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Integrated Engineering Design Project 2 - Engineer 2PX3

Milestone Two: Idea Generation and The Design Funnel Framework

Source Water Monitoring

T06 - Water 16

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2.0 Executive Summary

The overarching goal of this project is developing a source water quality monitoring system, designed using image capturing drones and machine learning algorithms to detect the presence of bacteria and algal blooms in water bodies. Previously, Moose Lake in the town of Bonnyville, Alberta was chosen as the body of water around which research would be conducted, and so environmental and socio-cultural factors discussed in this report, while generally addressed in a broad sense, are at times targeted towards the selected location. A series of designs were conceptualized prior to their PERSEID analysis, of which three drone designs are detailed in this report. For these designs, environmental considerations such as noise pollution and wildlife interference will be considered. Additionally, issues of privacy and data sharing when it comes to machine learning will be weighed, alongside regulations both for this field and others, such as aviation laws. Lastly, the technical performance aspect will also be overviewed, with the aim of making important engineering decisions between different designs.

3.0 Introduction

Over the past few weeks, our team has worked towards developing a series of design solutions to the problem stated in the previous milestone: a need for cost-effective, practical water-quality monitoring with the use of drone technology. This process has bred innovative designs for both the drone hardware and the implementation of the technology, in the form of a flight plan and designs for a charge/upload station to facilitate the drone. For the purposes of this report, three drone designs were drafted and analysed. With prototypes in place, the goal of this milestone is using PERSEID metrics to measure the viability of every design in terms of each individual layer. An in-depth analysis of environmental impacts, socio-cultural factors, performance results and regulatory restrictions was conducted, yielding decision matrices for each design which will be summarized in this paper. The constraints ranged from general constraints regarding battery life, noise pollution, strength, image quality, etc., to more specific ones such as drone weight and flight altitude regulations. Based on the PERSEID analysis and design ideas covered in this paper, fundamental decisions were made to define the direction of the project for the coming weeks by narrowing down the realm of possibility for what each of the drone, flight plan and assistive technology can be.

4.0 Overview of Design Constraints

<table>
<tr><th></th><th>Performance</th><th>Environmental</th><th>Socio-Cultural</th><th>Policy & Regulatory</th></tr>
<tr><td rowspan="4">Broad Constraints</td><td>Imaging Quality</td><td>Weather Resistant</td><td>Privacy Concerns with capturing of Data</td><td>Aviation Laws</td></tr>
<tr><td>Durability</td><td>Battery Disposal</td><td>Trespassing via unauthorized entry into flight zones</td><td>Registration/Certification</td></tr>
<tr><td>Battery Life</td><td>Light-adaptable</td><td>Safety of nearby locals and population</td><td>Safety Regulations</td></tr>
<tr><td>Drone battery life vs Distance travelled</td><td>Strong but flexible</td><td>Noise Pollution</td><td>Data use regulations</td></tr>
<tr><td rowspan="2">Specific Constraints</td><td>Image Resolution of 12 MP</td><td>Doesn’t Oxidize and contribute to eco-waste</td><td>Asking permission from the relevant stakeholders prior to flying in their associated territory</td><td>Between 250 grams to 25 kg</td></tr>
<tr><td>Maximum Impact Resistance</td><td>Waterproof</td><td>Flight path must not interfere with locals and wildlife as much as possible, keep a relative distance</td><td>Adhering to Advanced operation requirements [1]:
- Register drone with Transport Canada
- Mark drone with registration number
- Pass small, advanced exam
- Pass a flight review
- Show pilot certificate</td></tr>
</table>

				- Fly within operational limits
	High image quality in high/low light	Medium high modulus value such that it is strong yet flexible	Under 60 dB [2]	Drone pilot license [3]
	Waterproofing	Light weight	Open-sourced (pre-censored, maintained) database for public members to view data freely	RPAS Safety Assurance declared by manufacturer to Transport Canada [3]
	Stabilized flight	Large Battery Life (regardless of temperature)	Censoring of data containing private information as requested by individuals.	Fly below 122 m in the air, 30 m away from bystanders, 5.6 km from airports, 1.9 km from heliports [3]
Design Idea 1	Fixed Camera Tractor Design	Carbon fiber, Lithium-ion battery	Small tractor blades (requires more force to stay airborne)	Refer to appendix X: Flight Map Covers the regulatory requirements.
Design Idea 2	Gyroscopic based Camera (too many parts/complicated) Push Design	Carbon fiber-reinforced composites/polymers, Lithium-ion battery	Thicker, push style spanwise propeller blades for noise reduction	Multiple Circuits Covering the entirety of moose lake
Design Idea 3	Gimbal mounted Camera	Glass composites, Lithium polymer battery	Thicker, push style spanwise propeller blades	Three Circuits, maintaining efficient coverage and fulfilling regulatory policies,

