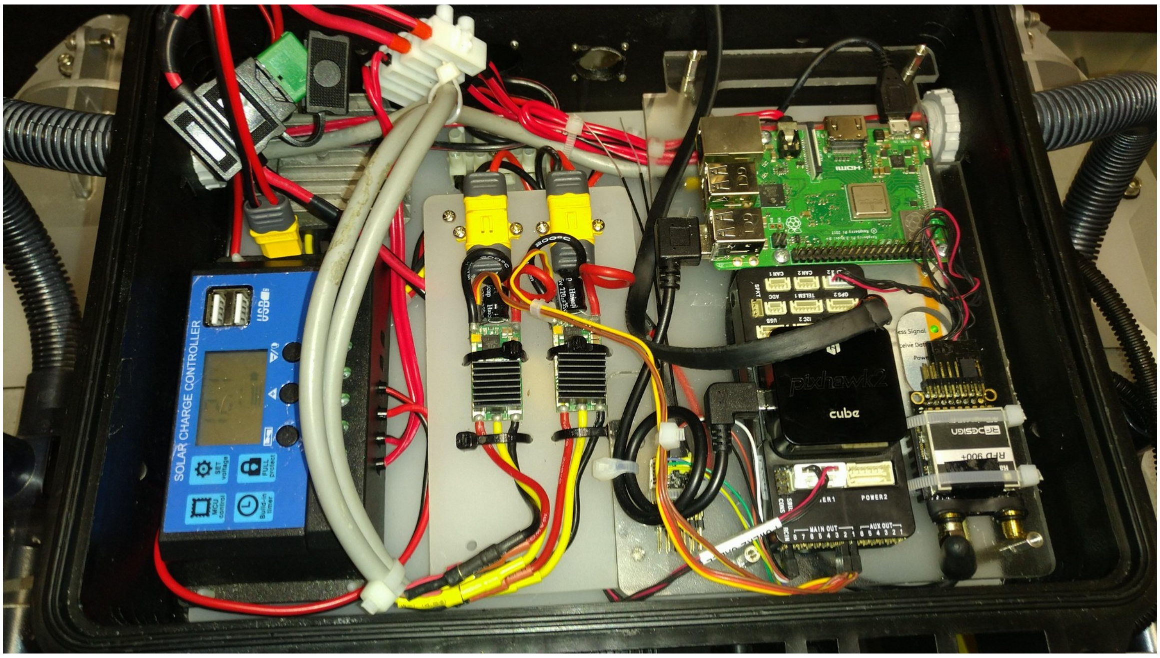


Illustration 12: Internals of the control box, with electronics mounted on acrylic plates

The control box was also designed to allow for optional additions, such as a more performant camera system than the basic camera currently in use. Also, plates can be mounted to carry instrumentation and additional motor controllers.

2.1.5 Awning and solar panel

The original 80W solar panel was replaced by a 150W flexible type, given the dimensions of the asset would allow for larger panels. It is attached to a lightweight but sturdy awning.

The design of the awning relies on three main arches made of aluminium flat bar (20mm x 3mm) which connects to the central hard points on the structural bridge. Additional legs are connected to the forward and aft hard points to lock the assembly longitudinally. As the assembly was still swaying transversely, adjustable shrouds made of stainless steel wires and turnbuckles were fitted in a cross bracing manner, and connected to the structural bridge,allowing pretensioning of the assembly and effectively locking it sideways at a very low weight cost.

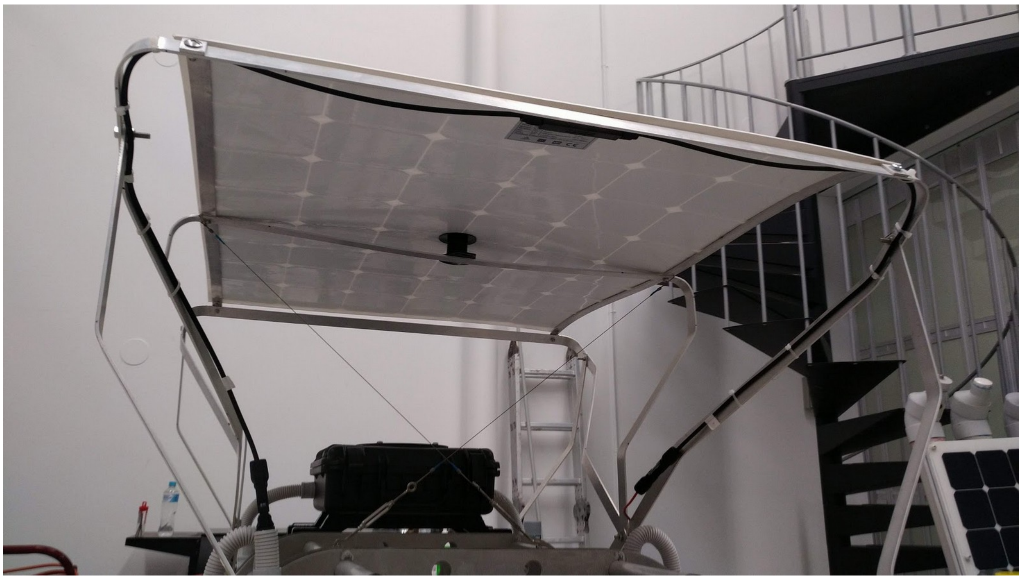


Illustration 13: Awning structure, showing the cross cable shrouds and turnbuckles

The vertical legs of the awning will be used for mounting additional antennae and accessories such as navigation lights etc.

One of the key deliverables of the build of the catamaran was to produce in a traceable manner a sturdy platform, capable of handling oceanic conditions, but also presenting a large degree of adaptability and potential for future modification.

The asset was built over the course of the last two years, with the integration of electronics occurring later during to the preliminary HDR thesis year of the author.

At this stage, the asset is completed and operational. Minor modifications can still be made, but overall the conceptual flaws of the SPAB have been addressed, allowing now for more focus on the electronics and software side of the project.

2.2 Electronics and controls

2.2.1 Documentation

As part of the recommendations issued in the previous year reports, a need for formal documentation was identified.

Therefore special attention was paid to the documentation of the project; the electrical diagram was produced using an open source software , QElectroTech[9], and the full size drawing is presented in annexure.

