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Integrated Engineering Design Project 2 - Engineer 2PX3

Design Project Report

T06 - Water 16

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1.0 Table of Contents

2.0 Executive Summary

With the issue of climate change comes many different problems one of which is the algal blooms that harm the drinking water of many communities. As such the team was tasked with developing a source water monitoring system that would allow for early detection of changes within the selected water body for the protection of the human health. In the process of coming up with a final solution there were 3 iterations made, with the final version consisting of a pusher-based, glass-fibre-reinforced-polymer drone that flew in 3 separate circuits over the chosen water body of Moose Lake, Alberta. The drone was to be powered by a lithium polymer battery and contained a gimbal mounted camera system for the collection of data. This final design iteration was more advantageous than the previous iterations mainly due to the efficiency, the overall longevity, larger amount of data collection, shorter collection time and longer material and battery life meant that it was a much more effective solution compared to its predecessors. Moving forward the next steps taken should focus on the actual implementation of this source water monitoring system, and to do so, the permits required to fly the drone must first be obtained. Aside from just the regulatory permits and certifications, it is also important to gain the acceptance of the nearby locals and Indigenous tribes, such that there is also a socio-cultural acceptance regarding the usage of drones near their residence. By gaining the above clearance it would allow for easy integration of the source water monitoring system into actual use without any hinderance from either the government or residents due to any regulatory or socio-cultural concern.

3.0 Introduction

Over the course of this semester, our team attempted to address the problem at hand with a series of engineering design solutions. The primary aim of this project was to create a cost-effective and time efficient method for monitoring water-quality. Drone technology and machine learning algorithms were used to replace the expert dependent system currently in place. However, such a technological shift comes with many different concerns not solely revolving around performance and functionality, for which all design solutions generated were analyzed under the PERSEID framework. To make this process less abstract, Moose Lake in the town of Bonnyville, Alberta was chosen as the target location for carrying out design analyses. Moose Lake has seen a steady rise in algal blooms over the past few decades [1]. Additionally, water quality has deteriorated further due to the gradual increase in presence of salts and other harmful chemicals [1].

Alongside the physical condition of the lake, there were several social factors which motivated this decision, primarily regarding the relevant stakeholders.

3.1 Stakeholders

The foremost stakeholders in this design solution were the residents of the Town of Bonnyville. There has been a long-standing need for a secondary water source for Bonnyville, as the current primary source (Cold Lake, Alberta) is over 50 km away [1]. However, this need for a source of clean water must be balanced with the possible negative impacts that come with the use of drone technology, which will be covered further later in this report. Among the residents, the Indigenous communities are specific stakeholders whose perspectives cannot be overlooked. These communities are, namely, the Fort McKay First Nations and the Kehewin Cree Nation. The traditional land around Moose Lake is used by these communities for various cultural activities [2]. The Indigenous Peoples of Bonnyville have voiced many concerns regarding the industrial use of this land, as well as the overall degradation of the water quality [2]. The Kehewin Cree Nation, for example, is the last remaining Indigenous community in Alberta with a long-term boil-water advisory yet to be addressed by the provincial government [3].

3.2 Refined Problem Statement and Scope

Due to the need for a secondary source of clean water in Bonnyville, Alberta, exemplified by the long-standing boil-water advisory given to the Kehewin Cree Nation reservation nearby, there is a need for a source water quality monitoring system that can easily be implemented. This method must be effective while managing the environmental, socio-cultural, and regulatory impacts. The scope of this project was creating a realistic solution to the problem at hand, analysing as many PERSEID concerns as possible. For the sake of this project, Moose Lake was viewed as an isolated case, targeted directly without a too many considerations about mass implementations of this system.

3.3 Objectives, Constraints and Considerations

With the refined problem statement in mind, the primary objective was creating a design involving three main aspects: drone hardware to collect image data of water bodies, machine learning software to convert data into a reading of the water quality, and a flight plan for the drone to follow that is achievable given the hardware while creating outputs acceptable by the software. Firstly, the capabilities of the actual drone hardware being used were to be maximised, prioritizing specific attributes that are more applicable in this case, such as camera quality. Designs for any accommodating technology, such as for charging drones and transmitting data from the source back to a computer were needed. In addition, the machine learning algorithm was to be designed to optimize the accuracy of results given the data being used, while keeping false positives and negatives in consideration. Lastly, an optimal flight plan was needed, tying in the performance and efficiency of the design with external concerns, vaguely outlined in the following constraints.

The major constraints placed on the design in its preliminary stages were simply underdeveloped versions of the PERSEID requirements fleshed out in detail later. The amount of interaction between the drone and its environment were to be reduced, while also creating a minimum amount of disturbance in terms of sound. Additionally, it was necessary to ensure the drone complied with all relevant legal regulations. Outside of design constraints, the two main concerns this specific project raised were Indigenous considerations, and issues of privacy which tend to go with any form of mass data collection.

