Cape Peninsula
University of Technology

FACULTY OF ENGINEERING & THE BUILT ENVIRONMENT
ASSESSMENT ONE: GA 9 Independent learning life long learning
COURSE: BACHELOR OF ENGINEERING TECHNOLOGY HONOURS IN ELECTRICAL ENGINEERING
SUBJECT: INDUSTRIAL DESIGN PROJECT 3 YEAR 2024
TOPIC: Open-Source based AUV/ASV

Proposal

SUBJECT LECTURER	:	Dr. Mnguni
MODERATOR (INTERNAL	:	Dr. N Tshemese-Mvandaba
MODERATOR (EXTERNAL)	:	Mr Q. Catherine
SUPERVISOR	:	Dr. Mnguni Mr B. Williams (Co-supervisor)

Student Name and Surname	**Jordan Williams**
Student Number	**221343687**

Table of Contents

1. Introduction

1.1 Project Overview

The ocean covers approximately 70% of the world's surface and we've only explored and documented around 7% of it [1]. The ocean is linked to weather and climate patterns, bio-diversities, carbon levels, and the impact humans have made on the planet. Data collected from the ocean is used by researchers to predict weather, develop medicines, and ensure resources are sustainably managed [1]. To collect these various types of data specialised instruments are used with precise sensors and samplers. These instruments include but are not limited to moored systems, buoys, gliders, AUVs (Autonomous Underwater Vehicles) and ASVs (Autonomous Surface Vehicles).

AUVs and ASVs operate independently from a pilot/operator unlike ROVs (Remotely Operated Vehicles) [2]. They are designed to be minimally invasive to surroundings, sample and log environmental conditions via sensors, and navigate autonomously. Some vehicles are designed to operate for several weeks to months on ultra-low power systems, while others are designed for short-term deployment [2]. However, these instruments cost large amounts of money which restrict underfunded researchers from utilising these tools.

By utilising open-source hardware and software, RnD costs can be drastically reduced. Open-source platforms allow for professionals, hobbyists, and knowledgeable individuals to collaborate and produce more reliable, robust, and flexible systems [3]. A large majority of software and web-solutions we make use of today are based on open-source designs, thus it is a tried and proven method that leverages speed, security, and support [3]. Proprietary solutions suffer from a lack of support, limited interoperability, licenses, and increased costs.

In this project, an outdated ASV "chassis" will be used as a platform to develop and integrate an open-source-based electronics system to control and navigate, log data, and have the potential for medium to long-term deployment. This is to serve as a proof of concept that an open-source-based AUV can replicate the outcomes of a proprietary solution. An ASV and AUV's electronics are similar in many ways and can be broken down into 3 main systems operating in unison: the navigation and directional system, the sampling and data logging system, and the power management system. Each of these systems utilises various types of electronic hardware such as sensors, microcontrollers, and output devices; as well as software algorithms that predict, interpret, and control different aspects of the vehicle.

1.2 Background

The glider being used in this project is a decommissioned Liquid Robotics SV2 glider (figure 1). It utilises a sub with spring-loaded fins and wave motion to propel itself. The sub is attached to a float via an umbilical that allows for sensors to be powered and attached to the sub. The float houses the controllers of the vehicle, the battery system, as well as sensors for surface data logging. The electronic system on board is a proprietary system owned by Liquid Robotics and is outdated. Thus, it serves as an ideal development platform. From here on out in this document when referring to a "vehicle" it implies AUVs and ASVs.

This project is aimed at bridging the gap between researchers limited by funds and the unlimited pool of data that surrounds the world (the ocean) by developing an AUV/ASV system based on open-source designs and "off the shelf" modules to replicate the results of proprietary solutions with a limited budget and resources available kept in mind.