The table above includes the specific and general design constraints that are associated with each PERSEID Layer. For the performance layer, constraints were prioritized based on how they impacted the drone's ability to capture high quality footage at a high frame rate, which would require a stable flight and image capture in low light conditions. It was also deemed important that the drone have high impact resistance such that in the case of crashes parts could be salvaged or easily repaired. Regarding the environmental layer, being weather resistant, light, adaptable, strong flexible, and there being a battery disposal system were deemed to be important constraints for the design. Considerations regarding socio-cultural included privacy concerns, trespassing via unauthorized entry to flight zones, safety of nearby population, and noise pollution. For the policy and regulatory layer, it was discussed that the drone should adhere to the regulations set by the Canadian Aviation Regulations, which included being within a certain weight, registering the drone, and certain distance limitations for the drone in-flight.

5.0 Detailed Assessment of Design Options

Throughout these past eight weeks of design research, deliberation, and iteration, the drone algae monitoring, and surveillance system has progressed through three design variations.

5.1 First Design Iteration

For the initial design there was a simple drone system consisting of a go-pro camera and four propellers situated at the top. The camera was in a fixed position due to thinking that the drone could be easily pitched downwards (see figure 3). The upward facing propellers, also called a "tractor design", has guards around it to prevent any collisions that could permanently damage the drone during any crashes. The overall frame of the drone was structured for strength to survive crashes with the thought of utilizing steel rods to secure the blades to the drone (see figure 3). However, the tractor configured design itself was not the most ideal as it required a greater thrust force to remain airborne as opposed to the push configured design used in the later versions of the drone, this would lead to a greater drain of the battery, reducing the data collection of the drone. While the carbon fiber body met all the criteria specified, there were still alternatives that were stronger, lighter, and more eco-friendly which is why carbon fiber reinforced composites were used in the subsequent designs. Lithium-ion battery was used as the power supply to this iteration of the drone as it was the most widely used and commonplace, however its effect on the environment was not considered and this was addressed in the future designs where it was switched to the more environment safe lithium-polymer batteries. Regarding the flight map, it was prioritized that the entire lake be monitored, and data collected, as such there was one large circuit over Moose Lake, this would ensure a large sample size of the data as well as make sure the results were highly accurate. However, this was not feasible as it did not account for the battery life of the drone, as well as the fact that it was very close by to the local community which is not ideal.

5.2 Second Design Iteration

In week 5 we discovered that the size of our data set of algae images to be used in our machine learning algorithm is proportional to the accuracy of the analysis. With the previous fixed camera design, the drone would be unable to take clear, top-down images of the water bodies; it was an insufficient design for data collection. In the second design iteration, this design was changed to a gyroscopic based camera attached to the belly of the drone, capable of taking images with a full range of motion. This means that the drone was able to take a larger number of photos at a greater quality from before. The tractor configured propeller system was replaced with a push configuration, with spanwise propellers. This design change was made due to the greater liftoff force that push figured propellers offer, as well as the propellers using less energy. The biggest reason for the propeller change was to reduce the amount of noise caused by the drone, and a push configured propeller system is a quieter system than tractor configured propellers [2].

The second design had an advantage over the previous design with regards to the performance layer of the PERSEID method due to the better camera system and propeller design changes, however stability of the camera system was not considered when choosing the gyroscopic camera, meaning the data had a high chance of being blurry. The flight path assumed in the first design was changed from a single over-encompassing path to multiple smaller paths that still covered the entirety of the lake. All regulatory constraints were still maintained in these small new paths, and these small paths were more isolated from the local citizens, meaning there is less concern from a socio-cultural perspective. However, in terms of performance it was still apparent that the system would be uncapable of monitoring the entirety of Moose Lake, which is improved in the third design iteration by focusing on more crucial areas. Research on weather resistant materials caused the carbon-fiber drone body to be replaced by carbon-fiber reinforced composites: a lighter, stronger, and more flexible material which is more resistant to heat and other weather conditions. Unfortunately, recycling and manufacturing CFRP is not as eco-friendly as other alternative materials, and the continued usage of Lithium-ion batteries causes a biohazard concern in the unlikely event of a drone crash into the surrounding wildlife of Moose Lake [2].