4.0 Conceptual Design

4.1 Design Alternatives

Our group had preliminary drone designs while we were experimenting with meeting basic requirements. The design features a fixed camera that would be attached to the front of the camera. The blades had guards around them to minimise the amount of drone crashes that could fatally damage the drone. The final drone design, the usage of stronger materials for the drone blades was used that would not break in drone crashing scenarios. With the battery type was a lithium-ion battery that would provide a long flight time. In the final drone design, a lithium-polymer battery was used instead given its design requiring no toxic materials compared to lithium-ion [4]. The preliminary drone also featured a tractor-configured drone design that can move along a waterbody at higher velocities making traversal faster. Although, a pusher configured drone has a greater lift off force and is more stable when idling mid-air. The charging stations were originally planned to be just metal pads that could be affixed to the ground. This idea was scrapped due to the high amount of maintenance required to have these relay stations stay operational year-round. Instead, the drone system utilizes a portable briefcase with the same wireless pad concept. The original fixed camera design was replaced by a gimbal mechanism due to how it can be attached to any part of the drone and still not be impacted by the vibrations from the drone motor or any external factors [5]. As well as gimbal mounts have been the industry standard for camera mounting meaning that if there be a need to upgrade or replace the camera in the future, the gimbal can readily support it. This allows for cost effective and fast repairability while also being future-proof as camera's are getting sharper with their detail but also smaller.

Material wise, the preliminary drone design was planned to be made from pitch-based carbon fibre due to its high tensile strength, low thermal expansion, and lower weight which is perfect for a drone. In the final drone design however, glass fibre reinforced polymer (GFRP) had the same qualities but can flex and bend further without breaking which is exactly what the drone would need to survive crashes [6]. As well as GFRP can be recyclable and has a lower impact on the environment when being manufactured compared to carbon fibres [6].

4.2 Decision Matrices

Name	Speed	Image quality	Flight stability	Battery Life	Ability to store/transfer images
Flying fortress	Low	Medium	High	Low	High
Hawkeye	High	High	Low	Medium	Low
Great Horned Owl	Medium	Low	Medium	High	Medium

Table X: Decision Matrix for Iterations of Drone

Model Name	Database Size	FP	FN
DNN	~10000 images	1%	3%
DNN	~ 1000 images	3%	7%
DNN	~ 100 images	29%	41%
RNN	~ 10000 images	5%	2%
RNN	~ 1000 images	10%	6%
RNN	~ 100 images	21%	20%
CNN	~10000 images	4%	1%

CNN	~1000 images	9%	12%
CNN	~100 images	39%	41%

Table X: Decision Matrix for Algorithms available for Machine Learning

Criterion	Weights	Design Choice 1	Design Choice 2	Design Choice 3
Flight Path Time	1	1	2	3
Accuracy of ML Algorithm/ Crash Survivability	3	2	1	3
Stability	2	1	3	2
Total Grade		9	11	16

Table X: Decision Matrix for Iterations of Solution

4.3 Design Evaluation

Using the above decision matrices specific design elements were able to be compared with each other to identify the ideal component for the source water monitoring system.

The first and second design matrix focused more on the mechanical and software aspects of the source water monitoring system respectively. As such there were very useful for identifying the corresponding elements of the mechanical and software aspects. For the decision matrix pertaining to iteration of the drone itself, the determining factors were researched, and it was found that the most important characteristic of a drone is their image quality to ensure that machine learning algorithm is intaking high quality data. For this reason, Great horned owl, although being the most average drone, was determined to not be suitable for the monitoring system. Hawkeye has very low flight stability, but because of its speed and image quality it is able to capture data very quickly, resulting in a shorter flight time. It's ability to store images was determined to be low but there were thoughts on implementing constant image transfer to bypass this issue. Finally, the flying fortress though being slow and as a result requiring a long time to capture data was discussed to not be a huge negative since it has a high capacity to store images. However, the longer flight time means a potential increase in socio-cultural concerns. To counter this issue, a potential solution that was discussed was to deploy multiple flying fortresses, ideally 2 or 3 to survey chunks of Moose Lake to speed up surveillance time.

With the decision matrix showcasing differences between the algorithms the best algorithm for when there is a large data set (~10000 images) was found to be the CNN algorithm. This is because it has the lowest false negatives, which is a more important metric than false positives, this was because it is more important to test the water quality when it is not required rather than not test the water quality when it is needed. The best algorithm for a medium sized data set is DNN. It has a higher false negatives percentage than RNN but the trade-off is worth when comparing the difference between the false positives. The best algorithm for a small sized data set is RNN by a long shot, with the lowest percentages of both false positives and false negatives. From these observations it can be seen better to switch to RNN algorithm when there is not a sufficiently large data set for the machine learning algorithm, otherwise the CNN algorithm is the best algorithm for analysis.

The third decision matrix compared the 3 iterations of the solution that were produced by the team and were based on the results gained from the first two decision matrices. Grading factors were chosen, being flight path time, accuracy of the machine learning algorithm/Crash survivability, and stability with a weight of 1, 3 and 2 being given for them respectively. With a grading scheme of 1 to 3 with 3 being the best of the 3 and 1 the worst, marks were assigned for each iteration, and ended up showing the most ideal source water monitoring system to be that of design choice 3.

