ENGINEERING

McMaster University

Source Water Monitoring

ENGINEER 2PX3 – Integrated Engineering Design Project 2

Tutorial 16

Team Water-48

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Executive Summary

Climate change brings some issues to the drinking water sources, and toxic algae are one of them, water treatment plant needs to be warned ahead to close the intake and adjust the treatment process. We develop a system the drone is equipped to take high-resolution pictures, the machine-learning algorithm analyzes a series of pictures to detect the presence of the algae. For the final design, we paint the drone in a bright color, we apply a blinking light, silent propellers, brushless motors, mesh cage, and noise-reducing shrouds around the propellers on the drone. We insert a SIM card for image uploading to a cloud service. The drone would fly at a height of 100-110 meters at a low speed to capture high-resolution images. It flies along the shores of the Cootes Paradise. We also place a contact-less charging pad near its flight path. As for the algorithm, 100 iterations are the best option for analysis. This design minimizes the impact of the noise of the drone, and there are features added to avoid bird collision hence minimizing the environmental impact as well. Unlike other designs with SD cards, the number of pictures is not limited by storage space with the help of a SIM card. Looking forward, we could work on accessing images stored in the cloud and implement that in the machine-learning code. We would also need a technician to do the maintenance of the drone and keep watch over the drone activities. Stakeholder meetings are also needed to introduce the systems and update them on any significant changes we make. This is important as it updates the stakeholders at every milestone that our team achieves while also considering the concerns that they might have. Furthermore, it will allow us to gain commitment on usability of our model as well.

Introduction

Climate change is significantly impacting aquatic ecosystems, resulting in progressive warming, acidification, and deoxygenation. Harmful algal blooms, caused by warming water temperatures, affect public health, recreation, tourism, fishery, aquaculture, ecosystems. [1] Harmful algal blooms emit toxins; particularly cyanobacteria which can emit cyanotoxins that may cause gastrointestinal, neural, hepatic, or dermal toxicity. Algae can disrupt the water treatment process in many ways. [1] Thus, drinking water treatment plants must informed in a timely manner to close their intakes or modify treatment processes to protect human and health. Our team intends to develop a source water monitoring system using drones equipped with cameras to collect high resolution images that can be analysed for early detection of algal blooms in Lake Ontario. Through early detection, technicians can be deployed to collect a sample to determine the presence of harmful cyanotoxins prior to disruption.

During the engineering design process, our team used the PERSEID method to help sort out the many different factors that influence our complex project. These factors include performance, environmental, regulatory, and socio-cultural constraints. This method not only allows us to make design suggestions for the elements of the system that intersect with these considerations, but also ensures we account for the stakeholders of our project. As shown in the figure below, as we move down the funnel the stakeholders' type changes from primary to secondary, which allows us to tailor our design to the needs of the most important stakeholders for each PERSEID method constraint.

Our engineering design process involved determining the technical performance metric for our design then identifying any socio-cultural, environmental, policy, legislation, and regulation constraints. Following this, we identified the specific design decisions will impact these consequences and reflected on design decisions we have already considered and made alterations accordingly if required. We used iterative design for prototyping, analyzing, and refining our designs to develop several viable options for the project that are in line with the PERSEID method.

Stakeholder Analysis

Water Treatment Plant

Late algae detection can clog filters and reduce water production and increases the formation of disinfection by-products in water treatment plants. [2] Thus, the accuracy of our system would allow them to identify algal bloom growth early on, which gives them time to determine how best to tackle the contamination. This ensures they don't waste resources treating water that does not need to be treated and they don't neglect treatment of water when algal blooms not previously detected are revealed to them.

Environmentalists and Local Wildlife

Drone flight interferes with the surrounding wildlife, since some species have more sensitivity to noises and vibrations by drones, which can be heard at levels between 70 and 80 decibels. [3] Additionally, drone crashes, collisions, and material waste cause significant damage to fragile plants or animal habitats. In light of this, we will alter flight path and flight height, use biodegradable materials, and add features to the drones to minimize these impacts.

People living and working in the areas to which the lake supplies water

People whose water is sourced from the lakes depend on it being safe for domestic use. Intake of algae water that has cyanotoxins can cause gastrointestinal, neural, hepatic, or dermal toxicity, which can result in stomach pain, vomiting, headaches, irritation, and diarrhea. [1] Thus, it is of utmost importance to ensure the accuracy and reliability of our system as the health and living conditions of the population is affected directly.

Tourism Industry/Governments

Scenic inland waters can provide significant tourism services. Algal blooms interrupt the tourism industry in the region and put many jobs in the sector at risk. Tourism losses can also disrupt the economy as tourists provide important demand for rentals and other expenditures such as restaurants and shops. Thus, the accuracy and reliability of our system is important to prevent such losses.

Fishing Industry

Algal blooms impact fisheries resources of the fishing industry since algal blooms produce toxins that are detrimental to aquatic species. [4] Also, they can negatively impact aquatic life by blocking out sunlight and clogging fish gills. [4] The reduction in commercial fish harvest leads to the economic losses and food insecurity. [4] Again, our system must be accurate and reliable to avoid such losses.

Drone Manufacturers

A successful system may result in a niche in the drone market, causing manufacturers to create drones that are suited to applications such as our project. Therefore, optimal performance of our system is especially important. Our system must be function efficiently with technical specifications that allow it to operate for extended periods of time, while ensuring risks of drone crashes and loss are minimized.

Media Corporations

The novelty of this source water monitoring project will be of particular interest to media groups looking for events to report on. Specifically, the performance, socio-cultural and environmental implications, as well as whether the system will be violating any regulations or policies in place regarding privacy, aviation, and environmental conservation. Thus, it will be important that our source water monitoring system meets PERSEID criteria.

Refined Problem Statement

Harmful algal blooms that can have severe impacts on human health, aquatic ecosystems, and the economy. To prevent such consequences, our team will design a system using drones, image analysis, and machine learning to monitor and detect algal blooms in early stages in source waters in the Cootes Paradise region of Lake Ontario. Our system will aim to mitigate negative socio-cultural, environmental, and regulatory impacts and concerns, while maintaining high technical performance to ensure early detection of changes in source water quality since its critical.

Objectives and Constraints of Design

PERSEID Layer	**Specific Constraints**	**Objectives**	**Design Features to help meet constraint**
Performance	Camera must take sharp images of entire lake area	To ensure high quality pictures for increased accuracy/decreased inaccuracy in detection of algae by machine learning algorithm	Drone model: DJI Phantom Pro, program drone to stop and hover intermittently during flight to capture pictures, gimble to maintain stability during turbulence [5] External storage device (e.g., SIM or SD card) to store images for later retrieval
	Must take at least 100 images per circuit of the lake	To sufficiently train machine learning algorithm for more accurate and reliable results in testing (actually implementing entire system)	
	Algorithm must have a minimum of 5% false negative results and minimum 40% false positive results (out of all results produced)	Minimize instances of non-detection when algae is in fact present more so than detection when no algae is present	

