Autonomous Water Quality Probing UAV

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EXECUTIVE SUMMARY

This summary provides an overview of the development and implementation of an autonomous Unmanned Aerial Vehicle (UAV) for water quality monitoring in partnership with Barwon Water as part of a final year engineering project with Deakin University.

The primary aim of this project was to design, develop, and evaluate if an autonomous UAV system would enhance the reliability, accuracy and safety of water quality data collection when compared to traditional methods. Current methods involve operators collecting the data manually via boat whilst dangling an apparatus over the side. This practice is quite unsafe and should be modernised with an applicable solution.

The UAV system developed has demonstrated a high level of reliability and accuracy in its current state as it has successfully completed a number of autonomous flights and tests. Likewise, the probe component has shown promising functionality during ground-based testing.

Unfortunately, due to time constraints, erratic weather conditions, and uncertain outcomes, the integration of the probe onto the drone and subsequent testing in a real-world environment could not be completed in time for the university submission.

While the UAV's ability to hover and fly autonomously has been established, the full assessment of its water quality monitoring capabilities is pending further testing.

Despite this limitation, the groundwork laid in this project serves as a strong foundation for future research and development efforts, with the goal of realising a comprehensive UAV-based water quality monitoring solution.

ACKNOWLEGEMENTS

I would like to express my sincere gratitude to Michael Thomas and Barwon Water for their generous funding and unwavering support throughout this research endeavour. Their commitment to supporting innovative solutions in the field of water quality monitoring has been instrumental in the successful completion of this project. Their financial support enabled the acquisition of essential resources, the development of the UAV system, and the execution of comprehensive testing and data collection.

I would also like to extend my heartfelt thanks to Dr. Andrew Price and Deakin University for their invaluable assistance and guidance throughout this journey. The academic environment provided by Deakin University offered a fertile ground for exploration, collaboration, and knowledge sharing.

This research would not have been possible without the collective support, guidance, and encouragement of all those mentioned above. Your contributions have been instrumental in the successful completion of this thesis, and I am truly thankful for your unwavering belief in this endeavour.

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1 INTRODUCTION

Water is a fundamental resource, essential for sustaining life and fostering diverse ecosystems. Its quality directly influences its suitability for various purposes, including drinking, agriculture, recreation, and industrial processes. Ensuring the availability of safe and sustainable water sources is not merely a global priority; it is an imperative for human well-being and environmental preservation.

Figure 1: Conventional Water Sampling

Traditional water sampling techniques as shown in figure 1 are fraught with inherent limitations as they are often labour intensive, time-consuming, cost-prohibitive, and intrinsically prone to human error. Moreover, their ability to provide comprehensive spatial and temporal coverage of water quality parameters is often restricted, particularly in remote and hazardous areas.

Presently, water quality data acquisition is often completed by contractors who are required to travel by boat towards the middle of reservoirs and other bodies of water before dangling a sample collection device over the side of the boat. This conventional approach carries inherent risks, from personnel safety to potential data contamination caused by the wake when travelling between sampling points.

On the other hand, unmanned aerial vehicles (UAVs) such as figure 2, have unparalleled reach and adaptability, providing access to areas that would be inaccessible by boats or foot, affording water authorities an unprecedented understanding of their assets and the necessary treatment processes.

Figure 2: Autonomous UAV Based Water Sampling

With the help of Barwon Water this thesis will cover the construction, testing and comparison of an autonomous UAV for water quality monitoring at some of their reservoirs. Hopefully providing Barwon Water with a tool that can collect water quality information in a more efficient, higher resolution, and cost-effective way than traditional methods.

2 LITERATURE REVIEW

Over the years many projects have been completed regarding autonomous drones, water sampling, and water probing. Each project has demonstrated a number of strengths and weaknesses that will need to be explored before embarking on the proposed project.

2.1 Autonomous Systems For Water Quality Monitoring

Autonomous UAVs are drones that can fly without human intervention, they are controlled by a computer or flight controller that is programmed to follow a set of instructions to complete a specific mission. As such, autonomous UAVs are becoming increasingly popular for water quality monitoring as they can collect data more efficiently, accurately and, repeatably than traditional methods.

Several studies have investigated the development of autonomous UAVs. For example, a study published in the journal "IEEE Robotics and Automation Letters" in 2017 found that UAVs can be programmed to autonomously navigate through complex environments whilst avoiding obstacles and following pre-defined paths.

Likewise, another study, "Nature Machine Intelligence", published in 2018, found that UAVs can be programmed to autonomously perform tasks such as search and rescue. Including: searching for survivors in a disaster zone, and delivering supplies to anyone located.

However, there are several challenges associated with using autonomous UAVs for water quality monitoring. One such challenge is that autonomous UAVs can be difficult to program, as they must account for the range of depths and shapes of water bodies they may encounter. Additionally, the flight computer must be able to consider a variety of factors, including: the weather, the terrain, and what water quality parameters are being monitored. Furthermore, an autonomous UAV cannot monitor anything without the appropriate sensors or tools attached.

2.2 UAV-Based Water Sampling Systems

By combining an autonomous UAV with a water sampling system, a range of data can be collected. UAV water sampling systems are designed to lower some form of sampling tube that can collect a small sample for later analysis. This is done by flying to the desired location, lowering the sampling device to the required depth, and closing the doors to seal the water inside. The tube is then pulled out of the water so that the sample can be analysed within a laboratory to determine a range of water quality parameters including: turbidity, conductivity, pH, iron, magnesium, and UVC content, any many more.

Several studies have investigated the development of UAV water sampling systems. One such study published in the "Journal of Unmanned Vehicle Systems" in 2018 found that UAVs can be used to collect water samples quickly and effectively from remote or hazardous locations. They did this by attaching a Van Dorn Sampler to a UAV that can be triggered by dropping a weight along the tether cable as shown in figures 3 and 4. Furthermore, the study concluded that “the UAV caused minimal turbulence on water surfaces while hovering compared to windy conditions.” As such, it is expected a drone would have a much lower impact on the water whilst hovering than a boat would when travelling to a sampling location.