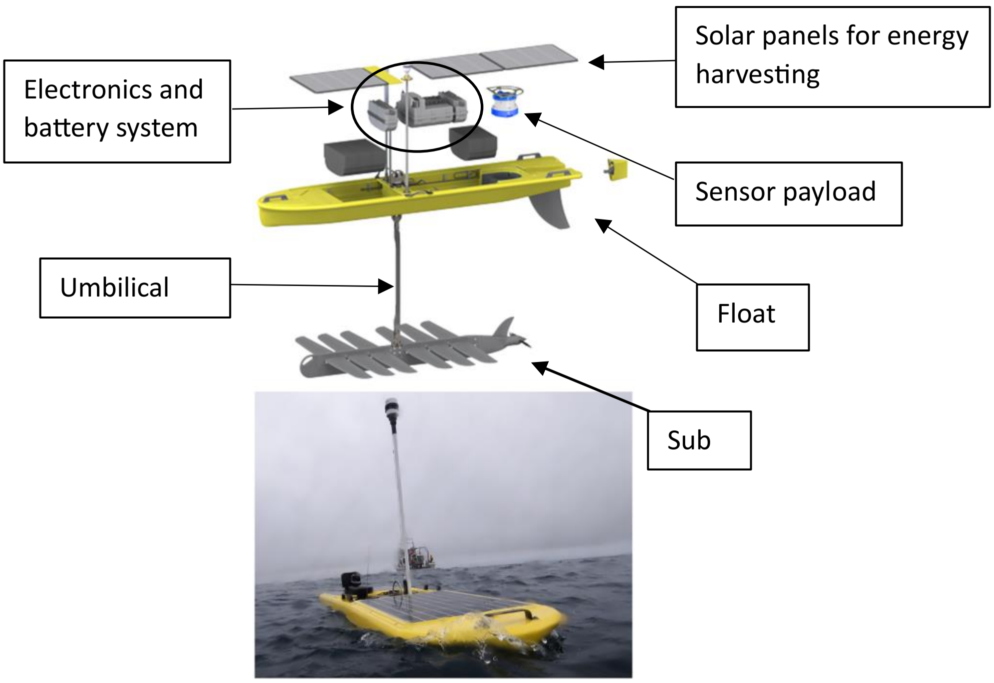

Figure 1: Liquid Robotics SV2 wave glider [9]

2. Interest and Curiosity

2.1 Inspiration

The student's interest in electronics stems from early exposure to robotics and circuits, this developed into a hobby for automating, designing electromechanical systems, and working on open-source projects. With industry experience from an oceanographic electronics development perspective. Practical electronic skills such as CAD (Computer-Aided Design) and circuit design, fault finding, and PCB (Printed Circuit Board) population were developed. The company delt with various gliders, AUVs/ASVs, and subsea instruments.

CPUT's (Cape Peninsular University of Technology) Electrical course feeds the natural interest and builds a well-defined foundation of knowledge. This project allows for linking theoretical, practical, and industry-based experience to produce a project that aligns with personal interests. While also making a positive contribution to the open-source community and other similar projects.

2.2 Relevance

Open-source systems have driven a multitude of industry breakthroughs that have positively impacted society around us. It is a structure that is being adopted by more and more industries to drive a change towards standardisation and uniformity throughout various fields [3]. It also fosters a peer-reviewed and knowledge sharing culture which leads to a higher quality of results. The relevance of open-source systems in the scientific research industry has promoted a culture of rapid development and constant improvements being made publicly available.

Autonomous vehicles are playing a vital role in collecting data from remote locations such as Antarctica, and the northern sea [9], but their applications are not limited to data collection. These vehicles are utilised by military and oil drilling companies to survey and map the seafloor and water conditions [3]. Therefore, a project such as this one has relevance and can make a positive impact towards monitoring and tracking ocean conditions.

3. Initiative

3.1 Project Kickoff

The initial meeting between the student and supervisor established that the project would be aimed at Oceanographic autonomous vehicles. The student was tasked with identifying different types of vehicles used by industry, their applications, and limitations. A follow-up meeting was held to finalise the project direction, the key factors were identified as: the project is to be untethered and fully autonomous, must be inexpensive, must follow a set waypoint, log data, and harvest power. The student met with their employer to discuss the project for an opinion from industry experts. Their keen interest and support confirmed the relevance and need for such projects. The employer offered a decommissioned ASV to be used as the vehicle in this project which greatly reduces costs and development time, allowing for more focus on the electronic systems. The subsystems of the ASV were identified as shown in Figure 2, this led to a discussion about whether open-source-based systems could replace proprietary systems and the relevance of this approach to industries.