	Battery must be rechargeable Battery must last for at least one full circuit of lake before needing to be recharged Charging station must be as central and as accessible (by drone) as possible Drone must not be flown in inclement/poor weather Drone must be able to withstand the elements in moderation (wind, rain, heat, dust)	To reduce e-waste and increase autonomy of system To increase efficiency of system To minimize distance that drone must travel to reach charging station from any point along its path Inclement/poor weather includes snowstorms, heavy rain, wind at speeds greater than 29-38 km/h Drone should not be damaged beyond use mechanically or electrically by brief/mild exposure to water or moisture, temperature fluctuations and/or dust	Fly drone at lower speeds to reduce power consumption Flat wireless charging pad (possibly elevated off the ground by stilts/beams) Smaller, heavier drone (to better resist strong winds), wet suit
Environmental	Drone must not fly through environmentally sensitive areas no faster than 20 m/s on a given traversal of the path Drone must operate at a noise level no higher than 60 dB [6] Drone must not interfere with birds' flight Drone must not cause severe collateral damage if it crashes during flight, and must not shed components where it crashes	Environmentally sensitive areas include (but are not limited to) breeding grounds for endangered species, conservation parks, wildlife sanctuaries Noise level comparable to that of moderate rainfall to minimize disturbance to natural environment Either fly lower/higher than birds in the area or repel birds Severe collateral damage includes (but is not limited to) fracturing eggs, injuring an animal or person, destroying	Drone with variable speed Lightweight propellers & drone, lower operation speed Brightly painted drone/brightly coloured wet-suit, blinking lights (LEDs) on drone Compliant mesh cage around drone to absorb and disperse impact of collision, while protecting drone from severe

		plants, breaking glass (such as a windscreen or window)	mechanical damage which could lead to shed parts
Regulatory	Must adhere to national/international/provincial aviation laws [7] Must not break any laws in place to protect people's privacy[8]	Drone can fly no higher than 122 m and with a minimum radius of 5.6 from airports and 1.9 km from heliports [9] Drone must be visible at all times during flight Denizens of communities around the monitored lake region must be aware of the presence and purpose of the drone	Program drone to fly no higher than maximum allowable height Reduce range of camera, plan flight path such that minimal extraneous data is collected (have drone fly more within the boundary of the lake so there are fewer land images captured) Release results of image analysis (presence or absence of algae in lake) to citizens
Socio-cultural	Must not violate any ***universal human rights*** Drone must operate below 80 dB when flying over residential, commercial & municipal areas Majority (> 50%) of community members must be amenable to having monitoring system in operation	UDHR* (Article 12 – right to privacy)[8] Distribute survey to communities to gauge citizens' acceptance/resentment towards system	Fly drone at off-peak times for majority of human activities

Table 1: Objectives and Constraints according to PERSEID

Scope of the Report

This report outlines the phenomenon of algal blooms, and why they are an increasing problem with climate change and increasing temperatures. It will discuss the different stakeholders that are impacted by this problem, our solution to this problem which has been guided by the PERSEID method, and the design iterations that we went through to get a final design. More specifically, this report will go into detail on the design tools that our team used to evaluate the three main design alternatives and the process of developing a final solution. Our codebase and simulation results will be provided for a technical evaluation of our designs as well.

Conceptual Design

Design One

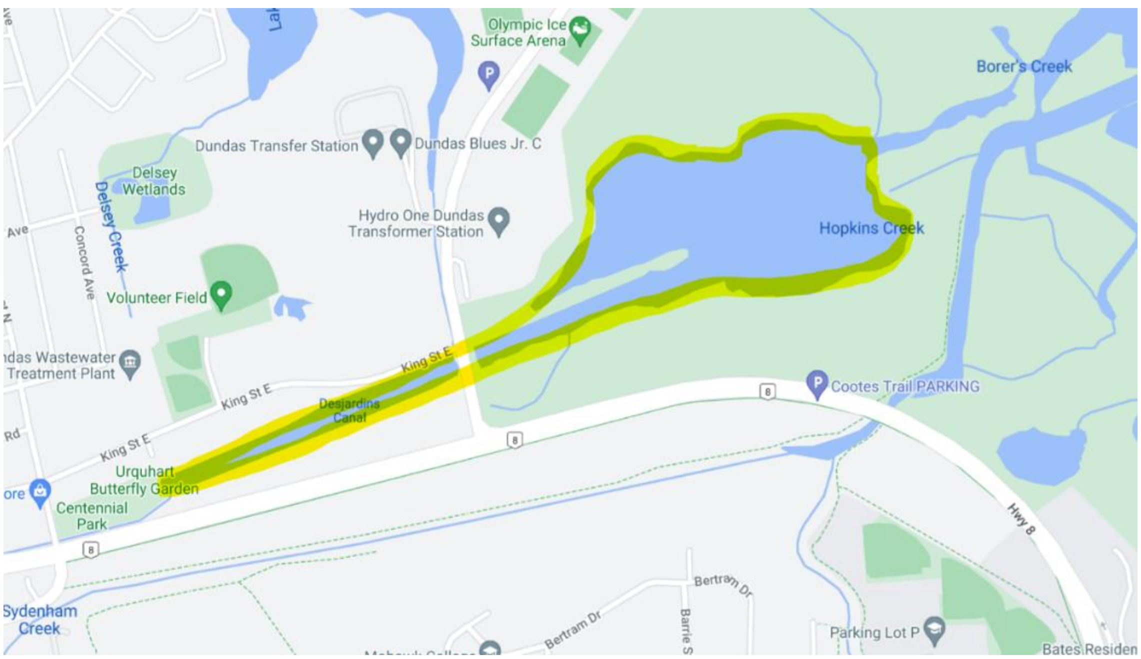

Figure 1: Flight Path of Drone (yellow) for Design One

Google. "Flight Path of Drone (yellow) for Design One." Accessed: March 13th, 2022. [online] Available: https://www.google.com/maps/@43.2698805,-79.930734,16z

Since algae initially accumulates on shoreline edges and eventually spreads across bodies of water, this design would follow a flight route across the edges of the shoreline such that we accurately detect algal growth in early stages using our algorithm and acquired images. In regard to technical performance, this flight route would require high battery capacity since the drone will be flying for approximately eight to ten kilometres at an altitude between 60-100 metres at an intermediate speed to ensure the capture of high-resolution images, while accounting for the response time of the camera shutters. Thus, we have situated the charging and deployment location near the Dundas Water Treatment Plant such that its accessible from the flight route by the drone for outdoor use and easily installed. The charging station is designed for autonomous and continuous drone operations as we will utilize contact-free wireless charging. The deployment location and flight routes avoid emergency operations, advertised events, airports, heliports, and other aircrafts and are outside controlled airspace, therefore this design abides by the rules in the Canadian Aviation Regulations. Additionally, uploading the acquired images to cloud storage requires high battery use, consequently a large capacity micro-SD card will be utilized. However, cloud data transfer and storage reduce data migration times from weeks to just days. On the other hand, physical storage options allow for increased memory capacity and avoids potential overage fees and provide an efficient way to back up content without relying on network strength. In regard to environmental concerns, the drone will inevitably disturb wildlife since it will be flown at low altitudes above an environmentally sensitive location where most species live. To mitigate such concerns, we will apply patterns to the propellers and pulsing light on the drone to reduce the risk of bird strikes. Also, to reduce noise disturbances, we will invest in silent propellers, a brushless motor, and noise reduction shrouds and sand down the surface of the propellers. We will also install a drone cage to protect people and wildlife from being hurt by a drone's propellers while also protecting the drone from being damaged in case of a collision. In regard to socio-cultural concerns, it will be difficult to maintain a minimum horizontal distance of 30 metres from bystanders since the flight path and charging station are in a populated commercial and residential area. Furthermore, it raises important questions and concerns about privacy, such as the personal information that may be captured by drones. Therefore, we intend to survey the area where we will fly to make the public population aware of our drone operations. Generally, this design will be optimal for early detection of algae growth on shoreline edges exclusively, which may result in false-negative errors and reduced efficiency of the machine learning algorithms since less images of the entire lake are acquired.