Figure 3: Water Sampling Drone

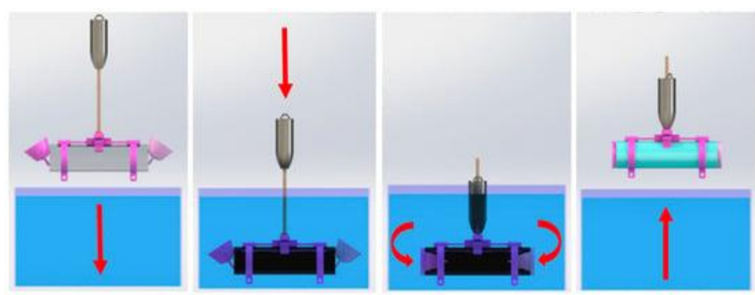

Figure 4: UAV Water Sampler

Another study, published in the journal "Marine Technology Society Journal" in 2017, found that UAVs can be used to monitor coral reefs. The researchers realized that drones can be used to identify areas of coral bleaching by checking samples for relevant markers.

Overall, these studies suggest that UAV water sampling systems have the potential to be a valuable tool for a variety of applications. However, there are several challenges that need to be addressed before such sampling systems can be widely used. These challenges include, the limited number of samples collected on each flight to and from the body of water and the shape of the sampling container that could easily become tangled in any submerged obstacles.

2.3 UAV Equipped With Water Sampling Probing

Several studies have investigated the use of autonomous UAVs with an attached multi-probe for water quality monitoring. The multi-probe is often connected via a tether hanging from the drone that facilitates data and power transfer. Furthermore, the probes shown can collect hundreds of data points in real time and are often streamlined to reduce the changes of tangling or getting caught when deployed.

One such study published in 2018, titled "In Situ Water Quality Measurements Using an Unmanned Aerial Vehicle (UAV) System" developed a probe called the "open-source multiprobe meter (OSMM)" which was able to measure "DO, EC, pH, and temperature" as shown in figure 5. Using the OSMM the researchers were able to collect a range of data that was within "2.1%, 3.43%, 3.76%, and <1.0% respectively of the same data collected via a commercially produced multi-probe meter (CMM) as in fig 6.

Figure 5: OSMM Custom built multi-Probe

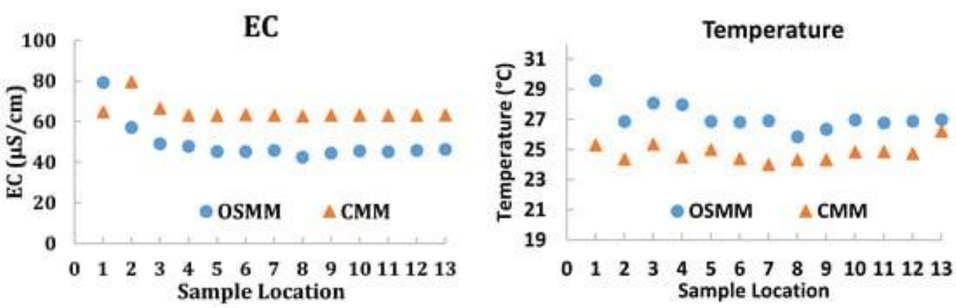

Figure 6: OSMM vs CMM Results

Another study published in 2018 found that UAV probes can be used to collect a range of data on water quality, including turbidity, chlorophyll-a concentration, and temperature. This information was then used by the researchers to map water bodies and identify areas of pollution that require additional treatment or that could be kept under observation for changes over time.

The studies presented each point towards UAV systems being a viable method of colleting water quality information. The main challenges probe-based studies faced include, that the probe must be able to withstand the forces of the wind and water pressure / currents. And, being able to store the probes safely to ensure they do not hinder any flight or landing procedures.

2.4 UAVs Equipped With Both Water Probing and Sampling Apparatus

Finally, one project titled "Adaptive Water Sampling Device for Aerial Robots" by Cengiz Koparan, A. Bulent Koc, Charles V. Privette and Calvin B. Sawyer demonstrated the feasibility of combining a water sampling and water probing system to produce a UAV capable of selectively sampling the water based on findings from the attached multi-probe as shown in figure 5 and 6.

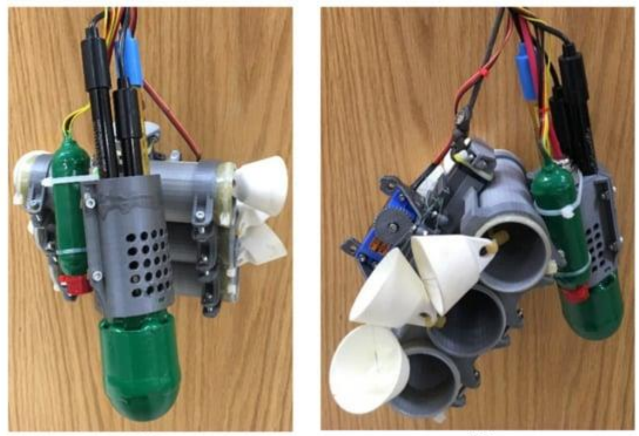

Figure 8: Multi-Probe with an Attached Water Sampler

Unfortunately, the project suffers from a few drawbacks including that:

- The drone lands on the water and can only be used in the absence of waves or a current.
- The attached tether hangs below the drone meaning it could get damaged when it hits the ground during landing.
- The hanging tether may reduce the UAV stability whilst flying to a sampling point as it becomes a pendulum.