5.0 Final Proposed Design

5.1 Description

A distinct characteristic of the final proposed design was its push configured propeller system. A push configuration where the propellers blades are situated on the bottom as opposed to the top in the initial choice of tractor style is advantageous since it allows for a greater amount of lift force and is perfect for low speed and hovering flights. Regarding, the camera system on the drone, a gimbal mounted camera system was chosen as the final design choice, specifically the DJI Ronin Camera. This design choice was made due to the large degree of freedom providing a larger visual area for the camera to capture, further, it also can maintain its stability. As a result of the above distinctions, it was clearly a better choice than the fixed camera design which was limited in its area of capture, and the gyroscopic camera system which was too unstable as well as consisting of a larger number of parts, of which there would be a higher chance of failure. Another highlight of gimbal system was the possibility for future modularity as cameras can be easily swapped with better camera technologies in the future. To ensure the safety of the drone during its flight by not crashing into any obstructions such as trees or birds [7], the latter of which are found often near moose lake, ultrasonic sensors were decided to be attached cover all sides of the drone to detect any possible collisions. To maintain proper cooling of the drone, vents were added to the top of the drone to help cool down the drone and battery since it will be active for a large amount of time due to flight path it must follow. Glass fibre reinforced polymer, GFRP, chosen as the material for the composition of the drone was selected so for its cheap price, non-conductive properties, and high general strength which included high tensile, flexural, and impact strength.

As for the drone frame itself, a bulky middle section was chosen to which 4 other propellors were fixed to. This design configuration allows for all sensors, motors, and large batteries to fit in a single place. Large propellor blades were chosen to allow for much more stable flights as well as a greater amount of pushing force that will allow the drone to reach farther in the air.

The charging and upload station of the source water monitoring system was solved through the implementation of a portable charging station in which the drone was designed to line itself up on top of the charging station and automatically lock itself onto the provided indents. Through the wireless charging the drone would not require any human interaction as well as decrease chances for port degradation that would otherwise occur using a traditional male to female connector. The design of the charging station is meant to be easily transported and setup in multiple areas, allowing for flexibility in the flight path of source water monitoring system.