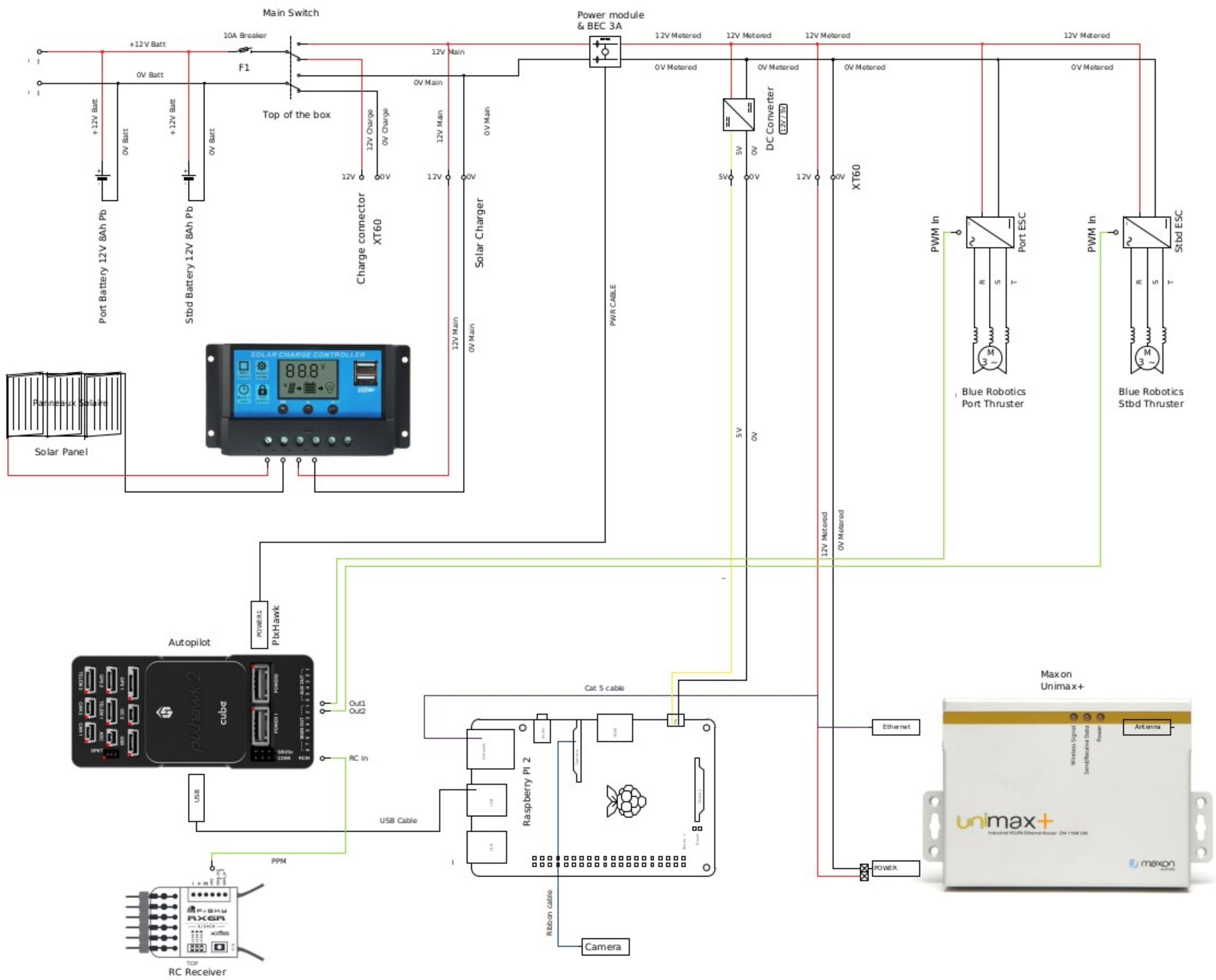


Illustration 14: Overview of the catamaran's electrical diagram

The source files are also provided for reference in the documentation package.

2.2.2 Power storage, production and monitoring

The power storage is ensured by two 8Ah lead acid batteries located in the hulls.

9 QElectroTech - Website link

The main switch allows for an “off/charge” and “on” position, and is located at the top of the enclosure, in a relatively accessible position. An external charger can be connected to the battery via an XT60 connector available in the enclosure, although the mains supply charge is only allowed when the unit is turned off.

The solar charger is connected directly to the distribution via its “battery” terminals. It was found that the internal logic of these controllers would cause spurious shutdowns under heavy load and the “load” output was therefore not used.

The main 12V supply is then distributed through an APM power module. This module has an integrated BEC (battery eliminator circuit), providing the stabilised 5V power to the autopilot. Additionally the power module allows for the autopilot to monitor and forward by telemetry the voltage and current delivered by the battery on the distribution side.

Another 5V DC/DC converter provides an independent stabilised power source for the Raspberry Pi and future accessories.

The 3G modem, and propulsion ESCs (Electronic speed controllers) are supplied directly from the 12V metered line.

During the trials in the swimming pool, and upon calibration of the power monitoring system, it was was found that the electrical system draws 6 watts at no propulsion load, and that at maximum loading (full ahead, zero speed), the propulsion draws an additional 252W. A fuse of 30A was therefore selected for the main distribution.

2.2.3 Propulsion control

The propulsion ESCs have been retained from the previous design, and provide the variable frequency three phase power supply necessary for driving the BLDC thrusters.

They are both controlled via a standard RC servo PWM signal issued by the autopilot.

Should additional thrusters be fitted onto the catamaran, additional ESCs can be added onto the metered line, and physically installed on top of the acrylic plate. The connection to the autopilot is trivial due to the large number of servo outputs available.

2.2.4 Autopilot and GPS

The autopilot was originally an APM2.5, and the very first in-water tests of the unit were conducted successfully in 2019 with this hardware.

However this class of autopilots is now obsolete and the last supported firmware was Rover v2.50, which allowed only for differential and rudder-steered drive. The various Omni configurations were made available from v3.5.

Eventually, in 2020, a more recent Pixhawk 2 Cube autopilot was freed from another university project and was integrated in the electrical design.

The Pixhawk autopilot receives a PPM signal (8 channel combination of servo PWM) from a FrSky RX6R 2.4GHz RC receiver for manual control. The receiver is supplied through the servo rail.

As a required peripheral, a Here+ GPS is connected to the GPS1 port, and mounted in the enclosure lid. This class of GPS can receive RTK corrections, and potentially offer a millimetric precision on the localisation of the mobile, through the setup of a ground station producing and forwarding corrections. At the time of writing, this function was not setup, but should be given high consideration in the near future.