Figure 7: Combined Drone Sitting by A Lake

2.5 UAV Real Time Kinematics (RTK)

Utilizing a Real-Time Kinematic (RTK) solution in our UAV system presents a compelling enhancement to its capabilities. While the M8N GPS boasts a positional accuracy of 2.5 meters, the introduction of an RTK receiver coupled with the time needed to refine its location elevates the precision to a remarkable 1.5 centimetres. This advancement ensures that the UAV consistently samples from precisely the same location, a crucial factor in yielding highly accurate and reliable data trends over extended period

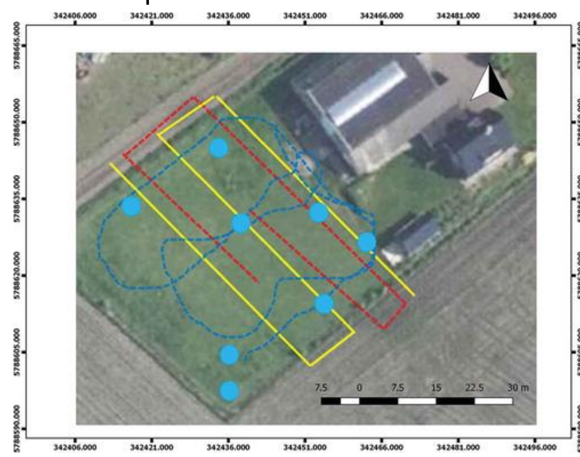

Figure 9: RTK Study Test Flight Path

A study conducted by Desta Ekaso, Francesco Nex, and Norman Kerle, titled "Accuracy assessment of real-time kinematic (RTK) measurements on unmanned aerial vehicles (UAV) for direct geo-referencing" [2], provides valuable insights into the accuracy achievable with similar RTK technology. The results, as illustrated in Figure 8 during the dotted blue test flight, reveal a mean XY error of -11.0 centimetres and a vertical, Z error of -26.4 centimetres. Additionally, the standard deviation and root mean square error (RMSE) in the XY axes hover around 30 centimetres, accompanied by an impressive standard deviation of 6.4 centimetres for the vertical axis.

	XY	Z
Mean	-11.0 cm	-26.4 cm
Sigma	26.6 cm	6.4 cm
RMSE	31.0 cm	27.2 cm

Table 1: RTK Study Test Flight Results

Incorporating RTK into the UAV system not only aligns with industry standards but also significantly enhances the precision and reliability of any data collection efforts. The exceptional accuracy achieved through this technology stands as a testament to the system's potential for providing invaluable insights into water quality trends, ultimately contributing to more informed decision-making in water resource management.

2.6 Monitoring Water Stratification

As the surface of a reservoir heats the water can separate into layers of different water densities as shown in fig 10. This creates a barrier between the layers, preventing mixing and limiting the exchange of oxygen and nutrients. Water stratification can have several negative impacts on water quality. Including: the growth of algae blooms, which can produce toxins that would make the water unsafe for drinking or require additional treating which would increase the costs to process it.

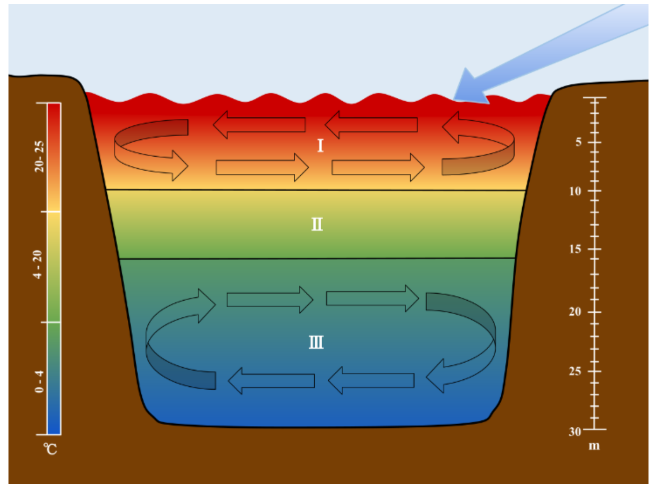

Figure 10: Water Stratification Diagram

UAVs can be used to monitor water stratification by measuring the temperature, salinity, and dissolved oxygen of the water at different depths. This information can then be used to create maps that may highlight areas that are at risk running into issues.

2.7 Literature Review Conclusion

In summary, the literature reviewed highlights the contributions and limitations of previous projects in the field of UAV-based water quality monitoring. By drawing upon their successes and identifying areas for improvement, this project aims to further explore the capabilities of UAV systems for water quality probing. This will be done by incorporating a tethered probe deployment system, RTK GPS, and by enhancing the overall efficiency of water quality assessments.

Through these advancements, the project strives to make significant contributions to the field, enabling better understanding and management of water resources for environmental preservation and human well-being.

3 AIMS

The primary aim of this project is to conceive, design, and construct an autonomous unmanned aerial vehicle (UAV) explicitly tailored for water quality monitoring applications. This envisioned UAV will excel in its ability to hover stably above bodies of water, facilitating the precise collection of crucial temperature and depth data using a specialized probe. Once the required data is acquired, the sensor unit will seamlessly retract back into the drone's body, enabling the system to autonomously navigate to the next predetermined sampling point or return to its designated landing location.

Central to the system's core functionality is its autonomy, ensuring that it can undertake missions with minimal human intervention. This autonomy encompasses the entire mission process, including take off, navigation between pre-defined waypoints, data collection, and the safe return of the UAV to its home position. Furthermore, the system will incorporate intelligent power management capabilities, assessing available energy resources to ensure that it initiates missions only when sufficient power reserves are on hand. This feature aims to optimize mission success by preventing premature terminations due to power constraints.

4 OBJECTIVES

To realize this overarching aim, the following specific objectives have been formulated to judge the project's success and timeliness:

Objective 1: Design a UAV With a Sufficient Payload Capacity and Flight Time
The first objective of this research is to design a UAV capable of carrying a 1.5 kilogram payload or water quality monitoring probe, whilst maintaining an adequate flight time of over 20 minutes to ensure the system can collect data from a range of remote points. This entails selecting efficient components and optimizing the UAV's structural design, propulsion system, and power management to ensure it can accommodate the necessary equipment and required flight duration.

Objective 2: Build an Autonomous UAV That Is Reliable and Accurate
In order for the industry to move towards autonomous solutions it is imperative that the system matches or exceeds the reliability and accuracy of traditional methods of data collection. As such, the first objective is to demonstrate that a UAV based approach does not suffer from human error and can return to a probing point reliably. This involves meticulous planning, precise instrumentation, and stringent calibration to ensure that the UAV system delivers consistent and accurate results.