5.3 Third Design Iteration

During week's 7 and 8 of the Design Studio, an in-depth analysis was conducted on the design to see if it was realistic. One of the major overhauls made was to the propellors as the drone was changed to a push configured style. A push configuration allows for a greater amount of lift force and is perfect for low speed/hovering flights. The gyro was decided to be replaced by a gimbal mounted camera system due to the instability of the gyro. Utilizing gimbals allows for future modularity as camera's can be easily swapped with better camera technologies in the future. As well as after researching the nearby areas of Moose Lake, there were a lot of species of birds that could cause random crashes. To mitigate any random issues, ultrasonic sensors would be used to cover all sides of the drone to detect any possible collisions (see figure 7). In terms of heat management, there are added vents to the top of the drone to help cool down the drone and battery due to the large amount of time that the drone must remain active for (see figure 8). As for the drone frame, the team decided on having a bulky middle section that is then fixed to 4 other propellors (see figure 6). This design configuration allows for all sensors, motors, and large batteries to fit in a single place. The large propellor blades 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. In terms of flight planning, both piloted and AI automated flights were made possible. This is mainly due to how Moose Lake has both long area's that the drone can cover by itself but also tightly knit islands that may have to require a pilot to oversee its flight path. This is due to the inability to recover any crashed drones that are too far from the mainland (see figure 2). The other problem that was tackled was designing the charging/upload station. The drone is designed to line itself up on top of the charging station and automatically lock itself onto the provided indents (see figure 9). Wirelessly charging the drone would allow for no human interaction while also decreasing the chances of port degradation when using a traditional male to female connector. The design of the charging station is meant to be easily transported and setup in multiple areas.

6.0 Conclusion

Through this report, our team summarized the progress made over the past 8 weeks in terms of engineering designs. In summarizing this process, the scope was narrowed down to only include three specific design ideas, each of which has been detailed meticulously with regards to its strengths, weaknesses, and constraints. These constraints were divided based on the PERSEID layers, namely technical performance, socio-cultural impacts, environmental considerations, and regulations. Under each category, a series of general and specific constraints were defined to aid with the decision-making process. By measuring each design against these constraints, it was clear that certain prototypes fulfilled the set requirements more so than others. To highlight these differences and provide some insight into the process, a summary table was provided, in addition to a more in-depth description of its contents. Furthermore, each design was rendered as a 3D model for improved tangibility and practical consideration. Looking to the future, it is important that with basic prototypes decided for the drone design, charging station and flight plan, our team continues to seek improvement and innovation wherever possible. With a thorough analysis of PERSEID considerations completed, the teams focus will lie towards improving the functionality and efficiency of the technology and software in future weeks.

7.0 References

[1] "Find your category of drone operation." https://tc.canada.ca/en/aviation/drone-safety/learn-rules-you-fly-your-drone/find-your-category-drone-operation#advanced (accessed Mar. 12, 2022).

[2] "DRONE NOISE LEVELS - Airborne Drones." https://www.airbornedrones.co/drone-noise-levels/ (accessed Mar. 12, 2022).

[3] "Drone Laws in Canada [Updated March 10, 2022]." https://drone-laws.com/drone-laws-in-Canada/#Notes_For_Basic_Drone_flying_for_fun_in_Canada (accessed Mar. 12, 2022).

[4] D. Borjan, Ž. Knez, and M. Knez, "Recycling of Carbon Fiber-Reinforced Composites—Difficulties and Future Perspectives," *Materials*, vol. 14, no. 15, Aug. 2021, doi: 10.3390/MA14154191.