2.2.5 Companion computer

The autopilot is connected through its USB port to a Raspberry Pi 3B+ SBC (single board computer). This also constitutes an upgrade from the previous design (based on a Raspberry Pi Zero).

The reason for the upgrade to a full size R-Pi was based on the availability of an Ethernet port, making the connection to the Unimax+ 3g modem easier. Additional processing power, while not strictly required, was also welcome.

It is connected to the autopilot via a USB cable and communicates serially on the physical port TELEM0.

A camera is attached via a ribbon cable to the camera port of the SBC, and points forward of the vessel.

The SBC is currently loaded with a basic Ubuntu distribution, although a plethora of specialised Linux distributions are available with preloaded companion computer libraries.

2.2.6 Long range telemetry and communications links

Additionally to the RC communications with the FrSky RC remote control, two more long range communication links are implemented.

The first link connected to the telemetry port TELEM2 of the autopilot and consist in a RFD900+ ultra long range radio modem. This link is primarily designed for ground control station connection, and is advertised as being capable of a 40km range. It is setup at 57600 baud and connects seamlessly upon power up.

The second link is a 3G modem , Unimax+, and is essentially accessible by the SBC via an ethernet cable. The modem is accessed as a network device and presents an internet connection in a completely transparent manner to the Linux operating system running on the SBC.

The internet connection is used for online publication of client data via a web-server for instance, or for receiving new routes.

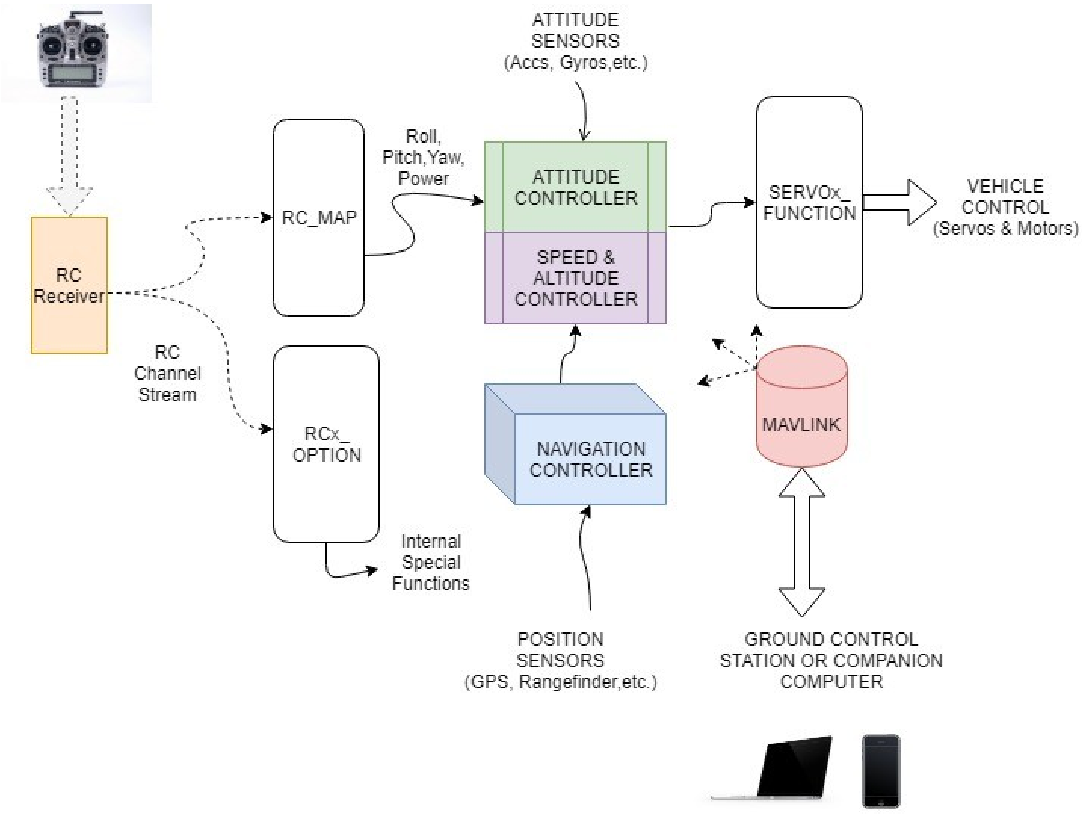
All the equipment was confirmed as functional and communicating at the time writing, although the adaptation/improvement of the existing software is beyond the scope of this document.

Whilst there was an effort to retain as much of the equipment from the previous project as possible, the components where deemed unsuitable or deprecated have been upgraded with other projects deprecated parts, thus keeping a minimal production cost, and offering current and up to date equipment.

The most significant issue of long range telecommunication has been solved, and the ASV has now several different ways of being accessed whilst operating.

2.3 Embedded software and configuration

2.3.1 MAVLink framework



Drawing 1: MAVLink Protocol (Credit: ArduCopter documentation)

The MAVLink protocol[10], Micro Air Vehicle Link, is an open source protocol for communication between drones and control stations. In practice, it sets a *de facto* standard for the configuration of the autopilot, the near real time transmission of status and navigational messages between the autopilot and the Ground Control Stations (GCS) and the mission planning.

The details of the protocol are widely documented online, although an exhaustive knowledge of the protocol is not required at operator level. The base principle of the protocol is that it effectively insert itself between a RC receiver and the servos/motor controllers on a unmanned vehicle, and provision is made to allow for manual operation and for the autopilot to take over the control of the vehicle.

It expects a MAVLink compliant autopilot to provide a number of RC inputs, and effectors along with attitude and position sensors and offer automated navigational function.

All the configuration parameters for the drone are stored in the autopilot and are recovered by the Ground control station at every initiated connection.

The GCS will interpret the parameters and messages from the autopilot and issue orders or mission plans, and allows for a graphical follow-up of the operations.

10 MAVLink Protocol - Wikipedia link

It is noted that the protocol was primarily implemented in flying vehicles and a lot of the terminology and functionalities is derived from aircraft's controls.

2.3.2 Ground control station

The ground control station (GCS) is the remote operational controller of the ASV.

In its simplest physical form, it consists in a laptop running a specific software, a RC remote control and a data link.

Several MAVLink compatible GCS softwares are available on the market, however the one retained for the configuration and mission planning of the autopilot is QGroundControl[11].