Objective 3: Design and Build an Innovative Water Probing System
A key facet of the project is the development of a water probing system that is both innovative and efficient. The main goal is to create a system that deploys and retracts the sensor probe automatically, ensuring that it does not interfere with flight characteristics or pose risks during landing. This requires meticulous engineering of mechanisms that can withstand the forces of wind and water pressure, ensuring that the probe remains stable and reliable during operations.

Objective 4: Feasibility Testing on Dry Land

Before deploying the UAV system over any real water bodies, it is important to conduct thorough feasibility testing on dry land to protect the aquatic environment and hardware. This objective involves testing the UAV's hovering accuracy, deployment and retraction mechanisms, and overall functionality in a safe and controlled environment. Dry land testing serves as a crucial validation step, ensuring that the system meets performance expectations before being exposed to the complexities of a reservoir.

Objective 5: Develop a Data Dashboard

The primary focus of the dashboard is to provide water resource managers, environmental authorities, and relevant stakeholders with real-time access to comprehensive water quality data collected through the UAV monitoring system. This data driven dashboard aims to facilitate informed decision making, enhance operational efficiency, and support long-term sustainability in water quality management.

The project objectives set out are ambitious, but achievable within the time frame set given everything stays on .

5 OUTCOMES & DELIVERABLES

To fulfill the goals of this research project, several key deliverables will be generated. These deliverables are designed to not only demonstrate the successful completion of the project but also to provide valuable tools and documentation for Barwon Water.

Functional Autonomous UAV For Water Probing:

A fundamental deliverable of this project is the development of a functional Unmanned Aerial Vehicle (UAV) capable of autonomously and reliably completing the project's primary aims and objectives. This UAV will be meticulously designed and rigorously tested to ensure its ability to operate autonomously, collect water quality data accurately, and maintain the highest level of reliability. It will represent a pioneering solution for efficient, cost-effective, and safe water quality monitoring.

Online Dashboard and Database:

In addition to the UAV system itself, an online dashboard and database will be established to store, manage, and visualize the results collected during UAV missions. This dashboard will serve as a centralized platform where users, including water resource managers, environmental authorities, and stakeholders, can access real-time data, statistical analyses, and visual representations of water quality parameters. It will provide a user-friendly interface for data exploration, facilitating informed decision-making, trend analysis, and collaboration among stakeholders.

Comprehensive Project Report:

A comprehensive project report will be produced, detailing every aspect of the research journey. This report will document the entire design process of the UAV system, including the structural components, propulsion system, and power management solutions employed to achieve the necessary payload capacity and flight time. It will also provide insights into the challenges encountered throughout the project and the innovative solutions implemented to overcome them.

6 METHODOLOGY

The methodology employed in this project is meticulously designed to translate the aims and objectives into concrete actions, ultimately leading to the successful development of an autonomous UAV system for water quality monitoring. The approach encompasses various phases and activities, all aimed at achieving the project's objectives.

6.1 Included Scope:

Review of Existing Technologies:

Commencing the methodology is an exhaustive review of existing technologies relevant to water quality monitoring and autonomous UAVs. This review includes a strong analysis of pricing, performance, and overall suitability for water authority applications. It also culminates in a well-informed recommendation for the most appropriate technologies to be incorporated into the UAV system.

Hardware and Software Benchmarking:

Building on the technology review, an extensive benchmarking exercise is conducted. This step scrutinizes various hardware components and software algorithms that could potentially be integrated into the UAV system with the goal to identify the optimal combination, aligning with the project's objectives whilst considering factors like cost, reliability, and compatibility.

Prototype Development:

With a clear understanding of the chosen technologies, the project moves forward to the heart of the endeavour; the development of a functional UAV prototype. This prototype is equipped to carry a sample payload, which can be released onto a target location once the UAV has signalled it is in position.

Hovering and Deployment Precision Assessment:

Recognizing the critical importance of collecting samples from the same position every time to minimise error in any trend data analysed it is important to assess the hovering precision and deployment mechanisms of the UAV. This phase focuses on repeating a range of tests to evaluate the accuracy and repeatability of the UAV system. Before moving onto the next step, the platform should demonstrate a result on par or better than traditional methods of data collection.

Documentation and Reporting:

Throughout the project, meticulous documentation should be maintained. This documentation includes design processes, challenges encountered, solutions implemented, assessments of UAV performance, recommendations for future work, and a comprehensive comparison of the UAV system to other commercially available alternatives. The reporting phase involves collating this information into a comprehensive report that serves as both a project record and a knowledge repository for future research and development.

6.2 Excluded Scope:

Building or Testing Multiple Prototypes:

To maintain a focused and efficient project timeline, the scope is restricted to developing and testing a single prototype. This approach reduces the project budget requirements and ensures that excess time is not spend tuning additional systems.

Developing Additional Functionalities:

While the UAV system's primary objective is water quality monitoring, the scope is limited to the core functionalities necessary for this purpose. Additional features, such as obstacle avoidance or advanced communication, are excluded to maintain project focus and efficiency.

6.3 Scope Limitations:

Hardware and Software Availability:

The availability and suitability of hardware components and software algorithms may impose limitations on choices. A careful assessment of the market and technological landscape is conducted to make informed selections.

Budget and Time Constraints:

Budgetary constraints may limit the extent of experimentation and prototyping. To address this, cost-effective strategies are adopted with essential components and features prioritized. Likewise, time constraints when ordering new parts and making repairs are also managed efficiently to meet project milestones.

Ethical and Legal Implications:
The use of autonomous UAVs carries ethical and legal responsibilities. Compliance with all relevant regulations and ethical guidelines governing UAV operations will be strictly followed. This includes any CASA laws, Parks Victoria restrictions and data privacy regulations.

6.4 Approach:

Prototyping:
The project commences with the design and construction of a functional UAV prototype capable of carrying a sample payload and deploying it accurately.

Testing and Evaluation:
A significant portion of the project involves extensive testing and evaluation. This includes assessing hovering accuracy, deployment mechanisms, and overall system functionality under varying environmental conditions.