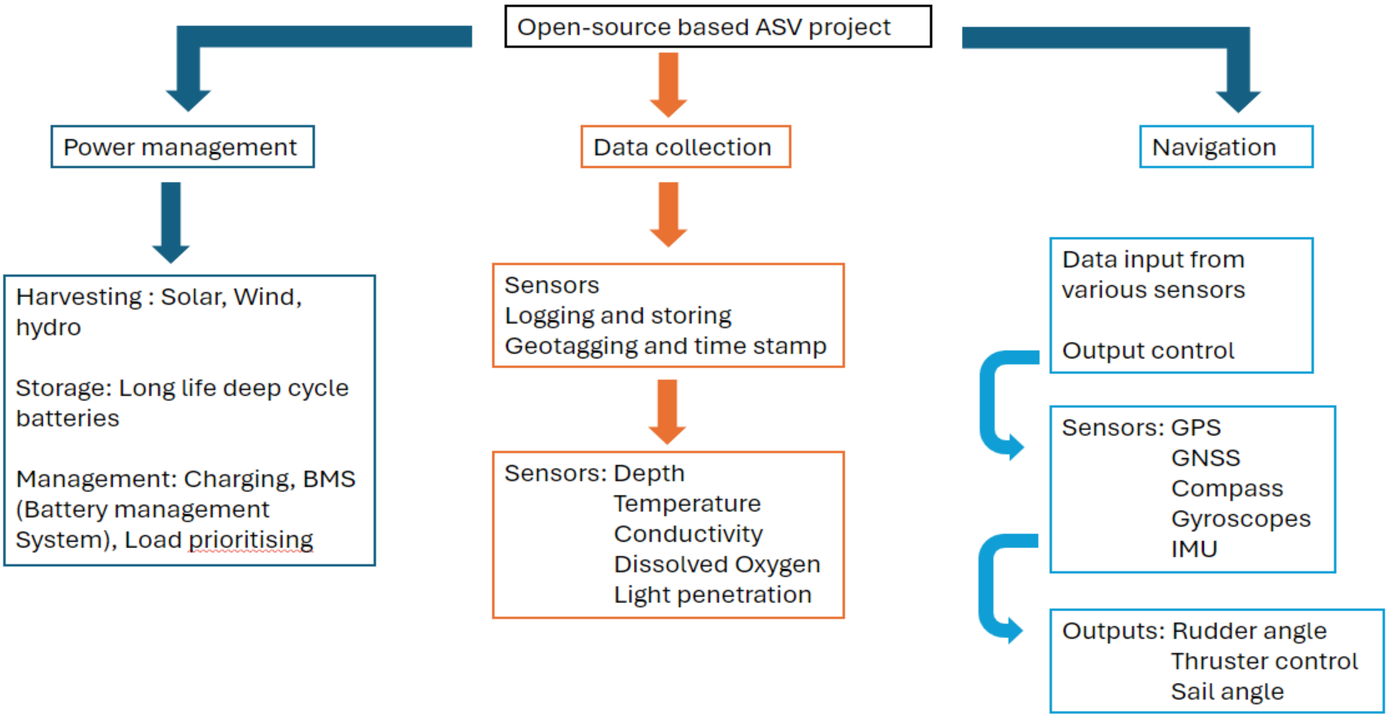

Figure 2: Project mind map

3.2 Research and Development

3.2.1. Navigation software

Navigation is the key to success. Independent and autonomy allow for minimal human interaction with these vehicles. Thus, a reliable software is required to execute missions. ArduPilot is a great example of an open-source autopilot software that can be integrated into drones, ROVs, AUVs, and much more with a vast collection of documentations. First developed in 2016 [5], it has become a rapidly growing and popular software of choice for vehicle automation. It can operate on different hardware based on its application and hosts features such as Ground Control Station (GCS), mission planner (figure 3), real-time feedback [5]. Another industry used open-source software is PX4 offers users a modulised design for ease of customisation to suite the mission needs. It is supported by several open-source controllers has useful features such as sensor fusion, accurate navigation, and supports outputs for heading control.