This particular software can run on Windows, Mac OSX and Linux, is open-source and based on the Qt Framework[12], which makes the GUI easily modifiable with custom code.

Beyond the mission planning component, the GCS is also used for the firmware update and configuration of the autopilot.

2.3.3 Firmware update and autopilot configuration

Upon completion of the installation of the GCS, the autopilot is connected to the laptop with a USB cable, and the firmware is updated. The stack installed is ArduRover 4.0[13].

This stack is specifically made for surface vehicles, has the majority of the flight controls stripped down, and additional functionalities have been added for specific frames.

Another MAVLink compatible open source stack is also available, PX4[14], and can also be run on the Pixhawk autopilot. It still is very focused on aerial drones.

2.3.3.1 Sensors and input calibration

Once the firmware is selected and flashed onto the autopilot, several steps are required to finalise the calibration at the GCS level:

- Accelerometer calibration: The procedure requires the autopilot to be positioned in various orientations, and is made easier by removing the top plate from the control box, and proceed with the calibration process in a desktop manner. The autopilot will then be powered by the USB cable.
- Compass calibration: Similarly to the accelerometer, the compass calibration requires the autopilot to be moved in random directions and is best made on the bench.
- Level horizon calibration: The unit just requires to be flat and the zero is measured.
- Radio calibration: Once the radio is paired with the RC receiver (the FrSky process is well documented online), the radio trims are corrected in the Radio setup menu under the form of a wizard, and all RC stick channels assigned along with their range.

The battery monitoring system calibration is best left for in-water trials, and requires a clamp meter and voltmeter, and the thrusters to be tested at full load. The actual voltage and amperage values at

11 QGroundControl - Website link
12 Qt Framework - Website link
13 ArduRover stack – Website link
14 PX4 - Website link

the power module, along with their raw input values at the autopilot are read, and a dividing coefficient for both values is calculated by the setup software and stored within the autopilot.

2.3.3.2 ArduRover parameters

The ArduRover stack is customised through the use of parameters, accessible by the GCS and transmitted as MAVLink messages.

The below is a summary of the parameters required to configure the propulsion for the catamaran equipped with a differential drive. The parameter options are usually available as drop down menus in the GCS, and the process is well assisted.

Parameter	Value
FRAME_CLASS	Boat
FRAME_TYPE	Undefined
SERVO1_FUNCTION	ThrottleLeft
SERVO1_TRIM	1100
SERVO2_FUNCTION	ThrottleRight
SERVO2_TRIM	1100
SERVO3_FUNCTION	Disabled
ARMING_CHECK	None
MOT_SAFE_DISARM	Disabled
FS_ACTION	Nothing
FS_THR_ENABLE	Disabled
FS_EKF_ACTION	Disabled

In this instance, the frame class Boat is selected, and the type kept to “undefined”.

The online documentation for land rovers[15] is to be referred to for the configuration of differential drives. In effect the code will switch to a skid-steering configuration suited for the two fixed thrusters of the catamaran if the couple ThrottleLeft/ThrottleRight is assigned to output channels.

The output is trimmed to 1100us to allow for the full ahead-astern range, with a mid point at 1500us measured at zero stick.

The other servo outputs that were assigned by default to a function are disabled.

15 ArduRover Documentation - Motor and servo configuration - Online documentation link

The skid-steering or differential drive mode will mix surge and yaw inputs to generate orders for the motors. Surge is achieved by actuating the two thrusters in the same direction, yaw by actuating the thrusters in an opposite manner.

Beyond the functional configuration, the safety fallback configuration is setup as follows.

No hardware arming button is installed yet on this configuration. This is usually required for UAVs with exposed rotors as a safety measure, but not employed due to the low risk of exposure of the thrusters.

The actions taken in case of failure are set to disabled, as, at this stage, it is preferable to let the ASV disable its propulsion in case of major failure or collision. The wrong setup of the fail-safe action may cause the mobile to go full astern irrecoverably if disarmed, leading to the likely loss of the ASV.

Of utmost importance, the fail safe behaviour is to be imperatively tested before any open water trials.

It is noted that if the propulsion was to be upgraded to an OmniX configuration, the FRAME_TYPE parameter would be assigned here to OmniX(2), and the SERVOX_FUNCTION to motor 1 to 4.

2.3.4 Arming

At this stage of the setup, the catamaran can be tested in water.

Upon power up, the autopilot will display a status LED pattern indicating that it is going through its internal checks (flashing red and blue for gyros and accelerometer initialisation) and eventually flashing green, in a ready to arm state, with a GPS lock.

The GCS will connect to the drone via the RFD long distance link, and download all the parameters of the autopilot.

The remote control is powered up and the GCS should report a steady RC link.

The arming order is sent from the GCS (QGroundControl requires a slider to be activated to confirm the order), and the ASVs is armed, and displays a steady green LED. By default it enters the MANUAL mode, and can be controlled by the remote control.

If not already done, the battery monitoring system can be calibrated at this stage.

The ASV can also be armed using the remote control by holding the steering (yaw) stick to the right for 2 seconds.

2.3.5 Control modes

The autopilot is preconfigured with a number of modes[16] in which it will take over with various degrees of automation the navigational functions. Again, some of the modes derive from UAVs and have little relevance for a boat, however the most useful modes are listed below:

- MANUAL: The ASV is controlled directly by the manual surge and yaw inputs from the remote controller. This is the default mode upon arming.

16 Ardupilot Rover control modes - Website link

- STEERING: The ASV is given direct throttle and heading orders and will maintain the course that is set by manual input. Basic anti-collision are available if the a forward range sensor is fitted.
- AUTO: The ASV will initiate and follow the mission loaded in its memory. Basic anti-collision are available if the a forward range sensor is fitted.
- LOITER: The ASV will stop its current action and attempt to hold position and adjust it heading against the strongest external perturbing force.
- HOLD: No orders are issued to the servo motors, and the ASV is left to drift off.

Similarly to the arming functions, spare channels on the remote controller can be used to alter the modes.

2.4 Mission planning

The AUTO mode is at this stage the most advanced function, but requires a list of way-points to be able to follow a mission.

As evocated earlier, most GCS software offers a mission planning capability for generating the passages and QGroundControl is offering a very good ergonomic. The usage of the software is well documented and self explanatory, the path is drawn by using a mouse on a satellite view of the mission area.