Analysis and Iteration:
Findings from the testing phase are rigorously analysed, and the prototype undergoes iterative improvements to address any identified weaknesses or shortcomings.

Dry Land Testing:
Before venturing into water environments, comprehensive feasibility testing is conducted on dry land to validate system performance and reliability.

Real-World Testing:
The final phase involves real-world testing, where the complete system is deployed over a reservoir to assess its performance in a practical water quality monitoring scenario.

By meticulously following this methodology, the project aims to achieve each objective within the defined timeframe while ensuring the optimal allocation of resources and adherence to ethical and legal standards. This systematic approach lays the foundation for the successful development and deployment of the UAV-based water quality monitoring system, meeting industry standards and contributing to the broader research community.

7 RESULTS

Throughout the project's execution, a comprehensive set of data was meticulously collected to assess the performance and capabilities of the UAV system. Two critical aspects of this data collection pertain to the platform's positional accuracy and repeatability as well as its stability characteristics.

The insights derived from this data provide a nuanced understanding of the UAV's performance and lay the foundation for discussions surrounding its capabilities and potential applications in the field of water quality monitoring.

7.1 Positional Accuracy and Repeatability

Many test flights were undertaken in various weather conditions. However, the results below are focused on an autonomous flight from a home position to three waypoints in a square at an altitude of three meters. After flying past the last waypoint, the system climbed to a relative altitude of five meters before landing within centimetres of its starting location as shown in figure 11.

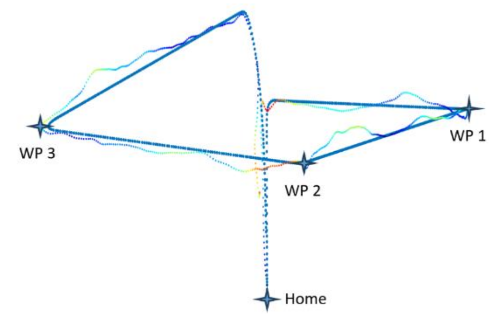

Figure 11: UAV Set Position Versus Real Position

	X	Y	Z
Max Difference	37.5 cm	45.9 cm	48.6 cm
Sigma	10.8 cm	14.7 cm	10.5 cm
RMSE	13.5 cm	15.2 cm	10.7 cm
MAE	10.2 cm	10.5 cm	7.7 cm
RMSE-MAE Ratio	32%	45%	39%

Table 2: Positional Accuracy Results

The test flight displayed shows notable positional precision as highlighted by a standard deviation (Sigma) of less than 15 centimetres in each axis. The root mean square error (RMSE), with its quadratic scoring, and the mean absolute error (MAE), with its linear evaluation, provide insights into potential causes of deviations. The fact that the RMSE is 32% to 45% greater than the MAE indicates that specific large disturbances, rather than consistent minor inaccuracies, affected the drone's path. Such variations in the positional accuracy could be attributed to gusty and erratic winds from the southwest during testing as reinforced by the greater horizontal deviations shown in the X and Y axes.

7.2 Orientation / Vibration Data

On the other hand, the vibrational and orientation data shed light on the UAV's stability and control during flight. This dataset offers valuable information regarding the UAV's ability to maintain a steady orientation and minimize vibrations or oscillations, which can have a direct impact on the accuracy of data collected by onboard sensors and reduce the systems tolerances against outside forces such as wind and turbulence.

The orientation data collected highlights the drone's exceptional vibrational stability, confirming consistent performance throughout a number of test flights. Where figure 12 shows large vibrations within the UAVs roll axis figure 13 represents the system after extensive tuning and optimisation. Given a standard deviation of under 2 degrees across all axes there is clearly a tight alignment between the anticipated and actual orientations experienced during each tuned flight.

Delving deeper into the data collected, the yaw MAE stands out as it is under half the associated RMSE value. This is likely due to the actual yaw closely following the predicted yaw throughout the flight but suffering due to overshoot when making a sharp turn as highlighted by the blue circles on figure 14.

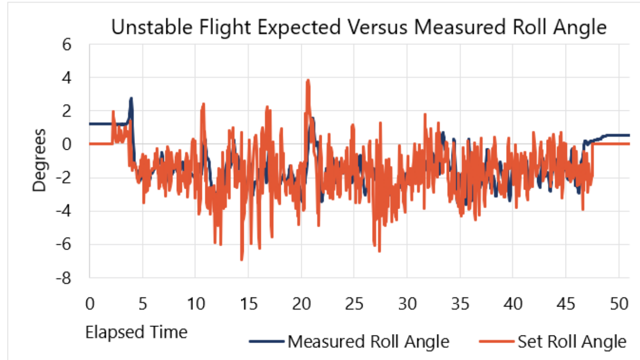

Figure 12: Untuned UAV Vibrations

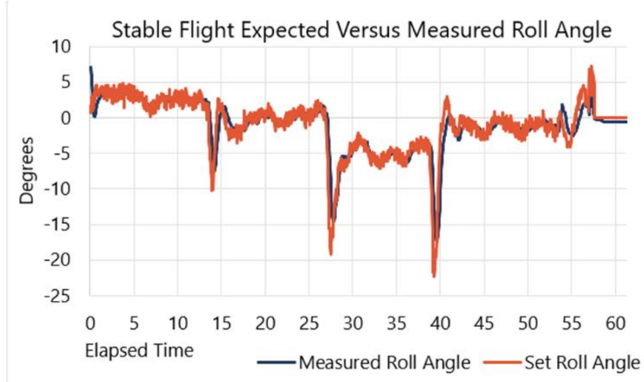

Figure 13: Tuned UAV Vibrations

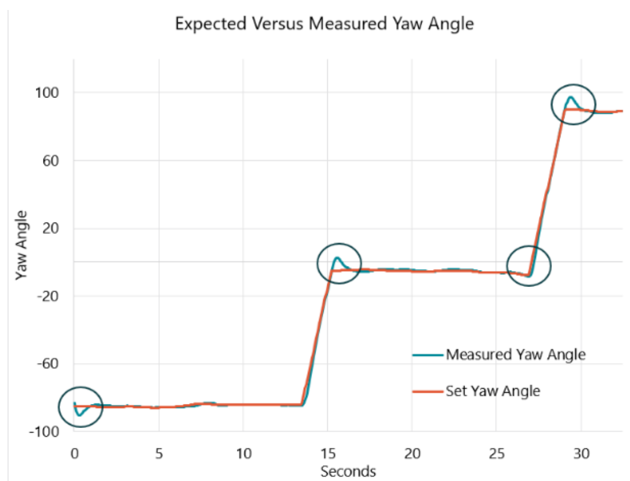

Figure 14: UAV Yaw Overshoot

	Pitch	Roll	Yaw
Max Difference	7.12°	11.63°	7.81°
Standard Deviation	1.78°	1.82°	1.83°
RMSE	1.79°	1.82°	1.83°
MAE	1.21°	1.09°	0.89°
RMSE-MAE Ratio	48%	66%	105%