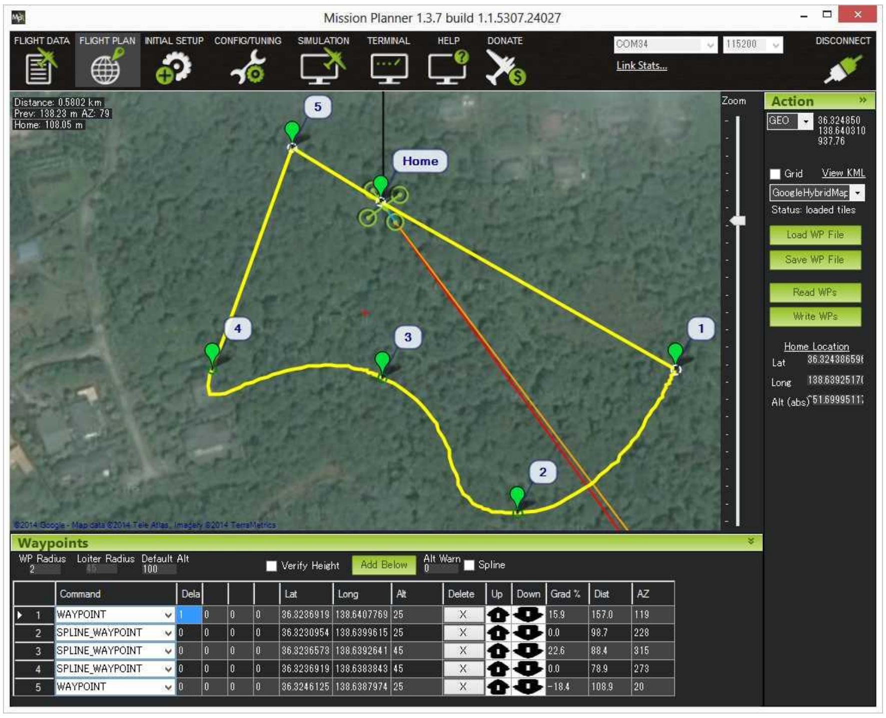

Figure 3: ArduPilot GCS mission planner [5]

The navigation software requires data inputs from a GPS (Global Positioning System) sensor to determine it location, this is then compared to a predetermined waypoint and adjusts its heading accordingly. Wireless communication methods to the GCS depend on the distance and infrastructure between the vehicle and "base station". 2.4GHz Radio frequency communication is ideal for short range (approximately 100m) [13] typically used for deployment and retrieval, as well as pre-deployment checks. 1620 MHz range of satellite communication is ideal for this type of project (figure 4) as data can be sent and received over vast distances [13]. However, this form does not have immediate responses as first establishes a secure link to the satellite using packet acknowledgment protocols. Commercially available solutions include Iridium Satellite Link, Inmarsat, and ORBCOMM.

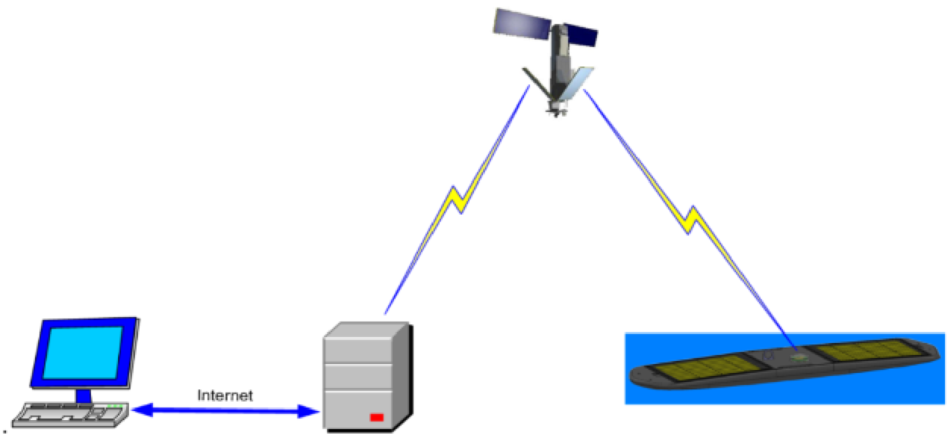

Figure 4: Satellite communication link [14].

An AIS (Automatic Identification System) broadcasts the vehicles details such as identification number, speed, heading, course, and GPS coordinates to nearby vessels [15]. This is useful in avoiding collisions and some countries mandate all marine vehicles be fitted with such equipment to comply with safety regulations [15]. The AIS can also detect nearby vessels and by using their broadcasted information (figure 5) the heading of the vehicle can be changed to avoid the nearby vessel.