2.4.1 Short missions and survey patterns

Prior to engaging in a risky sea going passage, a number of more reasonable missions needs to be carried out, first in sheltered waters, and eventually moving to more and more challenging environment.

One of the planning functions made available by QGroundControl is the ability to define navigational patterns in an geographically defined area.

The example presented below as illustration 15 shows a short mission, departing the Woodman Point Boat ramp, and surveying the inner waters of the Henderson break.

The survey area is defined as a polygon, along with a spacing value for the corridors and a main survey heading. The way-points are automatically calculated and eventually transferred and saved onto the non volatile memory of the autopilot.

The planning is based on a speed of 2.0m/s (approx. 4 knots) which needs to be adjusted to the solar production capability of the boat at energetic balance, but nonetheless is estimated at approximately 3000 m and is achievable in 29 minutes.

Among the related functions to the survey patterns, external functions such as camera triggers can be generated during this plan. The camera shots can be post processed after the mission along with the logs, and turned into geographically referenced tiles and assembled with a geographic data display software such as Google Earth.

Further testing is needed to measure the exact autonomy of the asset, for instance with or without solar production. With this data, it will be possible to assess the feasibility of much longer runs.

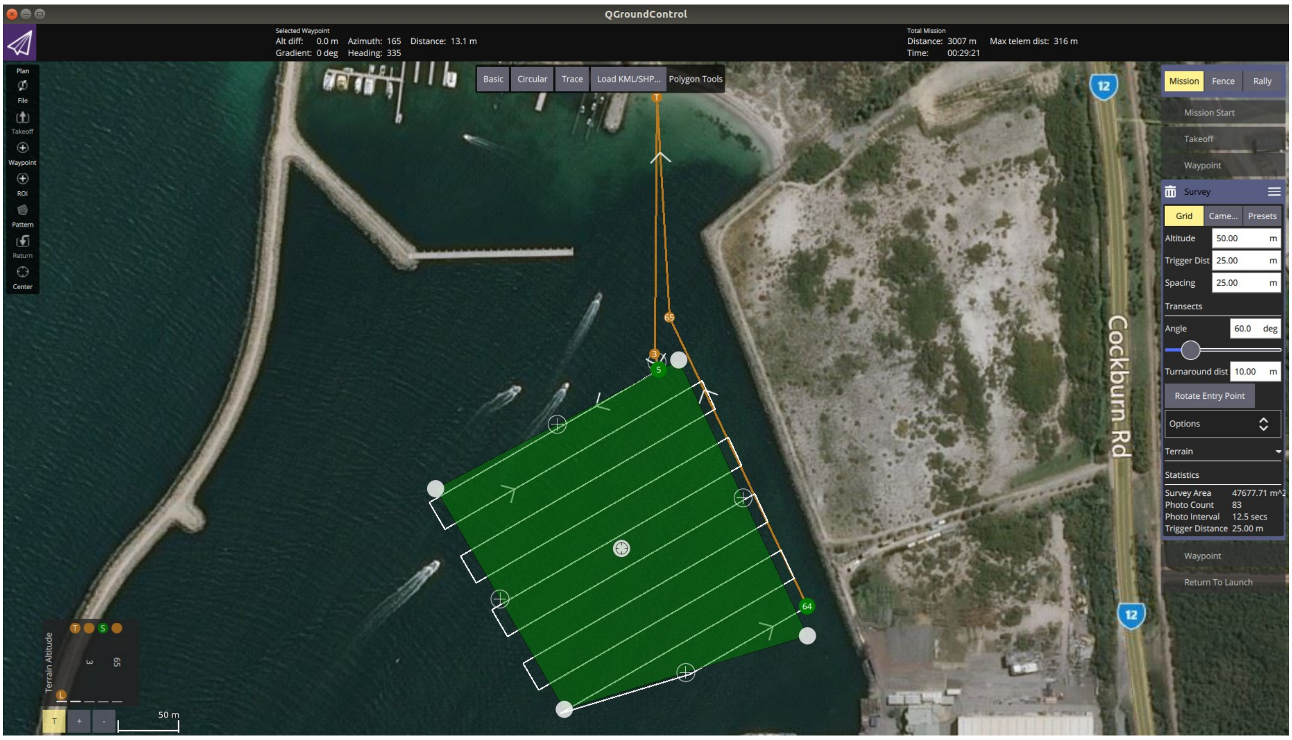
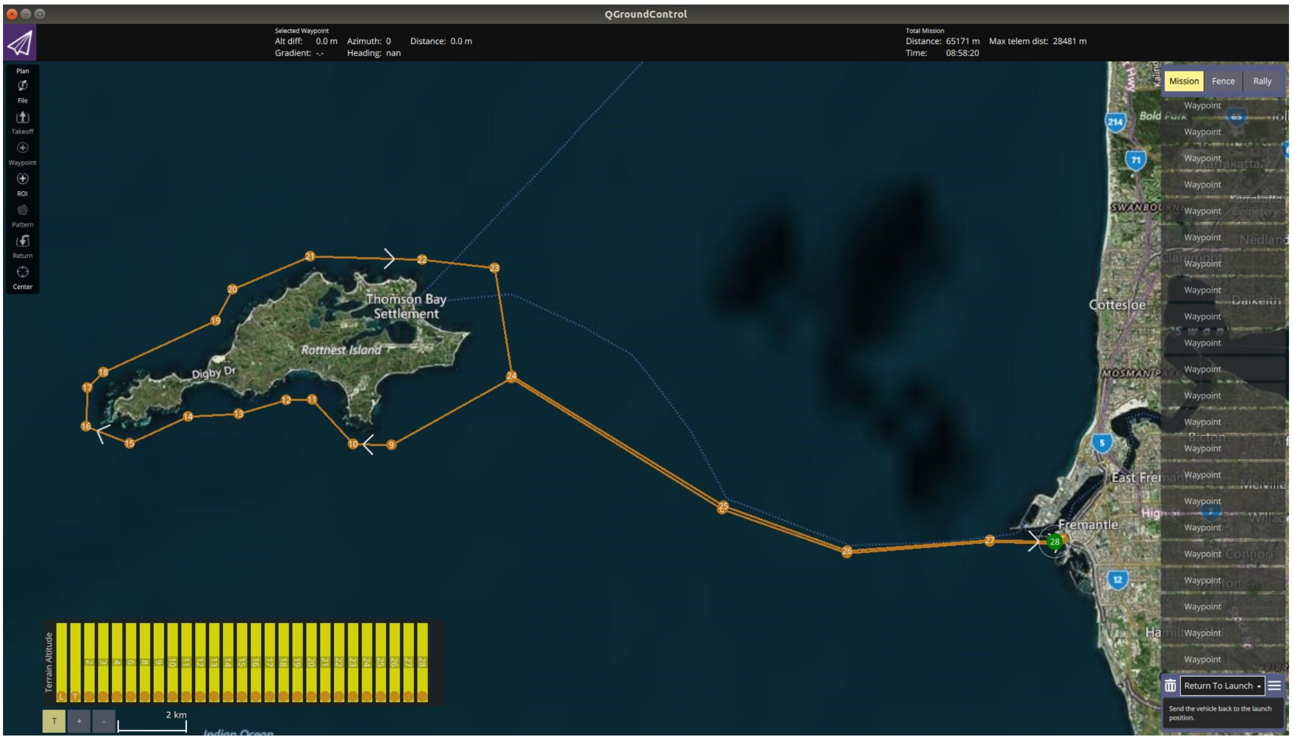