Table 3: UAV Vibration Data

7.3 Sensor Testing

To test the Bar02 depth and temperature sensor it was screwed into the top of a water bottle whilst connected to the companion computer as shown in figure 15. A python script then printed the depth and temperature in real time on the monitor.

Figure 15: Bar02 Sensor Bench Testing

Whilst this experiment proved the sensor works on a small scale it suffered from the water bottle being pressurised whilst closed. As such, if the bottle was held tightly the increased pressure would result in the sensor detecting a depth of multiple meters.

Further testing with a 3D printed enclosure submerged in a laundry sink overnight as shown in fig 16 matched the rated depth resolution of 0.16 millimetres and 2 degrees Celsius for temperature.

Figure 16: Bar02 Probe Sink Test

During this test the rate at which galvanised bolts rust and permeability of 100% infill 3D prints became apparent as noticeable colouration was observed around the bolt heads with some water leakage inside the probe.

In an effort to improve the water resistance a new probe was created with 3mm stainless steel bolts and adequate sanding around the O-ring seal to ensure both faces of the prints would mesh securely. A cross sectional view of this design can be seen in fig 17. Furthermore, this design allows the addition of ballast during the printing process to help the probe sink quickly and efficiently.

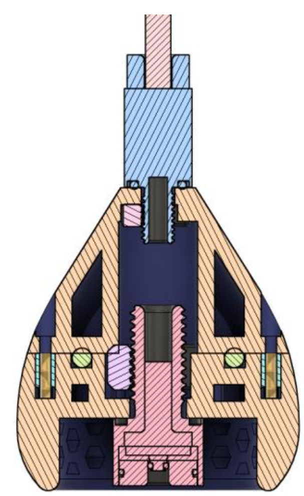

Figure 17: Probe Cross-section

7.4 Generative Design / Weight Optimisation

The optimization of weight in 3D printed components played a pivotal role in enhancing the overall performance and efficiency of the UAV system. Specifically, the camera & antenna and GPS & probe companion computer mounts underwent a significant weight reduction process, resulting in substantial improvements as shown by the reductions in figures 18 to 20.

Figure 18: Camera / Antenna Mount Version 1

Initially, the camera and antenna mount weighted 86 grams, which, when integrated into the UAV system reduced the flight endurance, balance and manoeuvrability. Recognizing the need to minimize weight while maintaining structural integrity, a thorough redesign and optimization process was initiated.

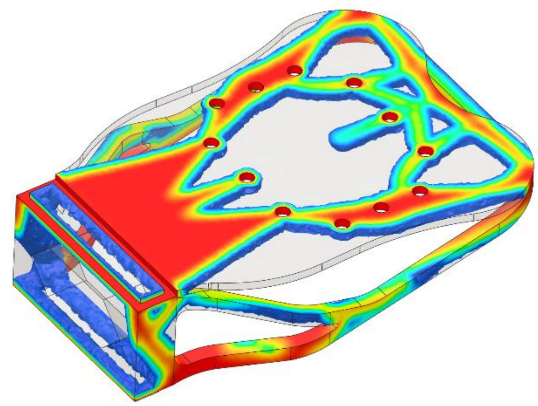

Figure 19: Camera / Antenna Mount Generative Design Study

Through the use of advanced design software and additive manufacturing techniques, the mount weight was reduced to 39 grams whilst maintaining a similar rigidity in the areas under the most stresses.

The benefits of this weight optimization were immediately evident in the UAV's performance as it exhibited an increased flight endurance, enabling longer mission durations.

This achievement underscores the potential for continued advancements on the project by further analysing other components and reducing weights where possible.

Figure 20: Camera / Antenna Mount Version 2

7.5 Simulations

In order to test the companion computer is working as intended, Ardupilot's "Software in The Loop" (SITL) simulation package was used to simulate a drone completing a waypoint mission over Barwon Water's, Highton Basin as shown in figure 21. The mission created involved the drone autonomously taking off, flying to five waypoints, collecting data, and returning to the home location. The data was then automatically uploaded to google sheets and processed by the dashboard discussed in section 7.6.

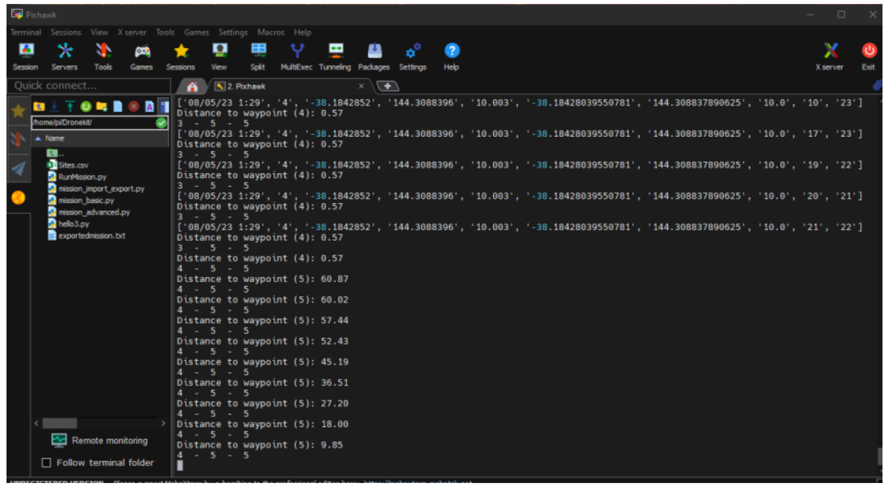

Figure 21: Simulation Companion Computer / Probe Output

A snippet of the probe's data output can be seen in figure 22, this shows how the UAV's altitude, position, distance to the next waypoint, temperatures and depths are all transmitted to the database using a simcard and 4G connection through the raspberry pi's expansion board.