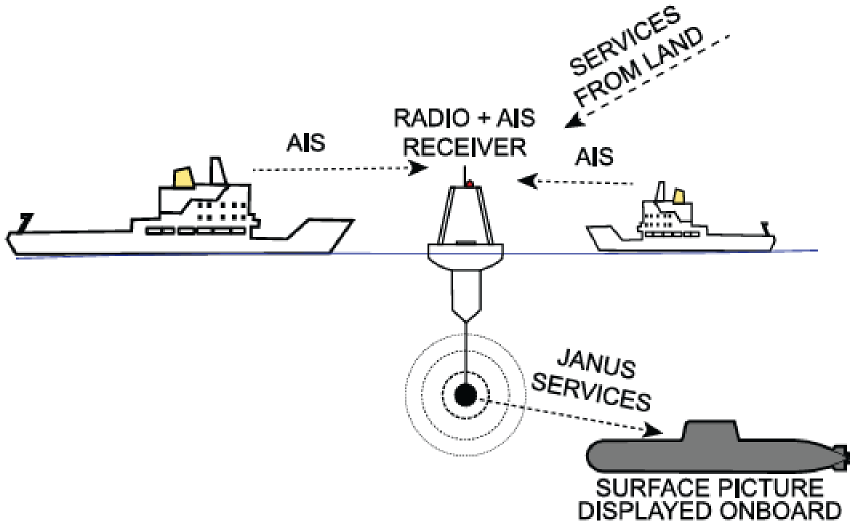

Figure 5: AIS system [15]

3.2.2. Microcontrollers and computers

Pixhawk controllers (figure 4) are designed specifically for flight controllers and is supported by most open-source autopilot software. These boards are based on an open-source design and therefore offer extensive flexibility and make use of a wide range of communication protocols such as I2C, CAN Bus, and UART [6]. This would be an ideal microcontroller for the project, however, most of their boards are discontinued or scarce to find. Thus, alternative controllers are to be considered.

Figure 5: Pixhawk flight controller [6]

Arduino, Raspberry Pi, and Beagle Bone Board are competitive substitutes as each offer an array of features and functions. Arduino boards are widely available and affordable, they are ideal for budget-friendly projects [7]. Raspberry pi boards are small, scaled computers that offer extensive I/O compatibility, and large processing power. They are ideal for data processing and high-level control but can be used to run an autopilot software [7]. Beagle Bone boards (Figure 5) are Linux based controllers that offer high level control and computation. They are ideal for robotic and automation applications as it has wireless communication, sensor interfaces and motor control pre-built into it [7].

Figure 6: BeagleBone Blue [7]

3.2.3. Sensors/payloads

Sensors are used in all 3 sub-systems. The vehicle navigates by using input from a list of sensors (figure 6): A magnetic compass is used to determine the heading, an IMU is comprised of accelerometers, gyroscopes, and magnetic field orientation sensors that measure the vehicle's linear acceleration, and angular rotation [8]. The vehicle uses GNSS (Global Navigation Satellite System) and GPS (Global Positioning System) to receive its coordinate location for navigation. A DVL (Doppler Velocity Log) can be used to determine the vehicle's speed over ground [8].

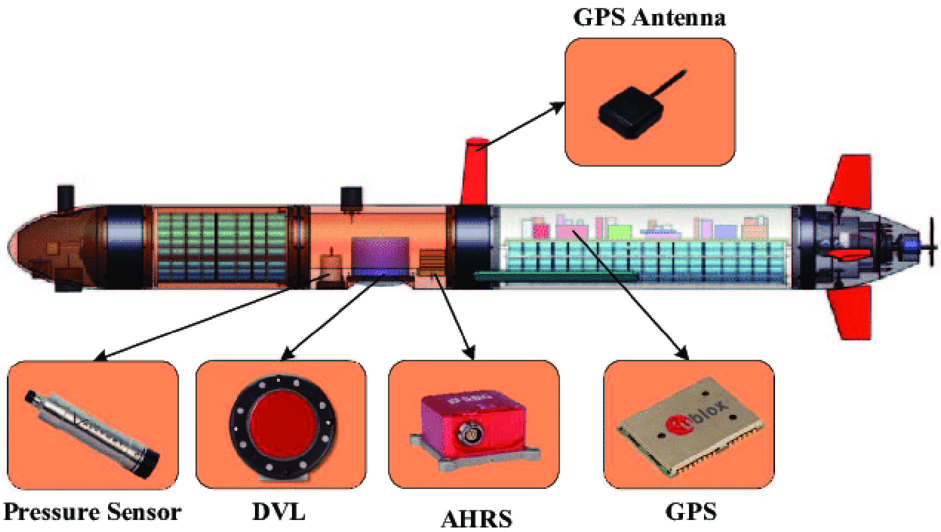

Figure 7: AUV basic sensors [8]

The Power harvesting and management system utilises current and load sensing to optimise and priorities power needs as well as safely charge the batteries. The Data collection and logging system's sensors largely depend on the data needed for the user's research. However, most vehicles are equipped with a CTD [8] (conductivity (salinity), temperature, and depth sensors), pH probes, and dissolved oxygen sensor. Addition sensors include sonars, cameras, light sensors, and other payloads attached.