Illustration 15: Mission planner: Survey pattern in Henderson, WA.

2.4.2 The Rottnest run

The ultimate goal of the project is the passage from Fremantle and circumnavigating Rottnest Island, WA and is presented below.



The same parameters were set (2.0m/s) and the planning returns a total distance of 65km, achievable in 8 hours and 58 minutes.

A number of remarks could be made regarding the outcome of the exercise:

- The satellite view offered by the GSC, based on Google Maps, is showing some limits as it does not display the marine information required for sea going applications. It would be wise to complete the passage planning along with actual and up to date marine charts (or eventually integrate electronic marine charts such as OpenSeaMap or Navionics to the GCS) to ensure that the ASV will navigate safe areas and avoid causing disturbance with other marine traffic.
- The need for a permit or some level authorisation with the Department Of Transport or the Australian Marine Safety Authority is anticipated (prior to undertaking such a navigation) due to potential interactions with other boats.
- The duration of the trip is close to 9 hours. The ASVs needs to be powered throughout the passage with minimal consumption from the batteries, the solar panels providing sufficient power to cover the thrust. It will be a necessary to adjust the speed of the crossing to ensure that the power consumed by the motors matches the power produced. The battery power would then be kept and used as a reserve should the need to reroute arises.
- The wind pattern during the summer in Perth is often starting with medium easterlies in the morning, easing around midday and turning into strong south westerly sea breeze in the afternoon as the mainland warms up. If the passage extends for a complete day, the departure time needs to be very early in the morning (nautical twilight) to ensure that ASV is back prior to the breeze setting, circa 1 or 2 pm.
- The GCS reports that the furthest distance of the passage from the departure point is approx, 28 km. It is theoretically achievable to maintain the newer long range telemetry during the entire trip.

As the higher level functions becomes available, some of the practical requirements for testing become more obvious, and careful mission planning will be the key of success for the enterprise.

2.5 Role of the companion computer

Whilst the system is already capable of navigating autonomously, a companion computer has been planned for and installed on the hardware side, and its role is to extend the communications and reporting capability of the ASV (for instance to publish online customer data), without interfering with the navigation .

The Companion computer embedded software produced by the previous student on the SPAB project would read the MAVLink status messages and publish them online on a web-server, thus ensuring long range reporting using the cellular network.

However the newer SBCs available on the market offer significant processing power allowing for more advanced functionalities, and higher level situational assessment.

It is acknowledged that in the currently devised system, the autopilot fulfils only low to medium level functionalities, mostly restricted to the control of the ASV in terms of attitude control and navigation. For instance, some anti-collision functionalities have been implemented in the autopilot firmware, but are very limited (based essentially on a forward looking range finding sensor) and do not have the ability to comply with traffic rules such as COLREG.

Typically the companion computer will process more complex sources of data (such as a Lidar scanner or cameras, or on larger units, radars, ARPA[17], AIS[18], sounders and other traditional marine instruments, electronic charts etc.) and determine whether a collision may occur and which avoidance strategy needs to be used to achieve compliance with top level rules.

Practically, if an ASV carrying out a pre-planned mission in AUTO detects an object, the companion computer would request through MAVLink message to be handed over the control in MANUAL or STEERING mode for instance, and take the appropriate action depending on the environment. Eventually the control is handed over back to the autopilot in AUTO once the situation is solved, and the ASV resumes its mission.

Beyond the update work on the previous code, one of the highest priority for future works is to setup a MAVROS[19] node and make a link between the MAVLink protocol and the entire ROS (Robot Operating System) ecosystem.

Techniques currently used on land based robots such as SLAM could be implemented using 3D sonars for underwater charting with minimal effort, as the framework is already existent.

This would pave the way for the integration of additional sensors and provide access to much higher level decision making, lessening the risk of collision, of loss of the asset and of potential damage to third party property.

It also would add value to the asset through its ability to produce significant and valuable data, at a fairly low production cost.

The software framework used for the control of the ASVs is by itself a substantial subject and the above description aims more at presenting the setup process in its main lines to obtain a functional unit, rather than studying in depth the controller functions.

The catamaran is at a stage where all the basic functions can be experimented with, and the future testing program will aim at building up a degree of confidence in the asset, and developing a knowledge base about the effect of the controller parameters and its capabilities.

The ultimate objective of sailing around Rottnest Island is clearly a challenging enterprise, although planning tools are available and will be used to assess the feasibility based on the data obtained on more accessible missions.

17 Automatic radar plotting aid – Wikipedia link
18 Automatic Identification System - Wikipedia link
19 Mavros - ROS Documentation link

3 Project outcomes and follow up

As the term draws to an end, the principal objective of migrating the SPAB project to a newer asset is completed, with a preliminary satisfactory result in way of a functional asset.

Throughout the document several potential areas for improvement are presented and the below aims at summarising the findings.

3.1 Asset development and future upgrades

3.1.1 Hull and structures

The build process provided the author with exposure to industrial techniques such as CAD design, toolpath generation, CNC water cutting, CNC milling and routing, aluminium TIG welding, fibre glassing, waterproofing etc. which all have some relevance in a professional marine context. It overall constituted by itself a valuable hands-on experience, and a substantial learning curve.

At this stage, the hull and structure is completed and unlikely to see immediate major changes.