Figure 22: Highton Basin UAV Simulation

Using the data collected the speed and accuracy of the probe system can be measured as well as an approximate idea of the UAVs battery consumption and performance.

7.6 Dashboard

The dashboard created provides users with an intuitive interface to navigate through the historical water temperature data from various missions. By selecting specific sites, dates, and depths, operators can seamlessly track temperature fluctuations throughout their assets. By offering a comprehensive view of a water body's thermal dynamics over time some statistical analysis can be used to estimate for water stratification and relevant water quality parameters.

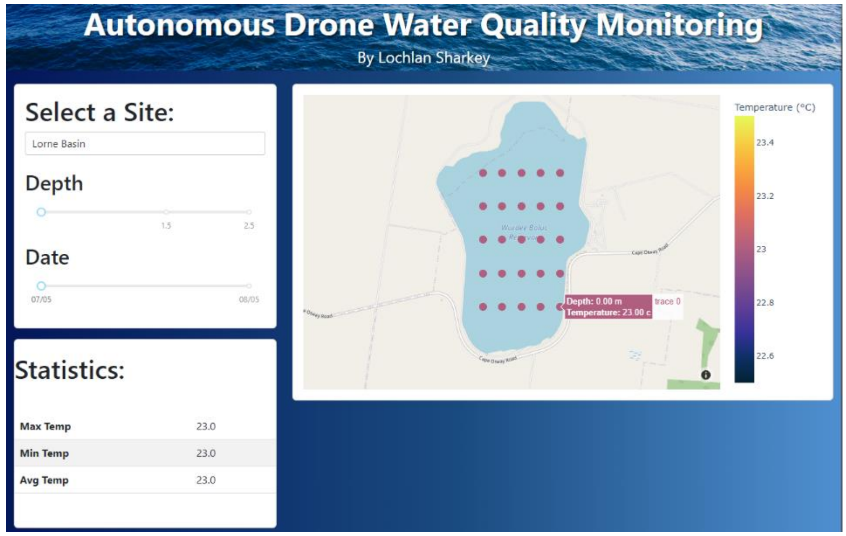

Figure 23: Data Dashboard

Currently an instance is hosted by python anywhere with the dashboard being automatically updated via a link to the UAVs google sheets page. Whenever an operator visits the site (http://lloocchh.pythonanywhere.com/) the data is refreshed in the background, ensuring the users are always looking at the latest data set. Currently, the visualisation places each waypoint on a map with a coloured dot based on the temperature as shown in figure 23.

Beside the map, two sliders are present to filter the data collected by date and depth collected Likewise, a searchable drop-down box is automatically updated to show data from any site listed within the attached google sheet.

Finally, the statistics box below shows the maximum, minimum, and average temperature of a given day and depth.

8 DISCUSSION

The execution of this project unfolded in a systematic manner, encompassing various phases aimed at achieving the set objectives. The project successfully achieved a key milestone, by demonstrating the UAV's capacity for autonomous hovering and reliable flight, as evident by the collected data and figure 24 showing the system hovering. Likewise, figures 25 and 26 demonstrate the systems folding ability for easy storage and its overall footprint before take-off.

Figure 24: UAV Flying Autonomously

The results of the project reflect the UAV's commendable performance in maintaining precision during hovering, even under varying environmental conditions. This achievement underscores the system's potential ability to reliably collect water quality data with an unprecedented level of accuracy when compared to traditional collection methods. Furthermore, the project highlights the probe's functionality during ground-based testing, laying the foundation for its integration into the UAV for real-world water quality monitoring.

Figure 26: UAV Folded For Storage

Despite the achievements completed in this project, the integration of the probe onto the UAV and its subsequent testing was not completed within the project timeline due to time, weather, and tuning challenges that were not immediately apparent when starting the project. As such, data presented in the results section pertains to the UAV's autonomous flight capabilities and separate probe functionality in a controlled environment. The full assessment of the system's water quality monitoring capabilities in a real-world environment is a critical next step, necessitating further testing and evaluation.

Figure 25: UAV Ready For Flight

8.1 Data Collected

To ensure the successful deployment of the water quality monitoring probe, it was imperative to conduct a thorough assessment of the drone's positional accuracy and stability during both hovering and data collection phases. This comprehensive evaluation involved extensive measurements, the results of which were subsequently compared with findings from relevant literature sources, as elaborated in the Results section.

Upon comparing and contrasting the performance of the UAV with that of systems relying solely on GPS, a notable improvement was observed. The integration of RTK technology proved to be a valuable investment, as the system exhibited an average accuracy of 16 centimetres compared to that of GPS at 2.5 meters. Nevertheless, it is worth noting that with the implementation of a longer antenna and extended ground station initialization time, the system has the potential to achieve even closer proximity to the theoretical target of two centimetre accuracy.

Furthermore, the assessment of vibrations and stability during UAV operations yielded valuable insights into the system's reliability and environmental resilience. Vibrations, in particular, can significantly impact data quality by inducing swinging motion in the tether, which may, in turn, lead to critical failures such as the loosening of bolts or components.

By meticulously measuring, comparing, and contrasting the vibrational characteristics experienced by the UAV during flight with data derived from existing literature sources, the project gained a deeper understanding of the system's mechanical and electronic stability and resilience. These measurements provide invaluable data that can be used for subsequent informed adjustments and refinements in the UAV's design.

8.2 Challenges Encountered

During the course of this project, certain challenges and limitations emerged that merit discussion. These challenges not only provided valuable insights into the development process but also shed light on the complexities associated with autonomous unmanned aerial vehicle systems for water quality monitoring.