3.2.4. Power harvesting and management

The vehicle used in this project does not have any thrusters, its propulsion is generated by the principles of wave motion [9]. Therefore, the power demand is drastically reduced. The SV2 makes use of commercially available long-exposure marine-grade solar panels. These panels have a trade-off of durability for efficiency. I plan to use its pre-existing system as it has been designed for missions that span several weeks or longer. Keeping this in mind the control system and sensors will need to operate on little power to extend the deployment period.

Power saving techniques will need to be designed into the hardware and software of the electronics systems. Software-based power saving can be achieved by reducing the sampling frequency and having a well-structured and optimized code [10]. This reduces the amount of work done by the controllers and sensors. Hardware-based power saving can be implemented by using isolating circuits to switch systems on and off [10]. Watchdogs monitor processing time and can trigger interrupts in the software to stop processes. This is useful for when an error is incurred, or the vehicle's batteries are critically low.

3.2.5. AUV and ASV projects

PyPilot is an open-source project that was initially designed by Sean D'Epagnier [11] to autonomously control the heading of his Bristol 27 "Alexandra" sailboat. This is done by determining the vessels course and altering the rudder angle to match the desired heading. It was further developed by the open-source community to be a ready to use kit featuring automatic sensor calibration, steering and low power consumption [11]. It has successfully completed hundreds of kilometres and various applications from sailboats to ASVs. The hardware utilises both Arduino and Raspberry Pi controllers along with a compass and gyro as inputs shown below in figure 7.

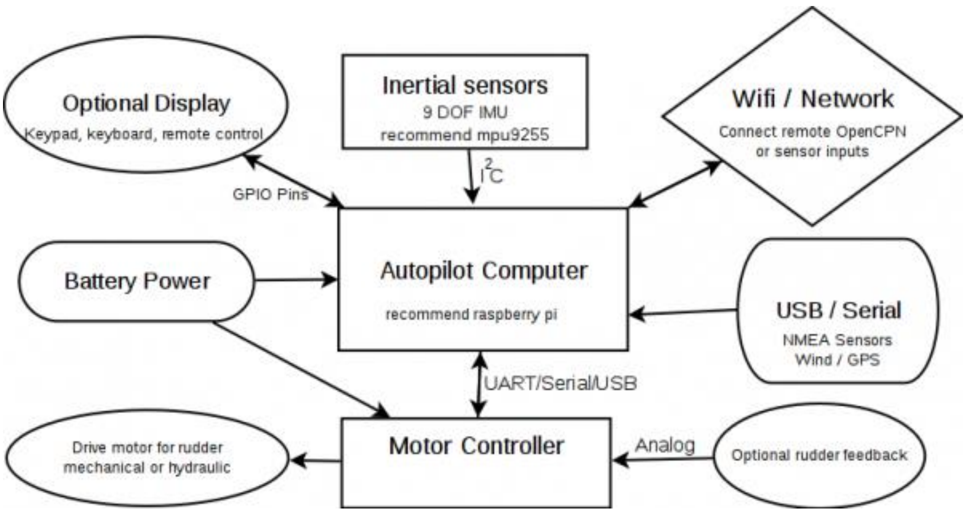

Figure 8: pyPilot system overview [11]

Clearbot started as a student-driven project established in 2019 to create a more efficient method of trash cleanups in rivers and beaches compared to manual methods where a net was dragged behind paddleboarders [12]. The vehicle can autonomously navigate through coastal and inland bodies of water performing tasks such as garbage collection shown in figure 8, monitoring, and surveillance, as well as delivering goods by water. Recent developments include the use of AI algorithms for more efficient operation and increasing the scale of their vehicles to accommodate more trash [12]. Their operating systems have not disclosed and are not available for open-source projects. However, the project highlights the need for more autonomous vehicles with various applications ranging from marine data collection to trash cleanups.

Figure 9: Clearbot vehicle cleaning trash from river [12]

4. Adaptability to New Situations

4.1 Flexibility

Open-source systems are designed to be interoperable, allowing for seamless integration. Some systems are designed to be modular, allowing the user to combine different aspects together to suit their project needs [3]. This allows for flexibility when changes are made or unavoidable.

Potential issues to be dealt with are keeping moisture out of the electronics, harsh condition the vehicle could experience, initial stages of designing the system and requirements. Some components might have large lead times causing delays, funding for the project is limited. Overcoming these issues can be achieved by conducting a thoughtful risk analysis and system breakdown, a proactive approach can be taken to foresee obstacles that will be faced during the project design and development.