Design Two

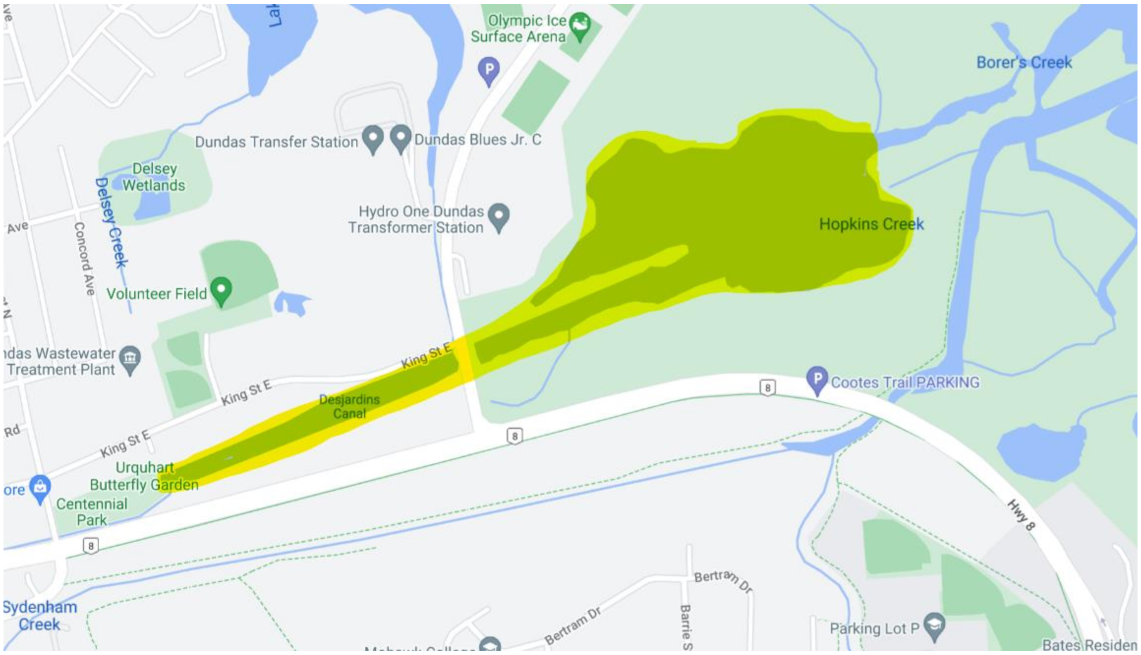

Figure 2: Flight Path of Drone (yellow) for Design Two

Google. "Flight Path of Drone (yellow) for Design Two." Accessed: March 13th, 2022. [online] Available: https://www.google.com/maps/@43.2698805,-79.930734,16z

Algal blooms are often large and dense and can cover large portions of a lake beyond the shoreline edges, thus, for this design it follows a flight route across the entire body of the lake including the edges of the shoreline such that we accurately detect algal growth past early stages. In regard to technical performance, this flight route would require more battery capacity since the drone will be flying for approximately ten to twenty kilometres at an altitude between 100-110 metres at a high speed to ensure the capture of high-resolution images, while accounting for the response time of the camera shutters and the 30-minute battery life. Therefore, charging and deployment will take place in a nearby location near the Hydro One Station. The charging station will also utilize contact-free wireless charging and the deployment location abides by the rules in the Canadian Aviation Regulations as well. Similar to the previous design, a large capacity micro-SD card will be utilized to minimize battery usage. Additionally, the flight route will be bounded by the borders of the lake to minimize flight over environmentally sensitive, commercial, and residential areas. Once again, we intend to survey the area of flight to inform the public population as well as avoiding flight over private property to address potential privacy concerns. The bounded flight path also preserves surrounding natural habitats of wildlife and reduces risk of wildlife interference. In addition, although the drone will fly autonomously using GPS positioning and obstacle identifying procedures, a drone pilot will monitor the performance of drone, ensuring no crashes occur. This reduces public and environmental safety concerns, while maximizing the technical performance of our system. This design will also utilize a drone cage in case of a collision for public and environmental safety, despite the negative impacts weight increase has on the maneuverability and speed of the drone. Lastly, the drone will be equipped with a wetsuit to prevent damage from rain and condensation since the flight route involves covering the entire body of the lake. This reduces public and environmental safety concerns by decreasing the risk of crashes, while simultaneously increasing technical performance by allowing us to fly the drone in suboptimal conditions. Since the drone will be flying at a high speed, less images will be obtained per unit of distance. This may reduce the accuracy of our machine learning algorithms since there will be fewer images to analyze. However, we will gather data on a larger area of the lake to ensure that no algal blooms are undetected.

Design Three

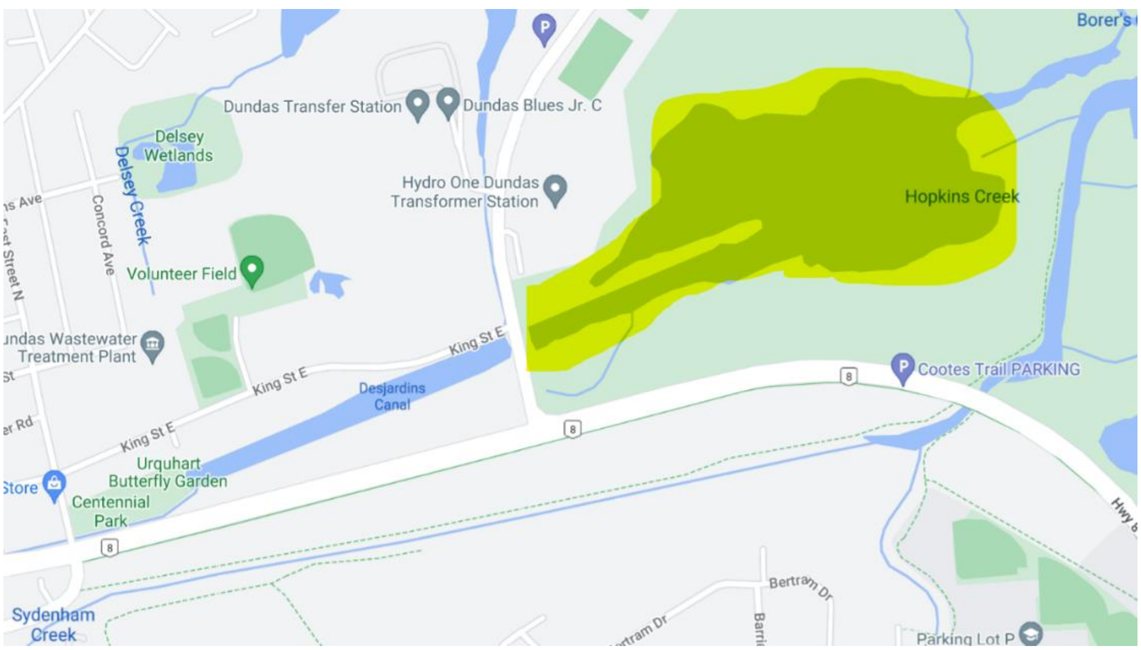

Figure 3: Flight Path of Drone (yellow) for Design Three

Google. "Flight Path of Drone (yellow) for Design Three." Accessed: March 13th, 2022. [online] Available: https://www.google.com/maps/@43.2698805,-79.930734,16z