5.2 Design Showcase

Figure 1: Front View of the Final Drone Design

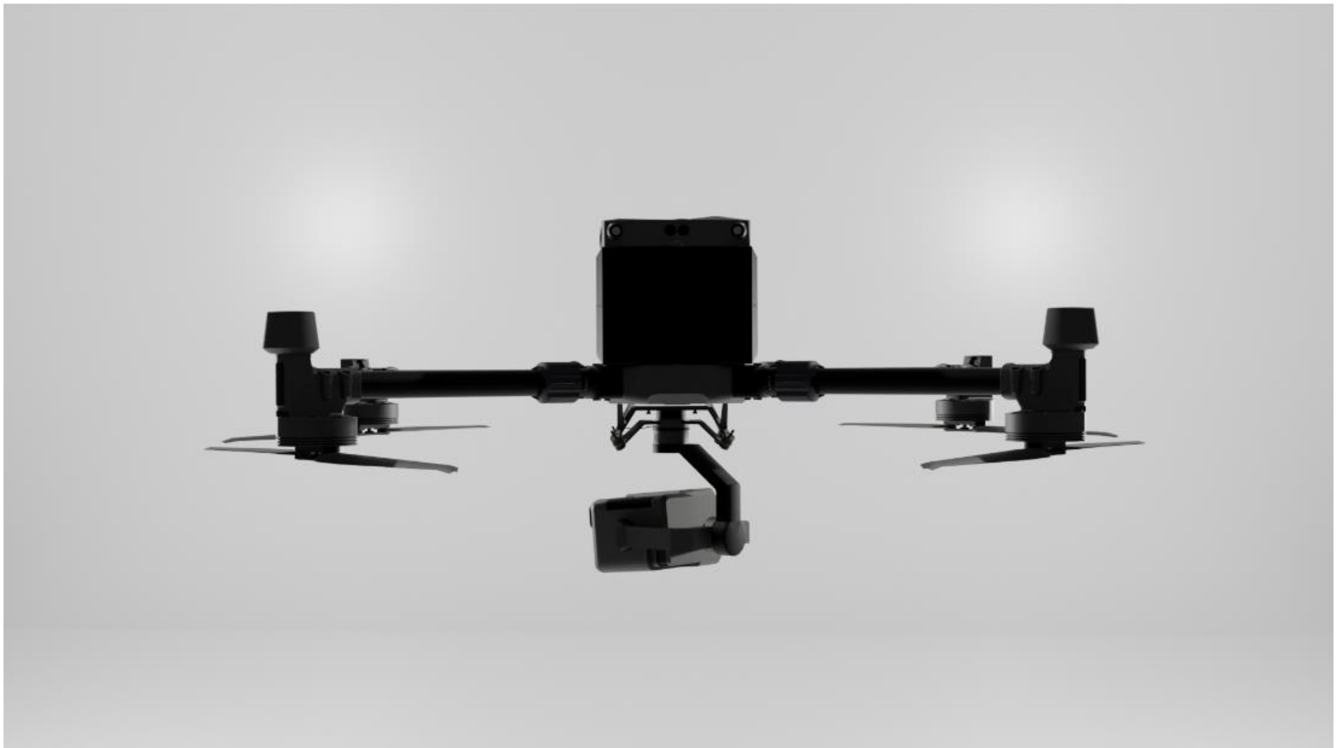

Figure 2: Back View of the Final Drone Design

Figure 3: Relay Station

5.3 Satisfaction of Objectives and Constraints

Constant analysis of the solution to ensure that the solution was satisfying objectives and constraints laid out at the beginning was accomplished through a process of segmentation of the system and organized such that it slowly fulfilled each specific objective and constraint.

Initial concerns were related to the performance layer of the PERSEID framework and as such, features such as camera quality, flight mechanism, stability and flight path time were researched. The chosen DJI Ronin Camera, met the requirements of high-quality footage capture whilst maintaining high stability, as a result the data captured through this camera system was of high quality. Using a push style design for the drone itself meant that a greater thrust or lift-off force was maximized, thus the flight mechanism of the drone was highly efficient. This push-style design also ensured a higher degree of stability when hovering. Regarding minimizing the flight path time, this was able to be accomplished through a detailed analysis on the map of Moose Lake, Alberta, where 3 circuits were identified as being the most efficient flight path so that the amount of data collected could be maximized whilst minimizing resources and time required to do so.

With regards to the regulatory, all appropriate certifications were researched and found to be obtained easily as they just required an online quiz [8], thus fulfilling that component of the objective and constraints. For the further specifications which Transport Canada Civil Aviation (TCCA), enforces such as maintaining a certain distance from bystanders, emergency operations, airports, heliports, other aircraft, this is already achieved through the chosen area, since Moose Lake does not have any of the above in the nearby vicinity as seen through researching the surrounding area on google maps, as such the source water monitoring system satisfies this constraint.

The environmental objectives and constraints were met in tandem while optimizing the final drone design for maximum performance. The glass fibre drone body allows the final design to be resistant to possible harsh weather conditions that could arise during a monitoring cycle such as harsh winds, and light rain and snow. This allows the drone to do surveillance in less-than-ideal conditions and allows it to withstand sudden changes in weather to mitigate any sort of drone failure. The use of ultrasonic sensors on the drone also allows for the drone to include its own automatic evasive maneuvers system. This means that the drone can navigate itself around protruding natural or man-made objects to reduce the possibility of drone crashes into the wildlife. In the event of an unlikely event such as a drone crash, the drone's use of eco-friendly materials and lithium polymer battery usage allows for the system to keep toxic waste pollution to its surrounding environment to a minimum.

Lastly throughout the design process socio-cultural constraints were the most impactful to our drone iterations and final design. From the many privacy and trespassing concerns, much work had to be done to ensure that all members in Moose Lake, Alberta felt safe and accommodated. To ensure that our monitoring process did not interfere with the daily locals who venture into Moose Lake regularly, we optimized our flight plan to a tri-circuit system that would allow it to minimize sensory contact from the public. To also mitigate drone crashes further in tandem with the ultrasonic sensors, modifying the propellers to a push configuration increased overall flight stability and drastically reduced noise output, so sensory pollution is no longer an issue with the system. To combat privacy concerns regarding the capturing of private property and residents, all data captured by the system will be screened for privacy infringements and appropriately censored, after which, all data will be uploaded in an open-source database for the use of any public organization. Furthermore, upholding relations with all stakeholders, including the Kehewin nations and Fort McKay First Nations who have allowed for the monitoring system to be used on their land, will ensure that there will be no disputes and issues about trespassing or privacy infringements in the foreseeable future.

6.0 Conclusion

6.1 Further Implementation

This report has covered the progress of this project, starting with the framing of the given problem, to the finalization of a detailed design solution. This design balances performance and efficiency with the remaining PERSEID layers, expected to produce results that is beyond acceptable, while minimizing the unintended consequences. Moving forward, the implementation of this design would start with consultation with the stakeholders. While their concerns were taken into consideration during the design process and are overviewed in this report, these inferences must be backed up by direct approval before any steps are taken. Once any necessary changes are made and public and government approval has been achieved, a pre-implementation phase would be needed to create required infrastructure, as well as collecting enough data for the machine learning algorithm to begin functioning at an acceptable accuracy.

6.2 Team Overview

Separating from the objective-oriented nature of this approach, we take a moment to reflect on the personal implications that the design process has had on our team and the individuals in it. Over the course of the past three to four months, we learned a great deal about the design process, especially pertaining to the PERSEID layers and their significance when tackling engineering problems. We gained insight as to how to implement these aspects of an engineering design through quantifying them as constraints. Additionally, the use of decision matrices to choose which attributes and requirements to prioritize was a skill that most of us will likely have to apply in many future scenarios. As for team dynamics, we found it easy to work with one another in an environment that bred individual growth and improvement, as well as overall productivity and innovation. For future team-based activities, we would like to carry over the same level of mutual respect and cooperative approach our team showed throughout the duration of this project.