8.2.1 Erratic Weather Conditions

Erratic weather patterns represent a significant challenge encountered during the project's execution. Given, the frequent gusty wind measured in Geelong during the latter half of the project it was difficult to find optimal time for test flights as the grass was often wet in the mornings posing a hazard to the electrical components in the event of a crash landing and windy in the afternoons. Fortunately, the wind often died down in the early evenings however, it is against CASA regulations to fly in the dark.

As such, this posed a major challenge when integrating new components into the system and recalibrating the sensors and PID control loops.

8.2.2 Folding UAV Frame

The utilization of a folding frame design for the UAV introduced a unique challenge related to excess points of failure and vibrations. While the ZD680 folding frame is advantageous for portability and ease of transport it is a disadvantage when attempting to reduce vibrations during flight. These vibrations, while generally imperceptible to the human eye from a safe operating distance, significantly affected the performance of both Ardupilot's and PX4's autotune features. As such, it became evident the system would have to be tuned either manually or through a digital simulation.

8.2.3 UAV Tuning

Tuning the UAV's flight characteristics and control systems presented another set of challenges during the project. As simulating the entire platform accurately was outside the scope of the project it became necessary to shift towards a manual PID (Proportional-Integral-Derivative) tuning approach.

This process involved adjusting a number of parameters such as the gain values for pitch, roll, and yaw control to optimize the UAV's responsiveness while maintaining its stability. However, this task proved intricate due to the dynamic nature of the project environment.

Variations in payload weight, wind conditions, and sensor performance necessitated constant recalibration and adjustment, adding complexity to the tuning process. Additionally, the need to integrate the water probing system introduced new considerations, as the drone's behaviour with the probe attached differed from its behaviour without it.

8.2.4 Probe Attachment And Testing

One of the primary challenges encountered in this project pertained to the testing of the probe deployment and retraction system. Despite the initial intent to conduct comprehensive testing of the probe's functionality, a series of unexpected crash landings significantly impacted the drone's stability. These incidents rendered it unsafe to attach a payload, such as the water quality monitoring probe, without necessitating extensive repairs and recalibrations.

These challenges underscore the critical importance of robust design and testing procedures in the development of UAV-based systems. The unexpected crash landings served as valuable lessons, highlighting the need for meticulous attention to drone stability, control algorithms, and error mitigation strategies. While these setbacks have temporarily delayed the total project assessment, they reinforced the notion that safety and reliability are paramount in the development of UAV systems.

8.3 Comparison To Commercial Options

In evaluating the performance and capabilities of the developed UAV, it is essential to consider how it fares in comparison to existing commercial options. This comparative analysis provides valuable insights into the system's strengths and areas for potential improvement. Commercially available UAV solutions have been designed and refined for various applications, including environmental monitoring and data collection. This comparison also aids in determining the system's suitability for widespread adoption by water authorities and environmental agencies seeking efficient and cost-effective water quality monitoring solutions.

In terms of positional accuracy, the Splashdrone 4 is rated at 1.1 meters according to its manual, whereas the project UAV has an average accuracy of 16.54cm. Likewise, the Aurelia X6 also has an RTK system with their marketing only mentioning the theoretical 2 cm landing accuracy.

		
Splashdrone 4	**Aurelia X6**	**Project UAV**
• $4,863 • 4k Camera • IP67 • One Sample • 0 – 1.5m sample • Not Autonomous	• $10,905 • No Camera • Not Waterproof • One Sample • Unknown Depth • Autonomous	• $7000 • 4k 30x Zoom Camera • Not Waterproof • Takes Probe Readings • 0-10 meters • Autonomous

Furthermore, the project solution consistently outperforms both the Splashdrone 4 and Aurelia X6 on the grounds of features, sample depths and overall value. Thus, proving the system would be a viable option assuming the probe integration can be tested successfully.

9 CONCLUSION

This project aimed to design and develop an autonomous drone for collecting temperature and depth data in reservoirs up to 10 meters deep. It successfully achieved four of five objectives, demonstrating the system's capability to autonomously gather data and seamlessly upload it for analysis in the dashboard.

When compared to traditional methods of water sampling, which are often labour-intensive, time-consuming, costly, and subject to human error, our autonomous UAV system offers a superior alternative. By harnessing the power of cutting-edge technology, this system not only enhances the reliability, accuracy, and safety of water quality data collection but also significantly improves efficiency and cost-effectiveness.

The ability of the UAV to autonomously gather data, navigate between pre-selected waypoints, and seamlessly upload information for analysis reduces the need for human intervention, making data collection swifter and more comprehensive. Additionally, the system's precision in flight path and orientation ensures that water quality parameters are measured consistently and accurately, providing valuable insights for decision-making processes.

Moreover, using a UAV based system mitigates the risks associated with traditional water sampling, such as personnel safety concerns and potential data contamination from the boat’s wake. Likewise, allowing access to areas that are often inaccessible by boats or foot, offers water authorities an unprecedented understanding of their assets and treatment processes.

In essence, the water quality monitoring system showcased in this project offers a transformative approach that not only meets but exceeds the capabilities of traditional methods. Its capacity for autonomous operation, precision, safety, and efficiency makes it a valuable tool for Barwon Water and the rest of the water industry.

10 RECOMMENDATIONS

While this project represents a step forward in UAV-based water quality monitoring, it also opens doors to future research and development avenues. The challenges encountered in probe testing underscore the need for continued work in enhancing the reliability and safety of water probing systems. Future research could focus on refining deployment and retraction mechanisms, as well as implementing robust error detection and correction algorithms to minimize the risk of crash landings.

Additionally, the autonomy of UAV systems remains an evolving field, and further research can delve into the development of advanced navigation algorithms that consider dynamic environmental factors and real-time adaptation. This could enable UAVs to respond to changing conditions more effectively, ultimately improving data collection efficiency.

Finally, the integration of AI and machine learning into UAV-based water quality monitoring holds immense promise. Future projects may explore the use of AI algorithms to analyse collected data in real time, facilitating rapid decision-making and predictive modelling for water resource management.

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