As mentioned previously, algal blooms may expand to large portions of a lake, therefore, for this design it follows a flight route across the entire body of the lake including the edges of the shoreline and avoiding the canal since an algal bloom in the lake would extend to the canal. In regard to technical performance, this flight route would require minimal battery capacity since the drone will be flying for approximately seven to nine kilometres at an altitude between 100-110 metres at a low speed to ensure the capture of a large database of high-resolution images, while accounting for the response time of the camera shutters. Once again, we located the contact-free wireless charging station and deployment near the Hydro One Station to preserve battery and follow Canadian Aviation Regulations. Since this design is not power-intensive and a large database of images is required for the algorithm efficiency, we will upload the acquired images to cloud storage by installing a SIM card. With the help of a dongle, we can insert the SIM card in the dongle and plug that into a USB port at the back of the controller, in this way, the controller is able to gain internet access without a phone connection. Then images can be uploaded to Google Photos or other cloud services using the DJI GO 4 app and DJI fly app. Using cloud storage presents various advantages such as loss prevention, recovery, easy access, sharing and collaboration and lastly mobility. On the other hand, the disadvantages include internet connection dependency, costs, and privacy breach concerns and reliance on third-party services for security. Furthermore, this flight route is also bounded by the borders of the lake and avoids the canal to minimize flight over environmentally sensitive, commercial, and residential areas to avoid privacy concerns and wildlife interference. Since battery life and speed of the drone are essential considerations for this design, we avoid altering the propellers and installing a cage to maintain a lightweight drone. The high flight stability can allow the drone to safely maneuver around obstacles and allows for operation in high-wind weather conditions. However, species in the environmentally sensitive surroundings of the flight path may still potentially experience noise pollution and collisions. Lastly, the drone will also be equipped with a wetsuit as in previous designs, which decreases collision and crash risks and increases technical performance. Since the drone the flight path is relatively shorter, more images will be obtained which minimizes error and increase efficiency of our machine learning algorithms.

Requirements Criteria/Constr.	WEIGHT (1-10)	Design 1		Design 2		Design 3	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Technical Performance	5	177	885	183	915	219	1095
Envionmental Performance	3	120	360	127	381	128	384
Socio-Cultural Performance	4	97	388	126	504	129	516
Regulatory Performance	4	77	308	97	388	99	396
TOTAL			1941		2188		2391

Table 2: Overall Decision Matrix

We utilized various decision matrices to assess the performance of our solutions according to the constraints developed through the PERSEID method. For each PERSEID layer we generated a decision matrix and evaluated each solution against criterions as seen in Tables 1-4 in the Appendix, since the three solutions presented above had strengths and weaknesses for respective our PERSEID constraints. Then, we generated a decision matrix with the PERSEID layers as weighted criterions and the results from each PERSEID decision matrix. In ascending order of weighting as seen in Table 5 were technical, socio-cultural, and regulatory, and lastly environmental. Technical performance was weighted the most since the solution must accurately detect when harmful blooms occur in time for drinking water treatment plants to close their intakes or adjust their treatment process to protect human health. The detection accuracy depends on the number of images used to train the algorithm, image quality, and the number of algae present in each image. Secondly, socio-cultural, and regulatory performance, since implications such as safety, privacy, psychological wellbeing, data security may negatively impact willingness to accept our system and image resolution, image frequency, fly height, and flight path. Environmental performance was weighted the least since it is less likely to reduce willingness to accept our system despite the various bidirectional environmental impacts. After evaluation using these weighted criterions, we made a final selection of solution three as the most optimal design and made final refinements as we continue to analyze project requirements and constraints and design performance.

Final Proposed Design

After design refinement, our final design consisted of Design three with some features from Design two. Figure 1 below shows the proposed flight path (highlighted in yellow) with the associated charging station location (highlighted in green). This design maximized the area of the lake covered while sufficiently minimizing flight time to make the most efficient use of battery power. This will allow the drone to take several pictures of the lake on a single circuit, which is necessary to improve the accuracy of the machine learning algorithm. In addition, the drone will be flown only when environmental conditions are ideal (little to no rain, wind speeds less than 29 km/h, humidity level lower than 80%) to ensure the best possible image quality. It will also be covered with a wet suit to protect the internal electronics and increase the longevity of the other physical components. The images will be stored on a SIM card (which has a high storage capacity) so that they can be retrieved without having to physically remove the card from the drone. Although this design may have greater demands on the battery (for flight, image capture and storage, etc.) than the other designs, the proximity of the charging station compensates for this shortcoming.

The drone avoids the residential, commercial and municipal regions of the chosen location, thereby mitigating the risk of privacy breaches and reducing the noise disruption for citizens. Nevertheless, we plan to issue a survey to community members to gauge their acceptance of this project and will require a minimum of 50% agreement before we proceed. The drone will fly at a height of 122 m above the lake, away from airports and heliports in compliance with Canadian aviation regulations. Finally, the following features will be added to the drone to enhance its compatibility and reduce interference with the natural environment:

- bright colours, blinking lights (to ward off birds and other flying creatures)
- sanded propellers, brushless motors & noise reduction shrouds around propellers (to reduce noise)
- compliant mesh cage surrounding drone (to absorb the impact of any collisions to reduce collateral damage)

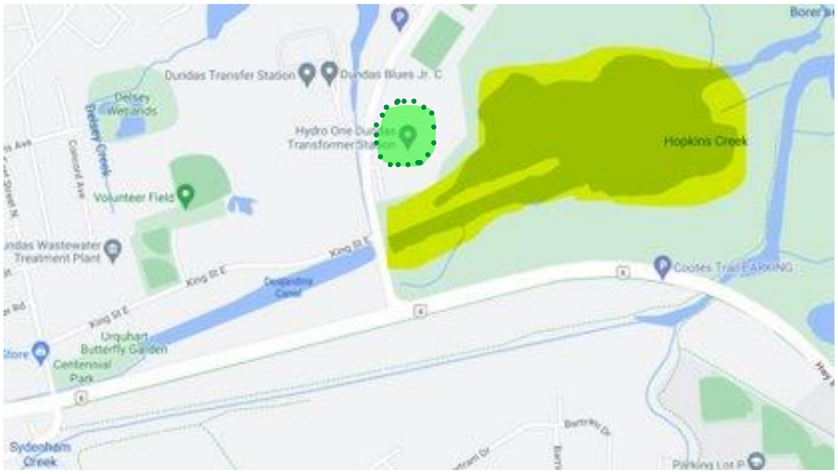

Figure 4: Flight Path of Drone (yellow) and Approximate Location of Charging Station (green) for Final Design

Google. "*Flight Path of Drone (yellow) and Approximate Location of Charging Station (green) for Final Design.*" Accessed: March 13th, 2022. [online] Available: https://www.google.com/maps/@43.2698805,-79.930734,16z

Simulation Results

We investigated the effect of varying the number of iterations, number of images and image resolution on the algorithm's accuracy and loss for both the training (blue curve) and validation (orange curve) stages of learning.

Number of Iterations	*Number of Images*	*Image Resolution*
We changed the number of iterations by changing the epochs_range value in our code (see appendix). As seen by the graphs, increasing the number of iterations increased the accuracy and decreased the loss.	Another input that we changed was the number of images. We lowered the number to around 50% of the original amount and noticed the changes to the output. A low number of images leads to a higher loss and a low accuracy.	We also changed the image resolution by using an online tool that allowed us to lower the resolution of specific image. We made copies of the same image with varying resolution and analyzed it using the simulation. The result was that a higher resolution results in a higher accuracy and a lower loss.

Table 3: Simulation Inputs explanation

Conclusion

If given more time and resources, we would have definitely aimed to 3-D print the features of our design (like the wetsuit). This would not only confirm if our solution were feasible but also if it satisfies the technical constraints or not. Moreover, it would also have pleased our stakeholders who would be satisfied that the drone indeed does the function it is intended to do. If we had more time, we could have also tested the algorithm and taken pictures of the lake at Cootes Paradise so that we would have had results that are relevant to the lake we chose.

Overall, this design project helped us learn a lot about the design process. It emphasized that in this process, constraints other than the technical ones are equally as important as they dictate the feasibility of the project as well. We were exposed to a new design process which covered the performance, environmental, regulatory and socio-cultural constraints and because we were able to focus on these key aspects, we managed to develop a successful solution to our problem statement. Furthermore, this project helped us to improve our analytical skills on these major constraints as our other courses cover mainly the technical aspects.