7.0 References

[1] “Concerns regarding Moose Lake water quality - LakelandToday.ca.” https://www.lakelandtoday.ca/bonnyville-news/concerns-regarding-moose-lake-water-quality-1904392 (accessed Apr. 13, 2022).

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[3] “This Alberta First Nation community is the only one left in the province with an unaddressed long-term boil-water advisory | The Star.” https://www.thestar.com/amp/edmonton/2018/08/06/this-alberta-first-nation-community-is-the-only-one-left-in-the-province-with-an-unaddressed-long-term-boil-water-advisory.html (accessed Apr. 13, 2022).

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[7] “Moose Lake Provincial Park | Alberta Canada.” https://www.travelalberta.com/ca/listings/moose-lake-provincial-park-1852/ (accessed Apr. 13, 2022).

[8] “Take a drone pilot online exam: Small Basic Exam.” https://tc.canada.ca/en/aviation/drone-safety/drone-pilot-licensing/take-drone-pilot-online-exam-small-basic-exam (accessed Apr. 13, 2022).

8.0 Appendix

8.1 Extra Photos and Models of Source Water Monitoring System

Placeholder Text

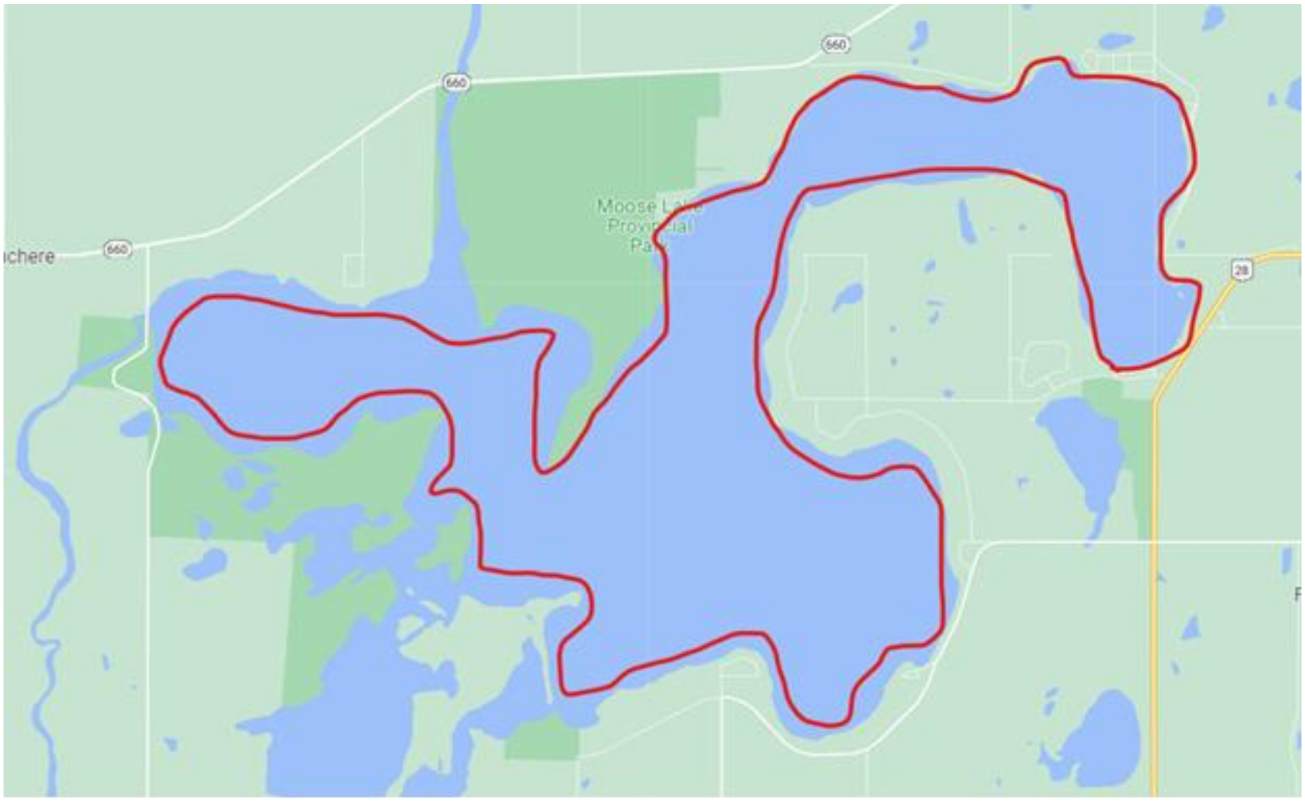

Figure 4: Preliminary flight path

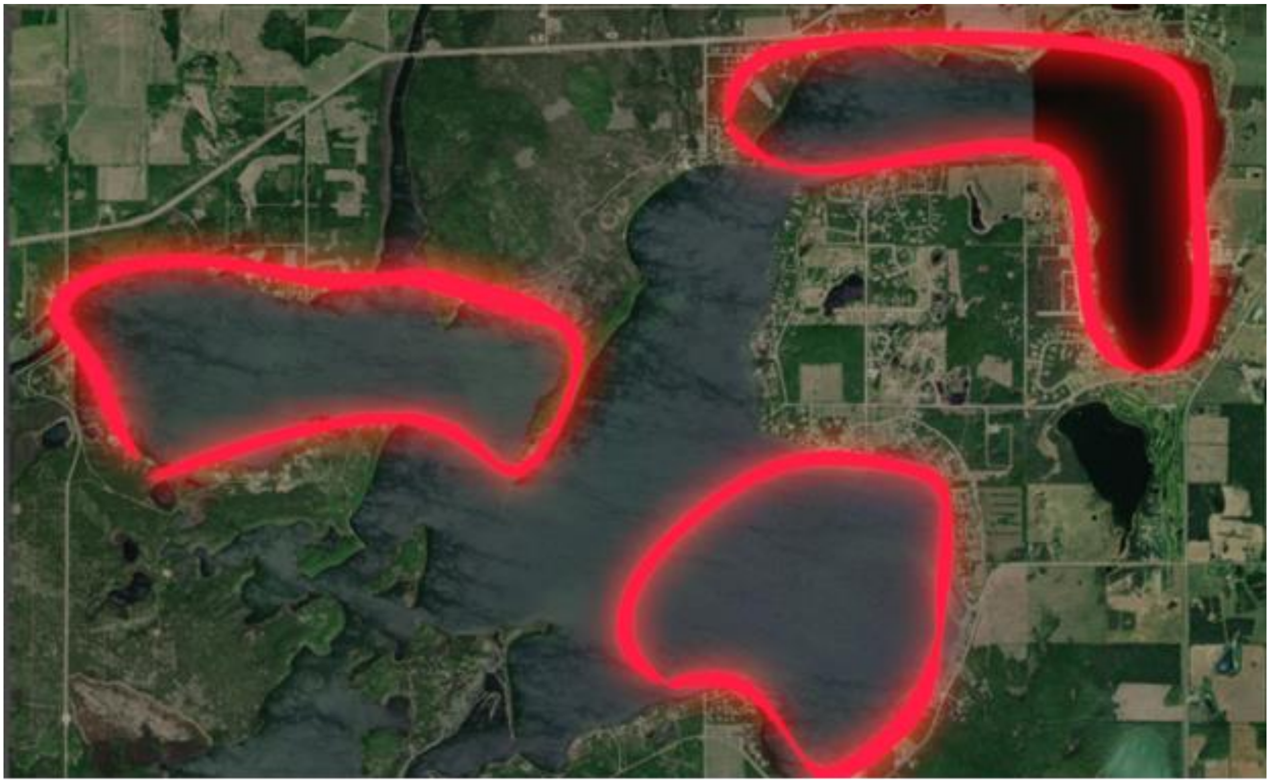

Figure 5: Revised flight path

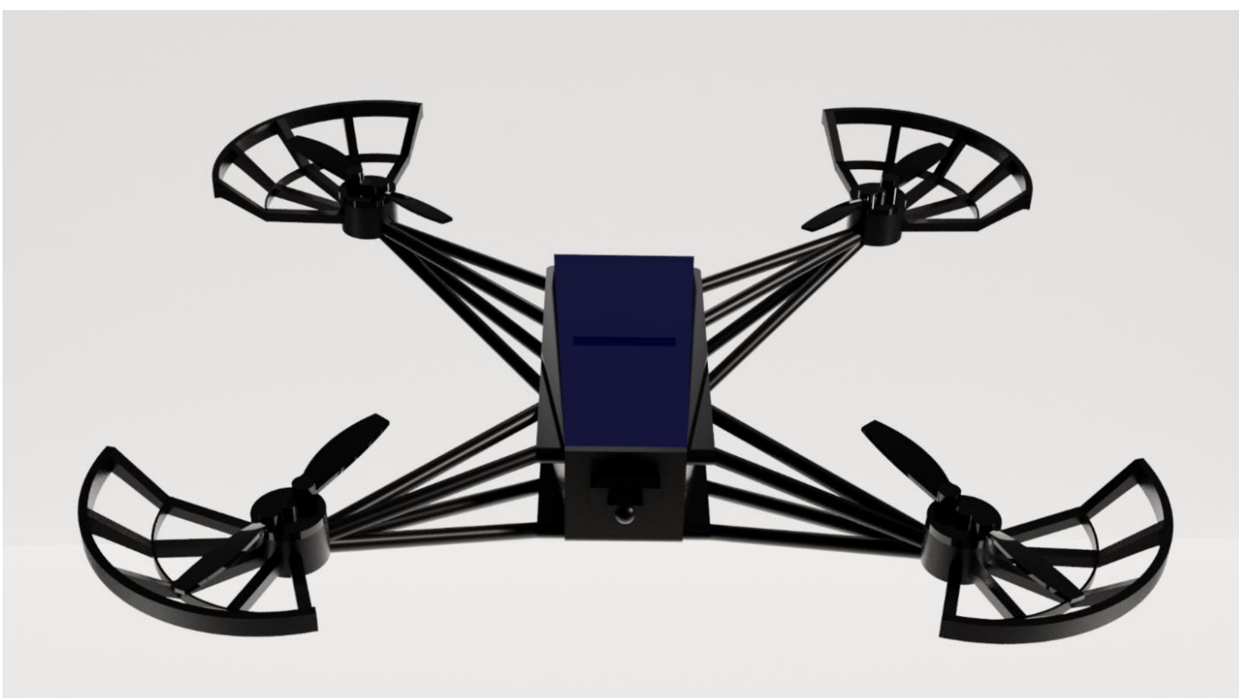