8.0 Appendix

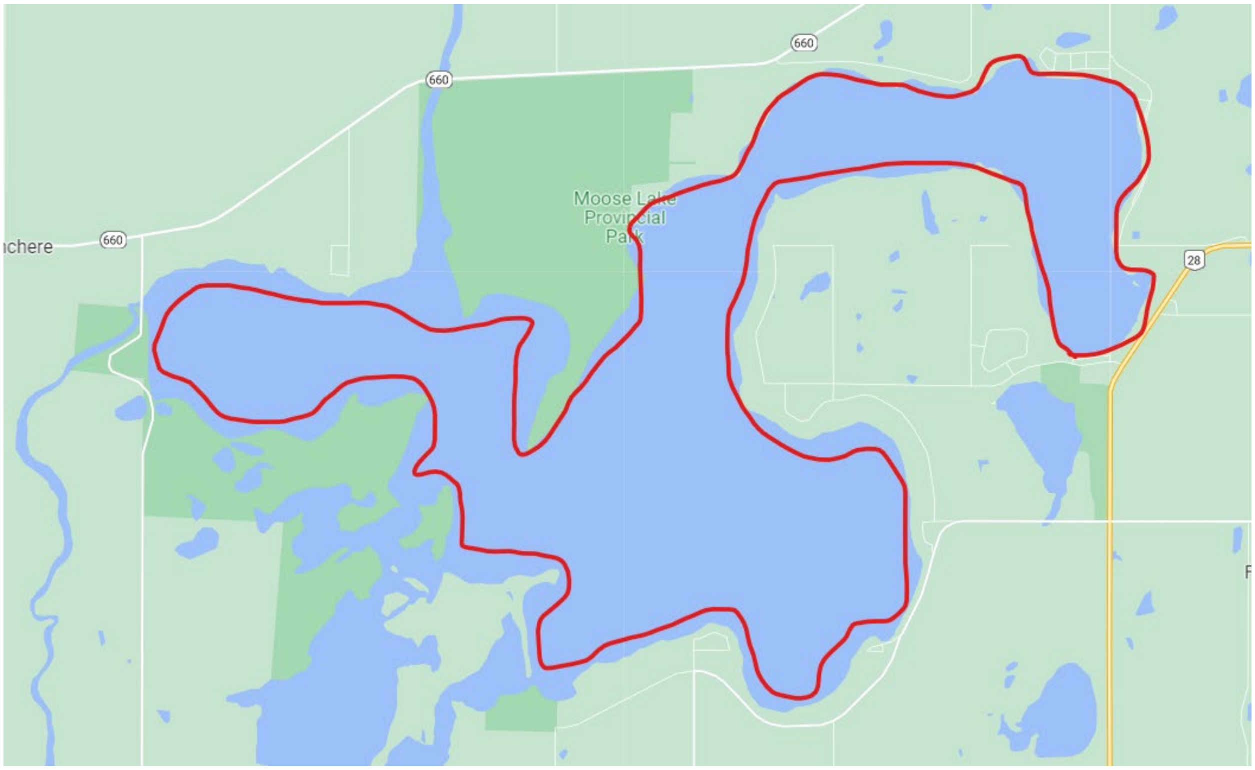

Figure 1: Preliminary flight path

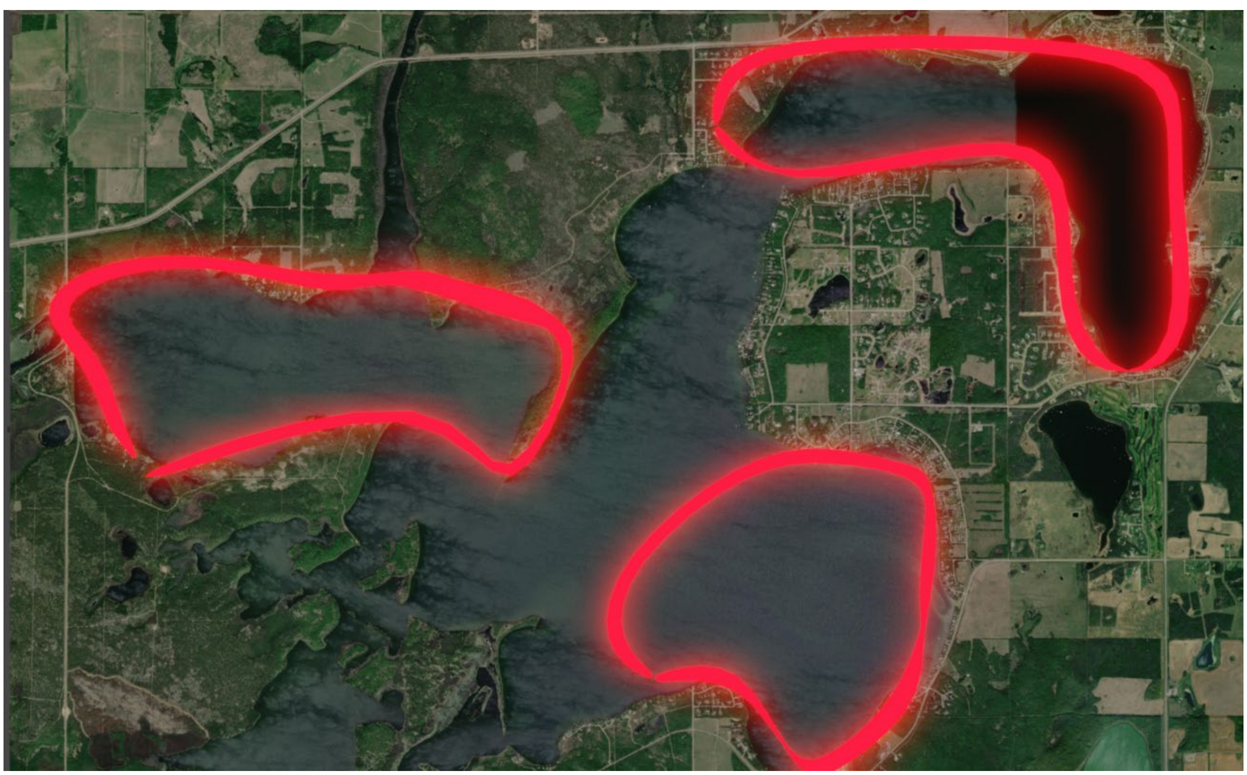

Figure 2: Revised flight path