Upon commissioning, the asset was tested as floating successfully with a fairly generous payload carrying capability, and has hydrodynamic properties that minimise the drag and glides effortlessly through water.

The main concern regarding the hull’s watertight integrity has been addressed through minimising the empty internal volumes, locating all technical accesses above the waterline and using inherently buoyant materials.

The main deck and structural arrangement is proven rugged and, whilst likely to be excessively dimensioned, is it not too heavy to proclude additional weight in the future.

The visibility of the asset has also been improved through a larger above water volume and height, and a brightly coloured hull.

Hardpoints are provided to erect antennas and signalisation devices (radar reflectors, and navigation lights).

None of the materials used are subject to destructive corrosion and a certain degree of longevity is ensured.

The design is traceable and documented. Provisions were made to add hardware functionalities or instrumentation without modifying the main parts.

From this perspective, the improvements identified during the previous years and deemed necessary have all been implemented.

If any structural modification could be planned for, the height of the awning does not allow for an easy transportation, and it has to be disassembled partially to fit the boot of a utility car. Reducing it by 100 mm would most probably solve the problem.

3.1.2 Propulsion

The original propulsion principle and equipment was retained as it already offered a functional solution, although as noted it produced only yaw and surge movement, and therefore was only able to perform course-keeping functions.

The need for a propulsive third degree of freedom was established to allow for station-keeping and modifications were offered to improve the newer design to evolve towards a fully holonomic model.

The additional or modified thrusters can be integrated at minimal cost and effort. However, the upgrade options each present advantages and inconveniences. Comparison of the propulsive capabilities could be achieved by establishing, for instance, polar capability plots in controlled environment such as swimming pool.

3.2 Control system and electronic future upgrades

3.2.1 Batteries, solar production and autonomy

The battery system is functional along with its monitoring system however the full autonomy of the boat is not known yet. This will be assessed during the future testing program as a matter of priority.

The electrical system was discussed with the project’s supervisor, and the potential upgrade of the monitoring system was devised in such way that the current drawn from the battery could be measured. The current scope of monitoring is essentially downstream and measures the consumption of the system, but it does not take into consideration the solar production. By adding a second power module on the battery leads and relocating the solar charger connection, it will be possible to deduce how much power is produced by the solar panels.

Eventually, the autopilot code could be reviewed to take into consideration the power production and attempt to adjust the speed and load on the motors to achieve a nil energetic balance.

3.2.2 Propulsion control

As previously mentioned, the current propulsion control is satisfactory, and does not require immediate modification.

However in case a 4 thruster configuration was installed, provisions for another set of ESCs have been made and are easily implementable.

Similarly, the addition of servos for steering the thrusters would have no impact on the general wiring of the unit.

3.2.3 Navigational instruments

The two main risks for the asset in engaging in autonomous operations are collisions and grounding.

As mentioned briefly, the autopilot is already capable of very basic collision avoidance strategies with the installation of a forward looking range finder. Whilst this function is unlikely to yield long term results, it would nonetheless be useful in the short term, especially considering the low cost of setting it up.

Similarly the risk of grounding can be alleviated by carefully planning the journey using up to date marine charts. However, and especially if the asset uses collision avoidance strategies likely to make it deviate from it planned course, a direct and immediate measure of the depth would allow for the early detection of a risk of grounding.

Another fairly readily achievable upgrade to the localisation system is to add another fixed GPS, connected to the GCS, which will produce differential or kinematic corrections for the position, and reduce the dilution. As stated the technical specification of the Here+ GPS, RTK corrections allow for a millimetric precision. This level of performance will be very useful for station-keeping, and performance measurement.

Finally some instruments such as wind sensors would be a valuable addition on the navigational side, as the wind is one of the most significant measurable perturbation affecting the asset, although these sensors are still fairly expensive.

3.2.4 Client instruments

Whilst this is not the primary objective of this study, the addition of client instruments would give some relevance and potentially produce meaningful data, thus adding versatility and great value to the project.

Options for mounting additional sensors have been presented, and the physical implementation is not complex. The collection, tagging and storage of the data would then be made by the companion computer, and geo-referenced using information provided by the autopilot.

The asset could potentially find its place into the broader academic context by providing automated water quality measures for other institutions such as the UWA Oceans Institute. It would be suggested to approach such departments to determine which measurable parameters are of relevance, and if automated survey could be of interest as cost saving.

Similarly, the data can be acquired as a series of images obtained via a camera and collated together using the autopilot references. As an immediate example, the Government of Western Australia, Department of Water and Environmental Regulation is actively monitoring the population of sea-grass in Cockburn Sound[20]. Given a sufficient precision in the acquisition and collation of the data, the sea grass occupation profile can be surveyed in an automated manner from one year to another and compared for evolution. Such a proposal would potentially attract attention.

3.3 Software

3.3.1 Autopilot

One of the points that was raised during the discussion about the autopilot software is the support of various types of propulsion configuration.

So far activity has been focused on applying existing configurations to the asset, but not all the possible configurations have been covered.

A review of the Rover 4.0 code showed that the rudder steering and differential configuration were implemented using basic arithmetic mixing. The more complex Omni configuration is establishing output orders from inputs using thrust factor matrices.

20 DER Seagrass monitoring fact sheet - Website link

As a side activity, and anticipating for a newer generation of asset, a method was established to correlate surge, yaw and sway with the output of an asset outfitted with two azimuthal thruster at the stern and two bow thrusters at the forward end, in common configuration found on dynamically positioned offshore support vessels (OSVs). Additionally the notion of pivot point for the yaw movement was integrated, allowing for real time alteration of the centre of rotation.

The purpose of the exercise was to establish the arithmetic control equations that would linearly mix the thrust for each inputs order, in such a way that they can be immediately programmed into an autopilot, and accessible by selecting a custom frame in the propulsion setup parameter.

The method was tested successfully on a RC simulator and then implemented physically on a test OSV model. The software implementation within the Rover stack will be one of the objectives of future works during the HDR cycle.