Figure 6: Front-Top View of the First Drone Design

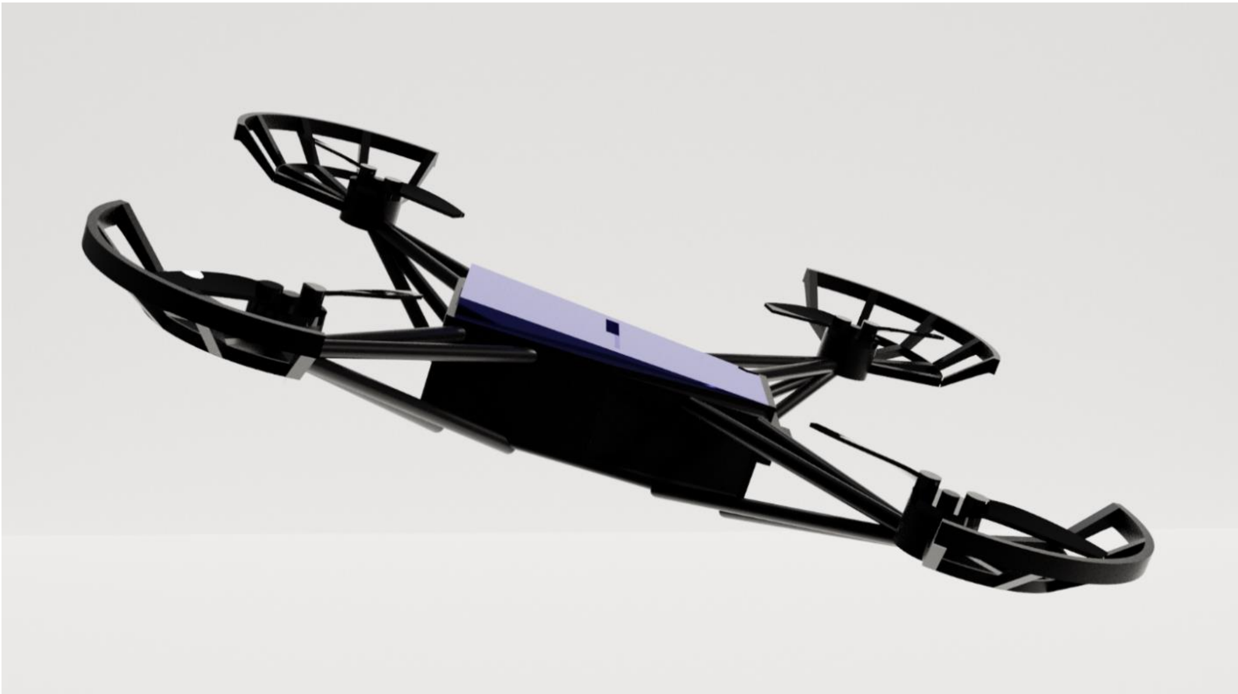

Figure 7: Side View of the First Drone Design

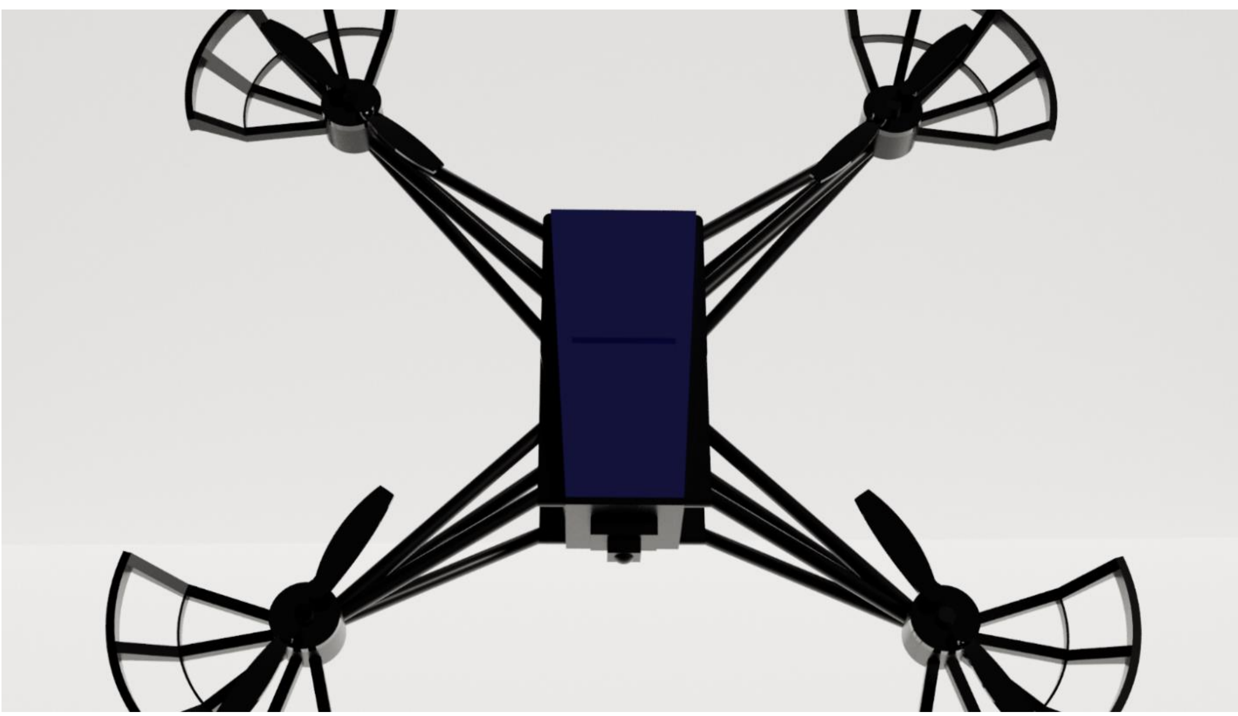

Figure 8: Top View of the First Drone Design

Figure 9: Front-Top View of the Charging Dock

Figure 10: Front-Bottom View of the Charging Dock

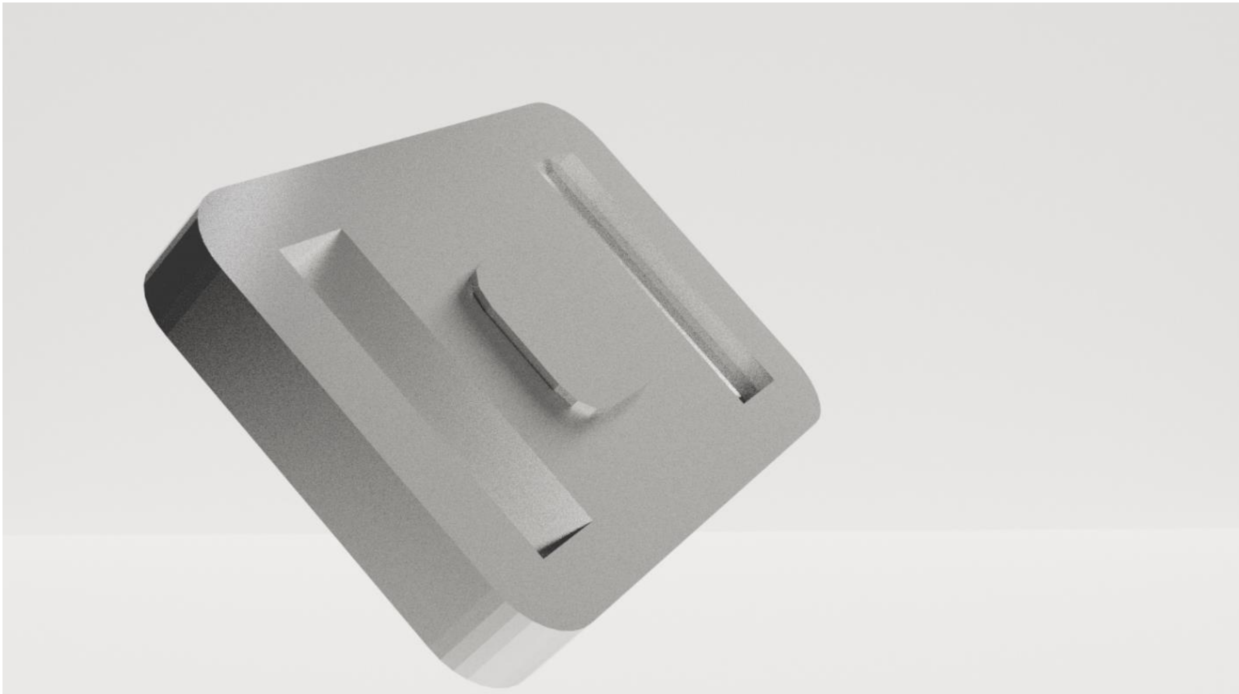

Figure 11: Side View of the Charging Dock

8.2 Design Studio Synchronous Worksheets