We learned that good team dynamics is an essential part of an engineering project which was not only useful for this project but will also be necessary in our careers. We learnt that communication is key when brainstorming ideas. All of us strove to have an equal part in the decision-making process. We used the lessons learnt from the lectures to implement certain aspects in our final design. For example, we considered the concept of universal design whenever possible.

Our work ethic, technical knowledge and communication skills allowed us to produce a project that not only satisfies the constraints but also meets the objectives of the design perfectly. However, all of us can agree that if we did this project again, we would definitely have put in more time considering the outputs of the algorithms. We would have made more inputs and noticed their effects along with working on pictures taken on the lake that we have chosen. With regards to the team dynamics, even though we had a lot of communication both during design studios and outside of it, we feel like we could have communicated even more in which might have resulted in a more efficient design process.

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Appendix

Decision Matrices

Requirements Criteria/Constr.	WEIGHT (1-10)	Design 1 Rating	Design 1 Weighted Score	Design 2 Rating	Design 2 Weighted Score	Design 3 Rating	Design 3 Weighted Score
Data Transfer Ease and Security	**8**	2	16	2	16	5	40
Low Battery Consumption	**7**	1	7	3	21	4	28
Maneuverability Preformance to Avoid Obstacles	**6**	2	12	2	12	5	30
Ability to Travel At Hight Speed	**5**	2	10	3	15	5	25
Close Proximity to Flight Path from Charging Station	**7**	5	35	3	21	3	21
Quality and Number of Images Obtained	**9**	5	45	4	36	5	45
Easily Installed Charging Station	**4**	3	12	3	12	5	20
Area of Lake Covered by Flight Path	**10**	4	40	5	50	4	40
TOTAL			**177**		**183**		**219**

Requirements Criteria/Constr.	WEIGHT (1-10)	Design 1 Rating	Design 1 Weighted Score	Design 2 Rating	Design 2 Weighted Score	Design 3 Rating	Design 3 Weighted Score
Flight Path Avoids Populated Residential and Commercial Areas	**9**	1	9	2	18	5	45
Reduces Noise Pollution due to Drone System Modifications	**7**	4	28	4	28	2	14
Reduces Likelihood of Capture of Non-Lake Images	**10**	1	10	3	30	5	50
Reduces Damage to People in Case of A Collision	**10**	5	50	5	50	2	20
TOTAL			**97**		**126**		**129**

Table 4 and Table 5: Performance Matrix (left) Socio-cultural Matrix (right)

Requirements Criteria/Constr.	WEIGHT (1-10)	Design 1 Rating	Design 1 Weighted Score	Design 2 Rating	Design 2 Weighted Score	Design 3 Rating	Design 3 Weighted Score
Drone is Visibille at All Times Given the Flight Path	8	3	24	2	16	2	16
Drone can Easily Maintain a Minimum Horizontal Distance of 30 Metres from Bystanders	9	1	9	3	27	4	36
Reduces Requirment to Survey Area (to take note of any obstacles or concerns)	5	1	5	3	15	4	20
Reduces Flight Height (is not Required to Fly Close to 122 metres)	7	4	28	2	14	1	7
Flight Path Avoids Municipal Areas, Airports and Heliports.	8	2	16	5	40	5	40
TOTAL			77		97		99

Requirements Criteria/Constr.	WEIGHT (1-10)	Design 1 Rating	Design 1 Weighted Score	Design 2 Rating	Design 2 Weighted Score	Design 3 Rating	Design 3 Weighted Score
Flight Path Avoids Environementally Sensitive Areas	7	1	7	2	14	5	35
Reduces Noise Pollution due to Drone System Modifications	9	4	36	4	36	2	18
Reduces Damage to Environment in Case of A Collision	7	4	28	4	28	2	14
Conspicuousy of Drone to Flying Animals due to Drone System Modifications	8	5	40	5	40	2	16
Reduces Likelihood of Crashing Due to Flight Path and Reduced Maneuverability	9	1	9	1	9	5	45
TOTAL			120		127		128

Table 6 and Table 7: Regulatory Matrix (left) and Environmental Matrix (right)

Simulation Results (before changing inputs)

```
datagen = ImageDataGenerator(
        featurewise_center=False,  # set input mean to 0 over the dataset
        samplewise_center=False,  # set each sample mean to 0
        featurewise_std_normalization=False,  # divide inputs by std of the dataset
        samplewise_std_normalization=False,  # divide each input by its std
        zca_whitening=False,  # apply ZCA whitening
        rotation_range = 30,  # randomly rotate images in the range (degrees, 0 to 180)
        zoom_range = 0.2, # Randomly zoom image
        width_shift_range=0.1,  # randomly shift images horizontally (fraction of total width)
        height_shift_range=0.1,  # randomly shift images vertically (fraction of total height)
        horizontal_flip = True,  # randomly flip images
        vertical_flip=False)  # randomly flip images
```

Figure 5: Zoom range changing according to constraints

```
epochs_range = range(75)
```