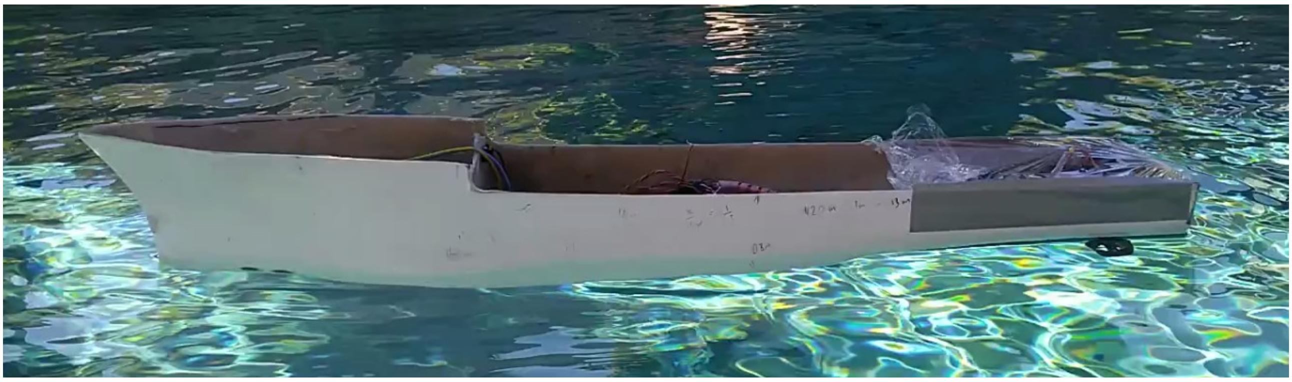


Illustration 16: In-water test of the control equations on the OSV model

3.3.2 GCS

Being open source, QGroundControlStation is freely modifiable. The interface is based on the Qt framework, which is also open source and fairly accessible.

Since it was designed for UAVs, a number of functions and terminology of the GCS have little relevance for ASVs, and a clean up of the terms could be envisioned.

Additionally, the Solar Boat has a specific energetic configuration, and the monitoring of the autonomy would be made easier by the the production of a specific widget, presenting the energetic balance in a clear manner.

Finally, the satellite view of the ocean is only providing partial information, so the support of dedicated marine charts (such as Garmin Navionics or OpenSeaMap) would greatly assist the mission planning, and should be given high consideration prior to engaging in long missions.

3.3.3 Companion computer

Apart from integrating it in the physical design, ensuring that it was powered, working and communicating with the other components, the companion computer has unfortunately been afforded limited attention yet.

As a starting point, the previous software needs to be adapted to the newly mounted hardware.

The reactivation and modification of the web-server software was handed over to a design project Computer Science student team with a view to refreshing the presentation and making it more relevant for the client data.

As mentioned earlier the integration of the ROS framework would allow to produced advanced higher level functions, and is again perceived as a very high priority objective.

Finally, and to follow the lead of other universities, through the ROS framework, it is anticipated that the companion computer could be used for implementing and testing various types of marine controllers.

3.4 Testing program

The real life testing of the asset is still a work in progress and as previously noted, the level of confidence is being built up at the time of writing.

Of the short term testing objectives, a number of functions still have to be tested and adjusted with reference to the response of the vessel:

- Fully tune the motor drives, and ensure all functionalities are implemented in the autopilot.
- Testing of all control modes for the autopilot: MANUAL, STEERING, AUTO, LOITER and action macros. Tune all the PID parameters to offer optimal course-keeping.
- Reporting and analysis of the power systems data, autonomy testing.
- Hand over control to the companion computer and execute ROS generated actions.

A number of short missions can be devised and tested in sheltered waters (using for instance the boat ramp at Pelican point or Henderson) prior to the attempt of circumnavigating Rottnest Island.

Illustration 17: Solar boat autonomously navigating at Pelican Point, Nedlands, WA

Until the vessel is proven seaworthy, contingencies need to be organised such as an escort boat should the unit suffer a major control failure. Additional difficulties such as the weather conditions are still throwing some uncertainties, although with the summer approaching, the problem should be alleviated, and more opportunity windows should present themselves.

As a last consideration regarding the testing of the catamaran, for longer missions, the GCS needs to be powered up for longer than a laptop battery could provide. Additional logistics have to be deployed though the provision of a portable power generator or, more in line with the intent of the project, an ensemble of solar panels, battery and inverter for the shore side control.

3.5 Documentation

The documentation of the project was indicated as lacking in the previous reports, and a special effort has been made to ensure that all the parts and systems produced as part of this project have a printable version and that source files are made available.

This ensures both a traceability from the conceptual phase, and also allows for all the future upgrades to be documented on this basis.

The following files will be handed over as a package along with this report:

- FreeCAD files and PDF dimensional files for the hull and structure.
- FreeCAD files for the acrylic plates of the control box
- QElectrotech files and PDF dump of the electrical drawings

Conclusion

Since the purpose of the preliminary HDR course was to allow the author to undertake further study in the field of autonomous marine assets, the scope of this document was as much to describe a production process as to highlight the areas where upgrades and anticipated developments could be made, as part of his future activities within UWA.

The report on the design phase and building of the asset, which extended over the course of 2 years, is hopefully comprehensive, but, as a significant amount of work has been produced, some details may have been omitted. A large number of objectives were attained, but some other are still a work in progress.

The document was therefore purposefully focused on the hardware design and propulsion, those being the basis of any other works in the domain of marine robotics. The production of a reliable ASV was perceived as critical for ongoing and repeatable testing, as the marine environment is unforgiving and the recovery of a failed asset is more often than not impossible.

Whilst the objective of sailing around Rottnest is seen as a interesting challenge, and would definitely prove the robustness of the asset, a focus on delivering actual monetisable survey data at low operational cost is seen as a more likely objective as it gives a commercial purpose and would eventually be funding more ambitious projects.

On the industrial side, and looking at the current trend, the marine industry has very heavily invested in unmanned ships[21], seen as a key solution to reduce cost in the transport of goods. The clearly advertised purpose is to reduce or remove crew on vessels, human presence and its supporting equipment being one of the key operational expense.

This leads to the very same questions asked in other transport industries as the relevance of a human decision making at the helm of a ship, and generates reportedly a level of anxiety among the seafarers as to their future relevance in the industry.

It is the author's opinion that there is still a long way and many hurdles prior to the transition to a fully unmanned maritime world. At the same time, if the demand for traditional marine skills is predictably likely to reduce if this technology is implemented globally, a new set of skills will be in demand for the maintenance of such units.

In the short term, it would be reasonable to predict that more advanced and AI technology will appear as a decision making assistance tool for the human operator, rather than replacing them entirely.

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Annexure 1 : Dimensional drawings

Annexure 2: Electrical drawings

Annexure 3: Equipment datasheets