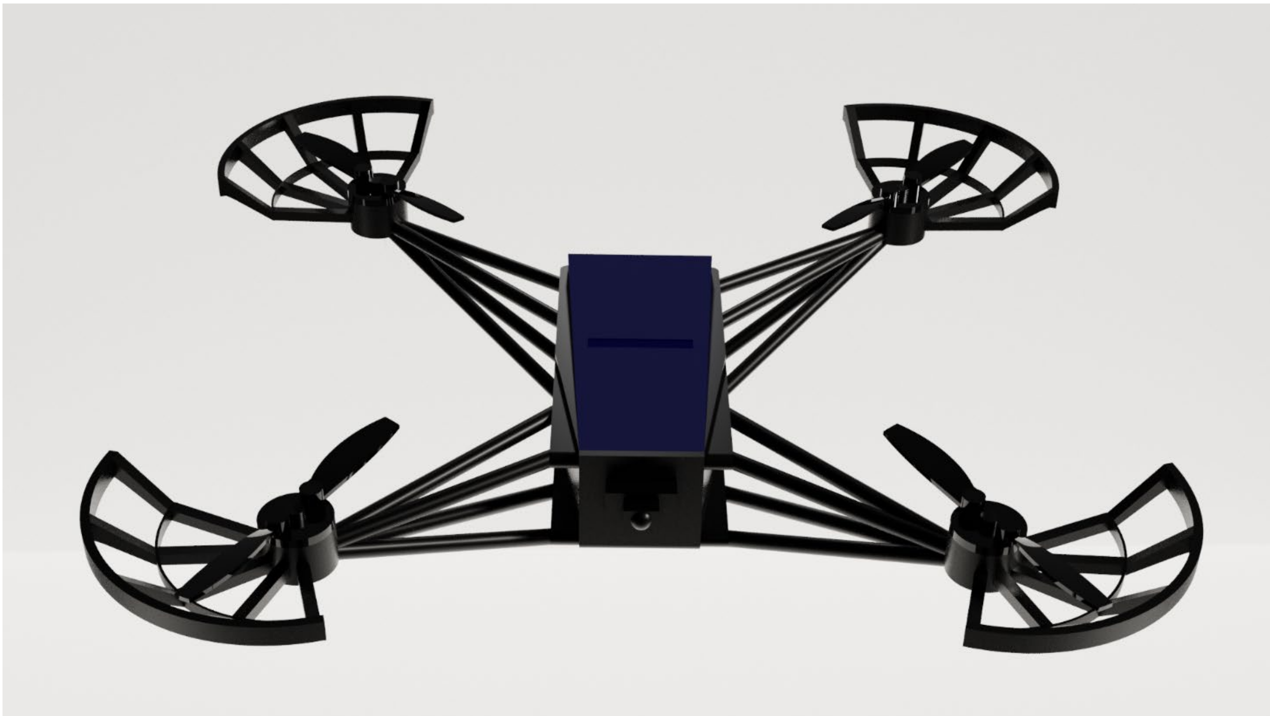

Figure 3: Front-Top View of the First Drone Design

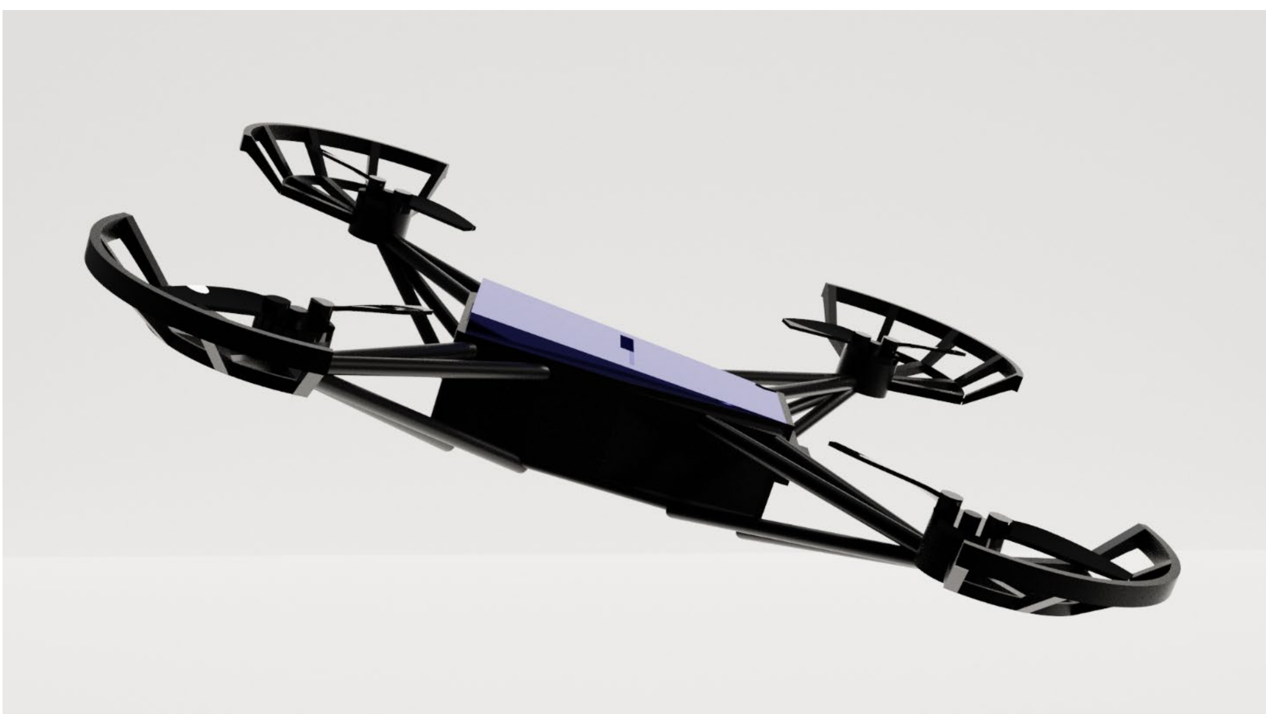