Figure 6: Number of iterations changed for improved accuracy

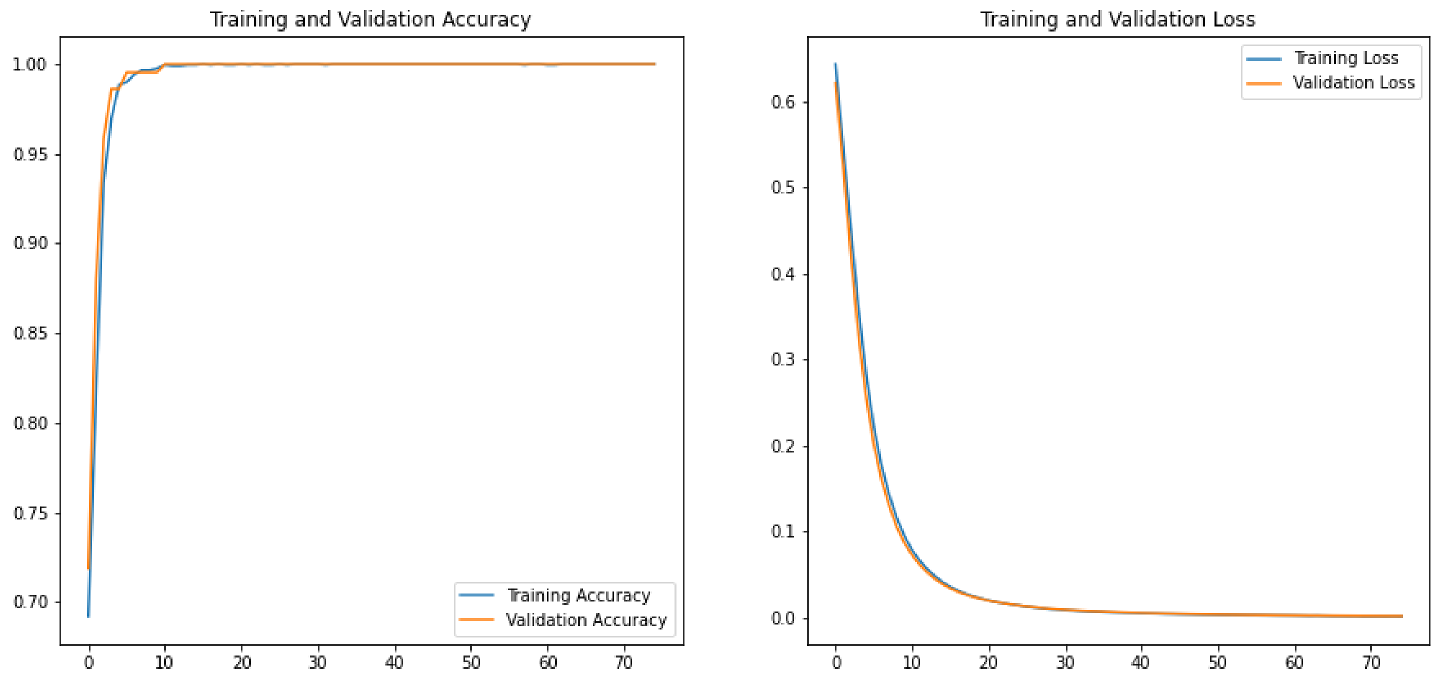

Figure 7: Terrain Graphs

```
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d (Conv2D)             (None, 224, 224, 32)      896

 max_pooling2d (MaxPooling2D  (None, 112, 112, 32)     0
 )

 conv2d_1 (Conv2D)           (None, 112, 112, 32)      9248

 max_pooling2d_1 (MaxPooling  (None, 56, 56, 32)       0
 2D)

 conv2d_2 (Conv2D)           (None, 56, 56, 64)        18496

 max_pooling2d_2 (MaxPooling  (None, 28, 28, 64)       0
 2D)

 dropout (Dropout)           (None, 28, 28, 64)        0

 flatten (Flatten)           (None, 50176)             0

 dense (Dense)               (None, 128)               6422656

 dense_1 (Dense)             (None, 2)                 258

=================================================================
Total params: 6,451,554
Trainable params: 6,451,554
Non-trainable params: 0
```

Figure 8: Terrain Outputs

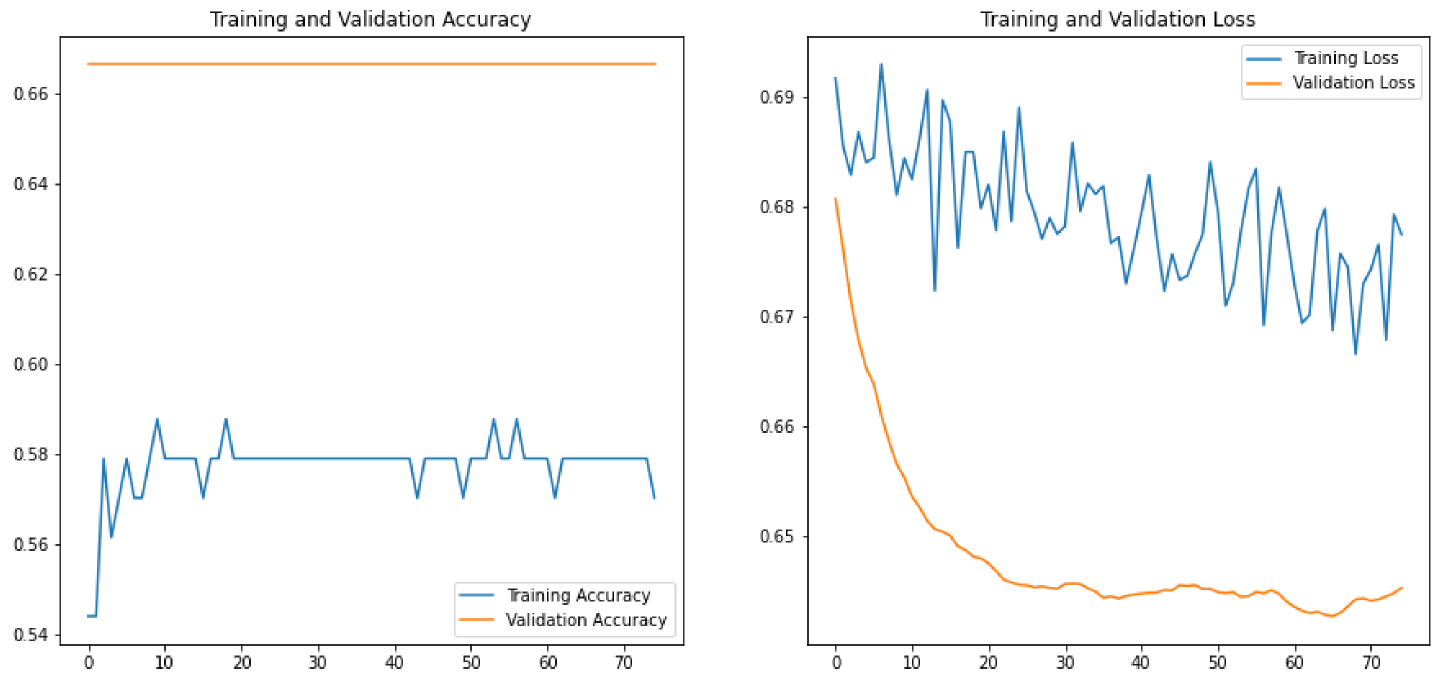

Figure 9: Algae Graphs (before changing inputs)

```
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_3 (Conv2D)           (None, 224, 224, 32)      896

 max_pooling2d_3 (MaxPooling  (None, 112, 112, 32)     0
 2D)

 conv2d_4 (Conv2D)           (None, 112, 112, 32)      9248

 max_pooling2d_4 (MaxPooling  (None, 56, 56, 32)       0
 2D)

 conv2d_5 (Conv2D)           (None, 56, 56, 64)        18496

 max_pooling2d_5 (MaxPooling  (None, 28, 28, 64)       0
 2D)

 dropout_1 (Dropout)         (None, 28, 28, 64)        0

 flatten_1 (Flatten)         (None, 50176)             0

 dense_2 (Dense)             (None, 128)               6422656

 dense_3 (Dense)             (None, 2)                 258

=================================================================
Total params: 6,451,554
Trainable params: 6,451,554
Non-trainable params: 0
```

Figure 10: Algae Outputs

Simulation Results (after changing inputs)