Prioritising risks based on the highest impact can help mitigate delays. Redundancy will need to be designed into the systems to safeguard against malfunctions. A rigorous prototyping and testing phase is to be designed into the project timeline to weed out faults and weaknesses within the system. Each sub-system of the vehicle is to be developed in a modular approach with realistic milestones to keep the project on track to success.

5. Staying Current

5.1 Market Analysis

Open-source forums are a hub for emerging and developing technology within industries, by signing up and being a proactive member, one would be able to stay current with industry trends and news. These forums and communities host a plethora of industry professionals who can collaborate or suggest changes to meet industry needs. This creates a feedback loop of constant improvement.

Partnering with oceanography research industries and marine engineering companies would be beneficial as their goals are to innovate, explore, and gather data from various parts of the ocean.

Their presence in the scientific research industry would allow for an inside look into trends of what data is presently and, in the future, needed for research, as well as the technical demands to meet researchers' requirements.

5.2 Technology Integration

By using interoperable and open-source systems, integrating the latest technological designs can be implemented seamlessly. The open-source communities often release new iterations of firmware and hardware and are made available allowing for rapid upgrades and staying current with industry needs while adhering to standards such as IEEE 1451 which refers to transducer interoperability [16].

Various software are flashed onto the respective microcontrollers to control navigation, communication, and data logging. The data inputs can be simulated with outputs logged to calibrate and configure the software. This is needed to ensure the controllers and software are functioning correctly before connecting real world sensors and outputs. Communication protocols such as RS-232 and RS485 are commonly used throughout industries for sensor communications [16]. Redundant systems are to be designed into the system as a failsafe along with other protective measures.

By partnering with the student’s employer, they have access to resources and skills that will benefit the project in numerous ways. Utilising their technical expertise and industry knowledge can guide the project to adhere to standards, safety measures, and the latest technical advancements.

6. Reflection (Lessons Learned)

176.1 Project Milestones

~~1. Meet with supervisors to discuss project idea topics and finalise the supervisor of choice (01/02/2024 - 07/02/2024)~~

~~2. Develop a problem statement and project overview (08/02/2024 - 14/02/2024)~~

~~3. Build a concise project proposal (15/02/2024 - 14/03/2024)~~

4. Review proposal and create presentation (20/03/2024 - 09/05/2024)

5. Begin designing the system and identify key components (25/03/2024 - 30/04/2024)

6. Circuit design and simulations (22/04/2024 - 30/05/2024)

7. Begin with physical assembly, wiring and prototyping (20/05/2024 - 20/07/2024)

8. Real world testing (01/06/2024 - 01/10/2024)

9. Integration and minor improvements (15/07/2024 - 15/08/2024)

10. Supervisor to review and comment on final project for any last changes and improvements (01/09/2024 - 01/10/2024)

11. Progress presentation (05/09/2024)

12. Final tests (20/09/2024 - 20/10/2024)

13. Final report submission (17/10/2024)

14. Demonstration (24/10/2024)

The design concept first began with an AUV idea, after realising the mechanical knowledge required to design the vehicle's chassis it was decided to pivot towards a decommissioned ASV glider as the vehicle. Luckily, however, the electronic processors are similar to each other and did not cause much backtracking with research. This allows for the focus to be placed on the electronics component of the project.

Research highlighted the growing demand for open-source solutions, this is a major driving factor in keeping with trends within the industry. Some sensors and controllers used in similar open-source projects are still commercially available, however manufacturers have either stop producing or developing these components. Such components must be avoided so the project remains technologically relevant.

7. Conclusion

7.1 Summary

The open-source-based ASV project aims to make autonomous ocean research vehicles more accessible to underfunded researchers through a process of cost reduction and streamlined integration. This is done using open-source and readily available resources integrated into a decommissioned Liquid Robotics SV2 Wave glider. The objectives of this project are to achieve an interoperable open-source based vehicle that can navigate and collect data autonomously using off the shelf and open-source hardware and software. A suite of sensors is to be used for navigation, control, and environmental logging. By using a modular design approach each independent system can be scaled and customised to meet the needs of users.

This project emphasises the need for open-source development and collaboration, resulting in a community fostering key engineering principles such as standardisations, interoperability, and peer review. By leveraging the latest technologies, this project has the potential to unlock new insights into marine conservation and monitoring.