Figure 4: Side View of the First Drone Design

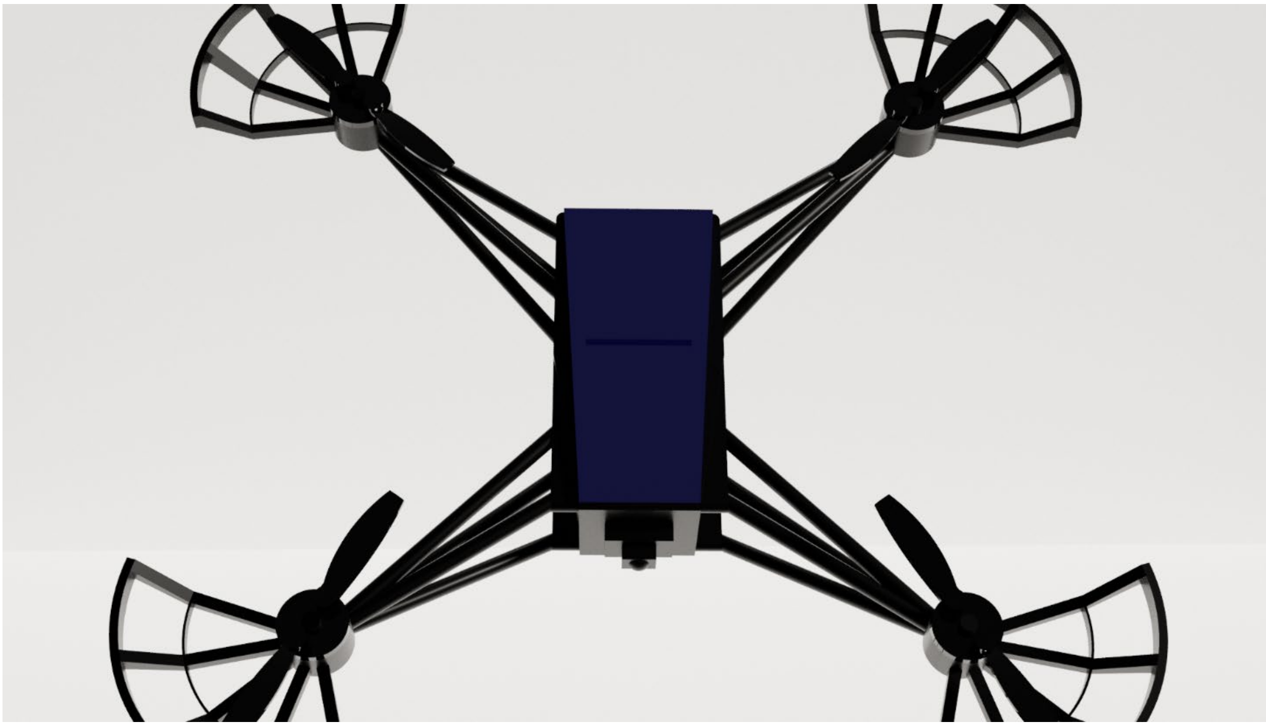

Figure 5: Top View of the First Drone Design

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