1. *Number of Iterations*

(a) Accuracy

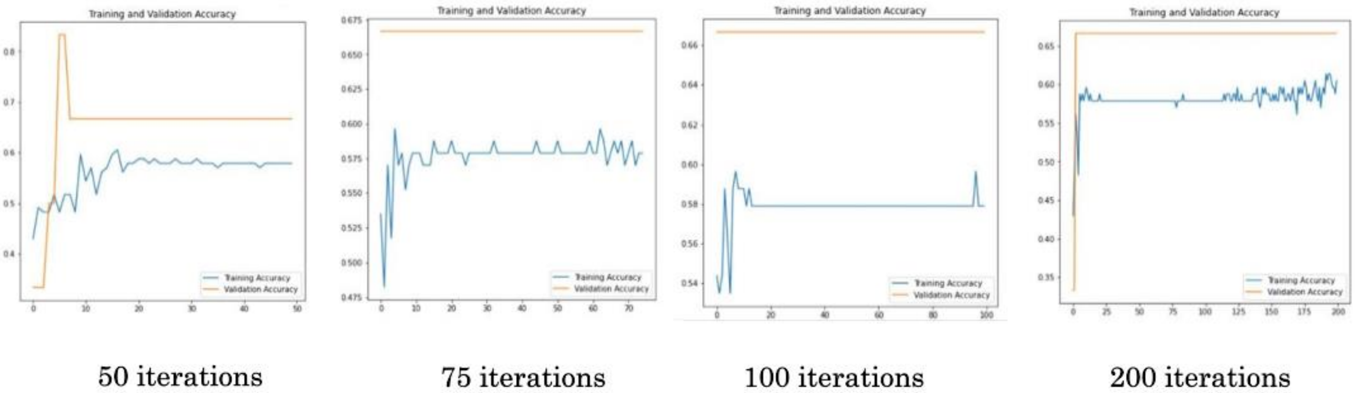

Figure 11: Increased iterations → Increased accuracy

(b) Loss

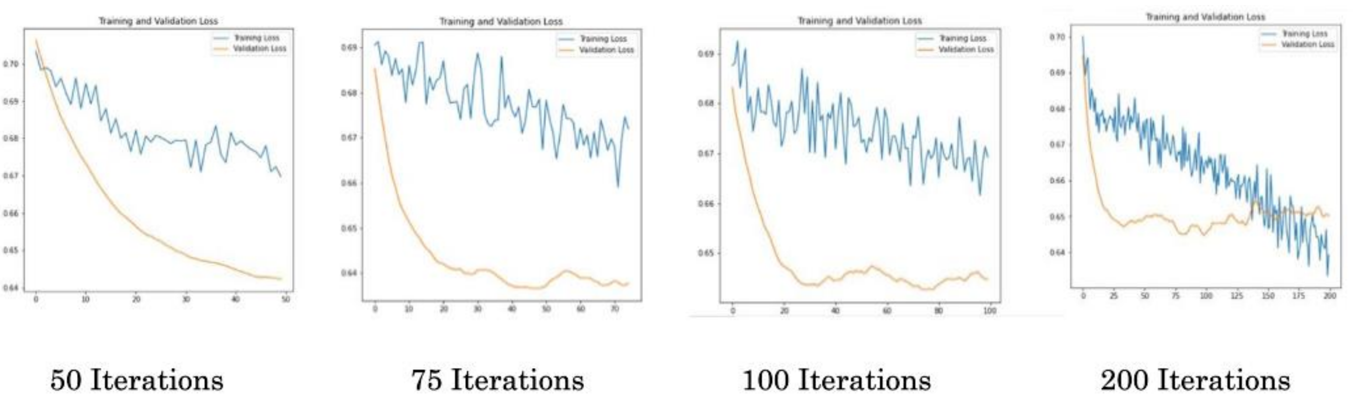

Figure 12: Increased iterations → Decreased loss

2. *Number of Images*

(a) Accuracy

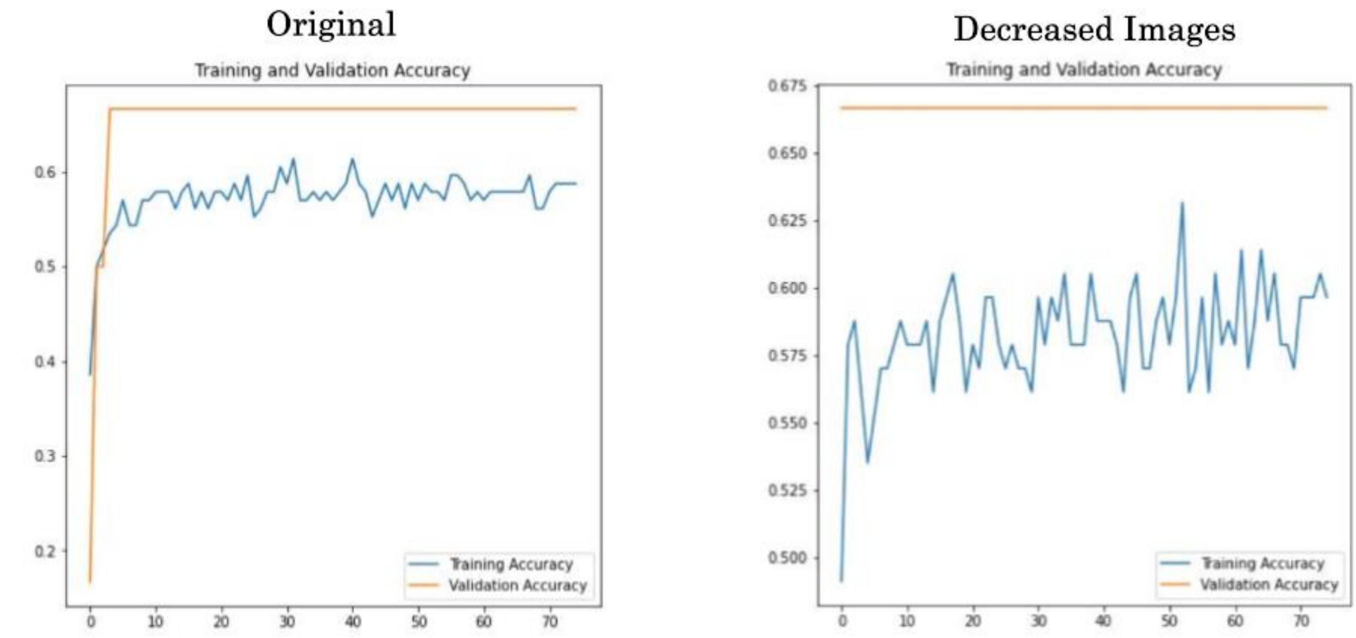

Figure 13: Fewer images → Lower accuracy

(b) Loss

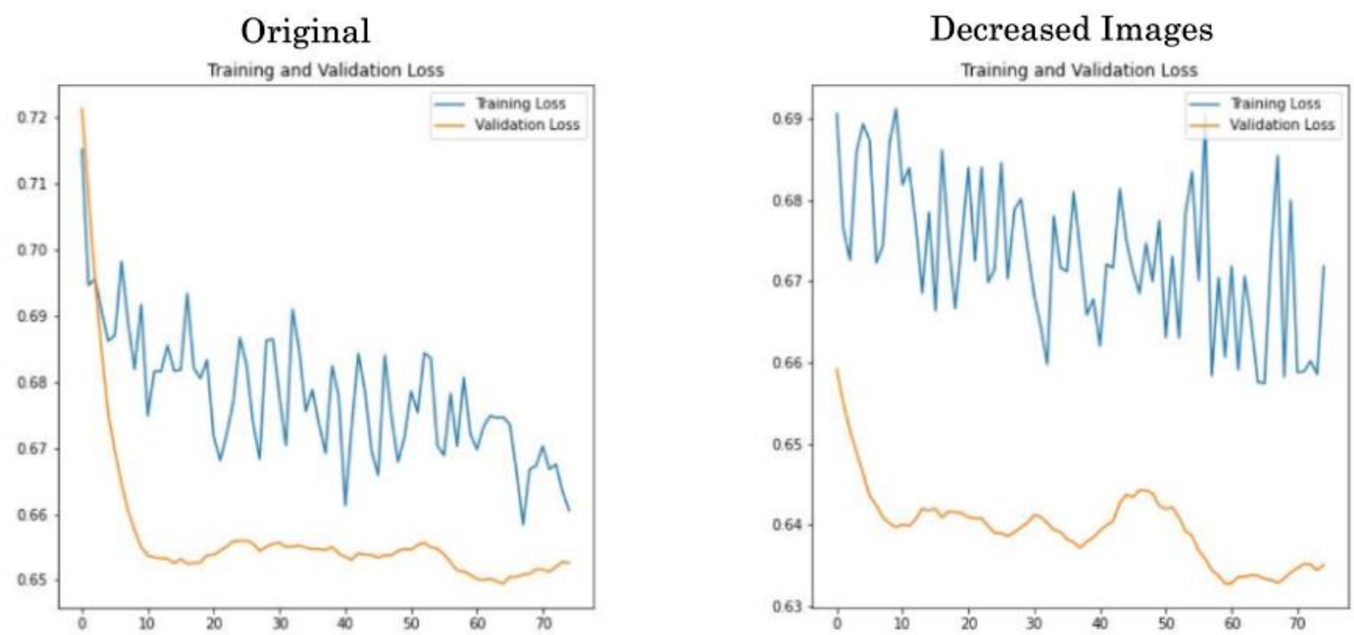

Figure 14: Fewer images → Higher loss

3. Image Resolution

(a) Accuracy

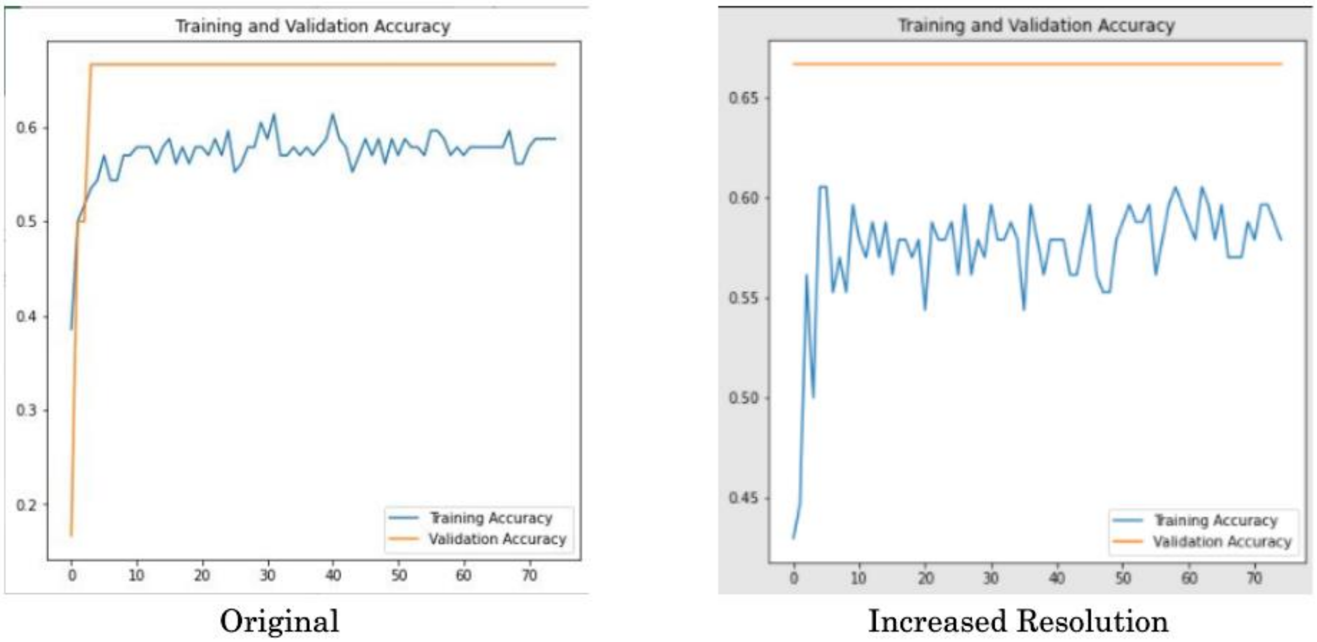

Figure 15: Higher resolution → Higher accuracy