Appendix: Supporting Documents

[1] National Oceanic and Atmospheric Administration, "Why do we explore the ocean? : Ocean Exploration Facts: NOAA Office of Ocean Exploration and Research," oceanexplorer.noaa.gov. https://oceanexplorer.noaa.gov/facts/why.html#:~:text=Information%20from%20ocean%20exploration%20can

[2] National Oceanic and Atmospheric Administration, "What is an AUV? : Ocean Exploration Facts: NOAA Office of Ocean Exploration and Research," oceanexplorer.noaa.gov. https://oceanexplorer.noaa.gov/facts/auv.html

[3] L. Congdon, "8 advantages of using open source in the enterprise," Enterprisersproject.com, 2015. https://enterprisersproject.com/article/2015/1/top-advantages-open-source-offers-over-proprietary-solutions

[4] OpenSource, "What is open source?," Opensource.com, 2019. https://opensource.com/resources/what-open-source

[5] ArduPilot Dev team, "ArduPilot Documentation — ArduPilot documentation," ardupilot.org, 2024. https://ardupilot.org/ardupilot/

[6] Dronecode Project, "3DR Pixhawk 1 Flight Controller (Discontinued) | PX4 User Guide (main)," docs.px4.io, Feb. 13, 2024. https://docs.px4.io/main/en/flight_controller/pixhawk.html (accessed Mar. 04, 2024).

[7] Random Nerds Tutorials, "Arduino vs Raspberry Pi vs BeagleBone vs PCDuino | Random Nerd Tutorials," https://randomnerdtutorials.com/, Dec. 05, 2013. https://randomnerdtutorials.com/arduino-vs-raspberry-pi-vs-beaglebone-vs-pcduino/

[8] R. Danovaro et al., "Towards a marine strategy for the deep Mediterranean Sea: Analysis of current ecological status," Marine Policy, vol. 112, no. 1561–5928, p. 103781, Feb. 2020, doi: https://doi.org/10.1016/j.marpol.2019.103781.

[9] V. Van Lancker and M. Baeye, "Wave Glider Monitoring of Sediment Transport and Dredge Plumes in a Shallow Marine Sandbank Environment," PLOS ONE, vol. 10, no. 6, p. 5/15, Jun. 2015, doi: https://doi.org/10.1371/journal.pone.0128948.

[10] E. Odunlade, “Minimizing Power Consumption in Microcontrollers,” Nerd For Tech, Jun. 10, 2021. https://medium.com/nerd-for-tech/minimizing-power-consumption-in-microcontrollers-b3eb9593c893 (accessed Mar. 07, 2024).

[11] S. D’Epagnier, “pypilot - open source marine autopilot,” pypilot.org, Apr. 09, 2022. https://pypilot.org/ (accessed Mar. 10, 2024).

[12] J. Hailstone, “How This Self-Driving Boat Is Helping To Tackle The Issue Of Plastic Waste,” Forbes, Jun. 22, 2023. https://www.forbes.com/sites/jamiehailstone/2023/06/22/how-this-self-driving-boat-is-heping-to-tackle-the-issue-of-plastic-waste/?sh=14efee313612 (accessed Mar. 10, 2024).

[13] R. Mitra, G. Brown, M. Huffman, and H. Zhu, “Long-Range Wireless Technologies,” *utsa.pressbooks.pub*, 2024, Accessed: Mar. 11, 2024. [Online]. Available: https://utsa.pressbooks.pub/networking/chapter/long-range-wireless/#:~:text=%3A16%3A11%5D-

[14] Liquid Robotics, *Wave Glider Interface Control Description*, 2.1 ed., vol. 1. LIQUID ROBOTICS, INC. 1329 MOFFETT PARK DR. SUNNYVALE, CA 94089 (650) 493-6300: Liquid Robotics, 2011, pp. 50–59.

[15] F. Ferreira, R. Petroccia, and J. Alves, “SCIENCE AND TECHNOLOGY ORGANIZATION CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION Increasing the operational safety of Autonomous Underwater Vehicles using the JANUS communication standard,” IEEE, 2018. Accessed: Mar. 11, 2024. [Online]. Available: https://apps.dtic.mil/sti/pdfs/AD1113750.pdf

[16] IEEE, “IEEE 1451 and IEEE 1588 Standards Chair of IEEE I&MS TC-9, Technical Committee on Sensor Technology.” Accessed: Mar. 11, 2024. [Online]. Available: https://www.nist.gov/system/files/documents/el/isd/ieee/Information-on-1451_1588-V36.pdf#:~:text=IEEE%201451%20standardizes%20two%20interfaces