Figure 7: Side View of the Third Drone Design

Figure 8: Top View of the Third Drone Design

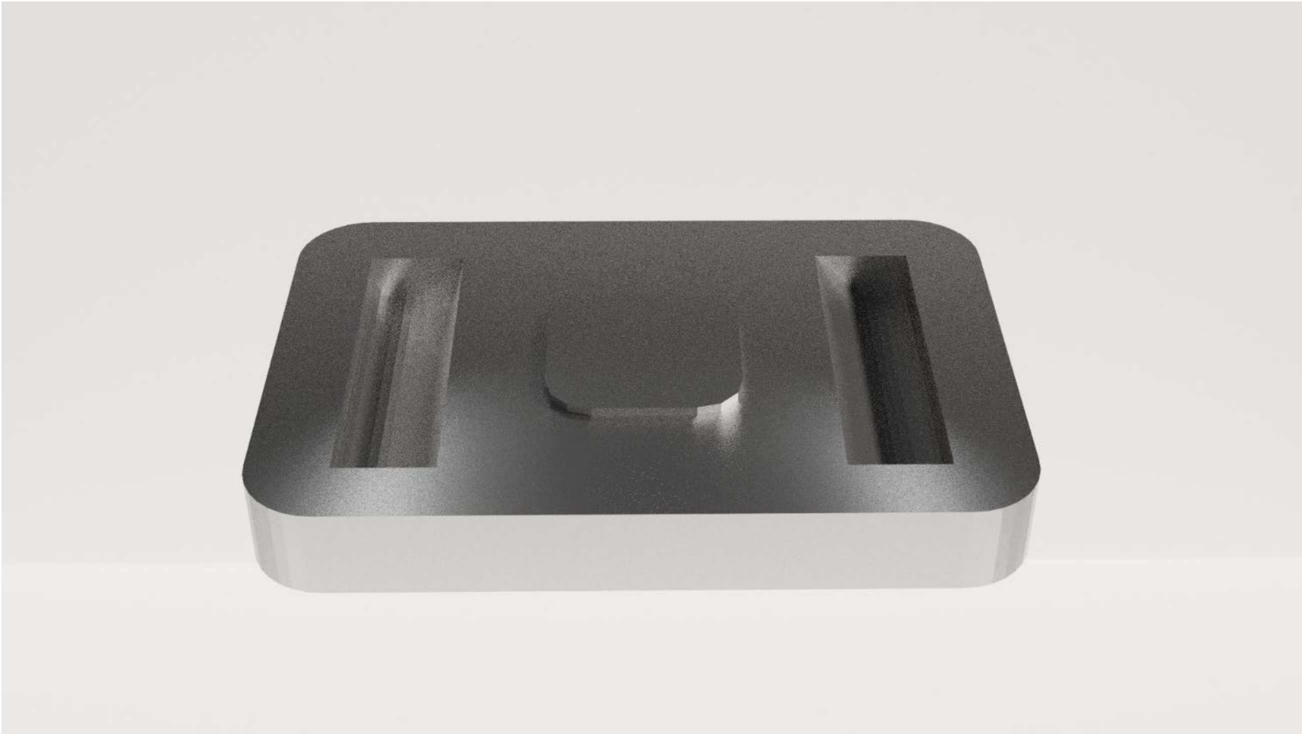