(b) Loss

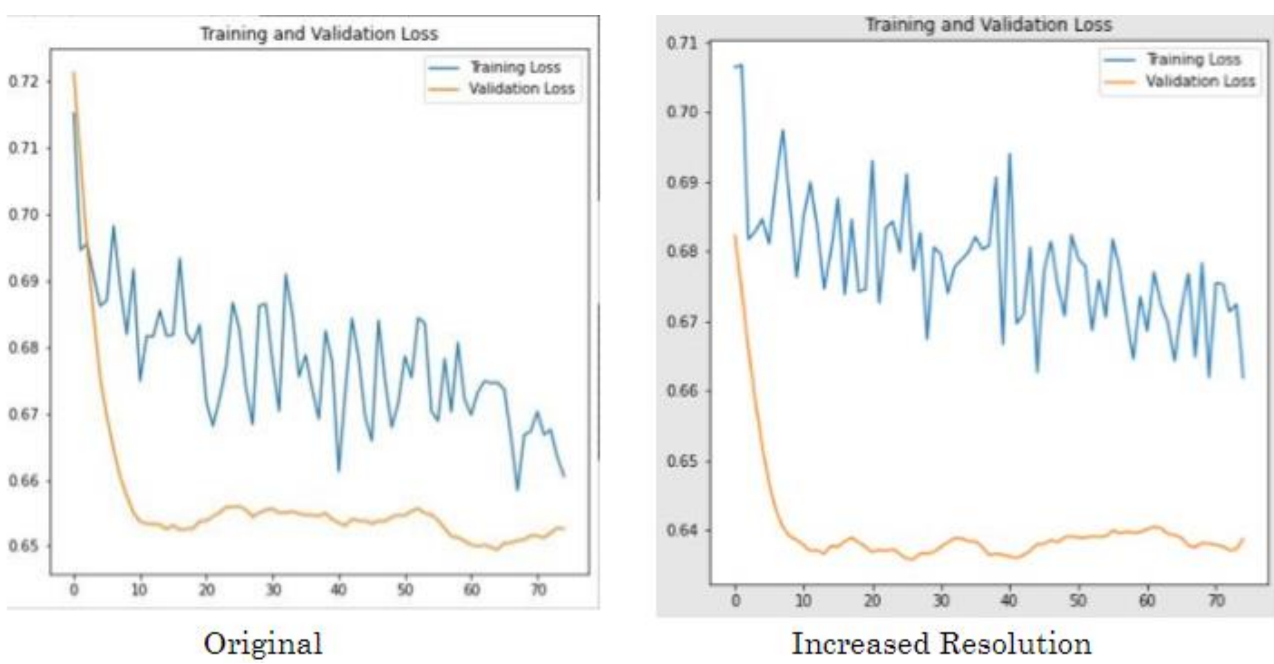

Figure 16: Higher resolution → Lower loss

Additional Figures/Images

Figure 17: Satellite Overview of Cootes Paradise Lake

Google. "Satellite Overview of Cootes Paradise Lake." Accessed: March 13th, 2022. [online] Available: https://www.google.com/maps/@43.2698805,-79.930734,1628m/data=!3m1!1e3

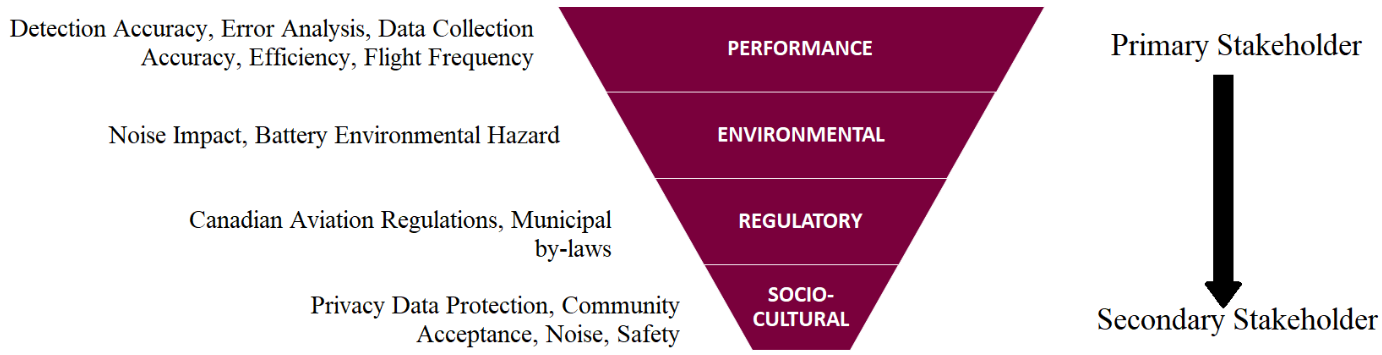

Figure 18: PERSEID Design Framework

Synchronous Design Studio Worksheets

Worksheet 1, Worksheet 2, Worksheet 3, Worksheet 4, Worksheet 5, Worksheet 6, Worksheet 7, Worksheet 8, Worksheet 9