Figure 9: Front-Top View of the Charging Dock

Figure 10: Front-Bottom View of the Charging Dock

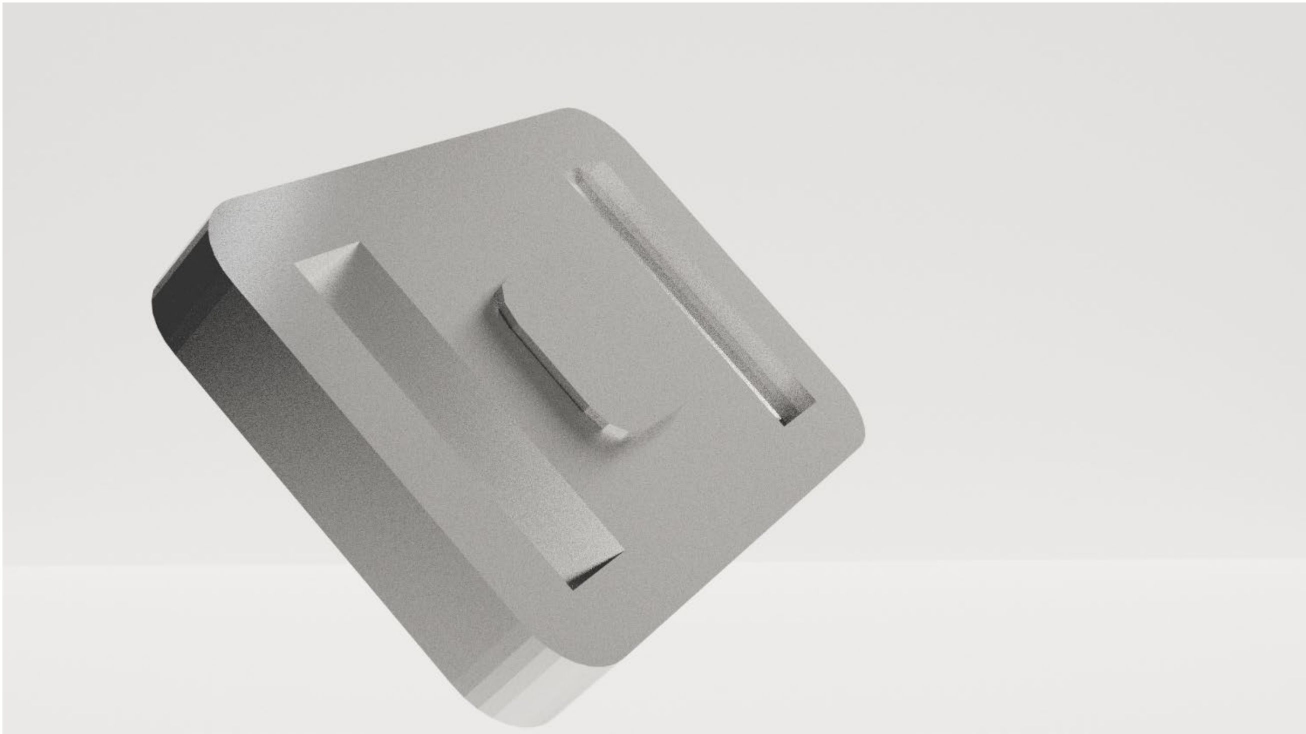

Figure 11: Side View of the Charging Dock