UAV Based 3D Modeling:

Drone Based Photogrammetry

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EXP-3001: UAV Based 3D Modeling

Professor Dr. Lieske

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A Table of contents would have been handy to signal the sections and structure of your report.

Context

With the support of Professor Lieske at Mount Allison University, and the help of the company RH Precision from Ottawa, Ontario, I was fortunate to partake in an experiential learning program during the summer of 2022, which provided an in-depth learning opportunity focused on the commercial applications of the technology called UAV based photogrammetry; a form of 3D modeling using UAVs. Little did I know that the academic application of the technology would quickly become useful in real-world conditions. This report is the summary of my experiential learning.

Introduction

Unmanned Aerial Vehicles (UAVs) or *drones* as they are commonly known, are technologically advanced flying machines of various sizes and capacities, which have become accessible to the public. In aviation terms, they are considered small aircrafts, typically with 4 propellers and a camera, but with some variations. They have become a common sight at tourist attractions, concerts, and various other venues.

can also be fixed wing

Although quite efficient at gathering quality cinematic scenes, to researchers, these small machines are powerful tools which can unlock numerous analytical possibilities, thanks to their high-grade cameras and Global Positioning System (GPS) capabilities. They are able to capture high-definition pictures, infrared heat signatures, as well as Lidar imagery. Flight routes can now be pre-programmed using the internal GPS, and pictures can be captured systematically. As the technology becomes more commonplace and accessible, the varied uses are growing. This paper will focus specifically on the workflow that encompasses the field of *UAV based Photogrammetry*.

Photogrammetry by itself is the interlacing together of pictures, into one single large picture called an *ortho-photomosaic*, (*orthomosaic* for short) or as Marriam-Webster defines it, *the science of making reliable measurements using aerial photographs* (Merriam-webster, 2022.)

RH Precision specializes in commercial uses of the photogrammetry technique using UAV capture (https://rhprecisionunmanned.com/about/, 2022). They use color images to build professional quality *orthomosaics*, which are then used for technical inspection, as well as construction documentation, amongst other uses.

Orthomosaics are a "*photogrammetrically orthorectified image product mosaicked from an image collection... to produce a seamless mosaic dataset.*" (https://pro.arcgis.com, 2022.) They have the capacity to produce high-definition 3D renders of building exteriors, in regular or infrared light. This 3D render can save thousands of dollars in future repairs by (one example) identifying areas of heat loss and facade degradation. It can also allow technical engineers to assess the structural conditions of tall buildings (without requiring scaffolding), to meet established inspection requirements.

not the right term

When Hurricane Fiona lambasted Eastern Canada in late September 2022, a ~40-acre parcel of land in Cormier Village N.B. consisting mostly of an overgrown Acadian pine forest, fell victim to the high winds. The weather event toppled hundreds of trees, and completely flattened out more than 3 acres of land.

We know this estimate is accurate because we were able to use photogrammetry to complete an effective post-assessment of the land following the storm, which we were then able to compare with our initial photogrammetry attempt earlier in August 2022. The timing of the hurricane following our initial capture suddenly provided an excellent case study for the use of photogrammetry, which we detail within this paper. Great!

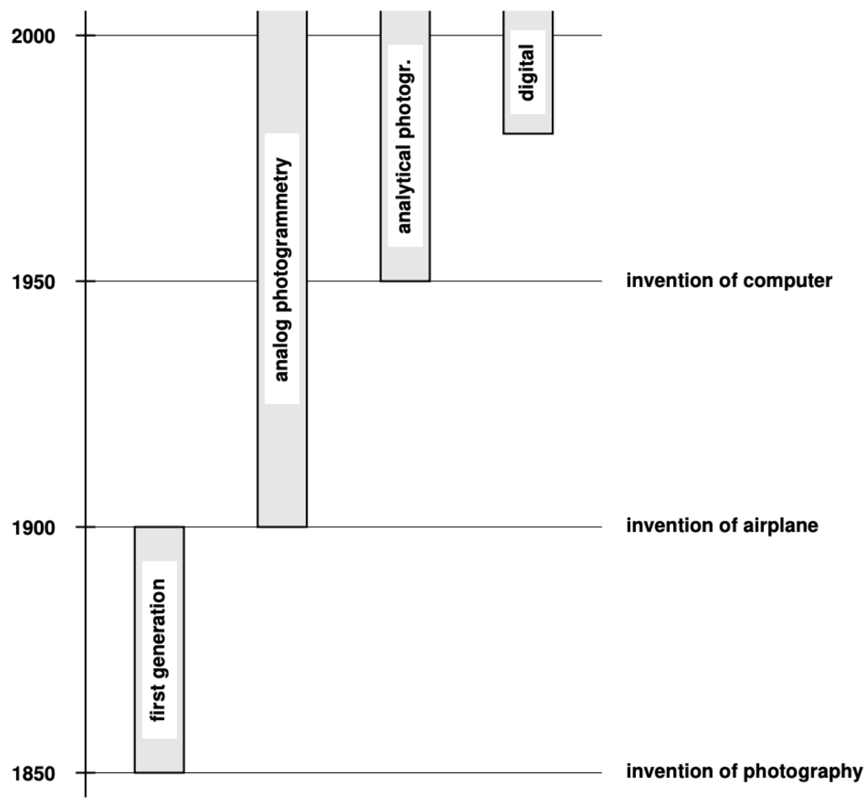
First however, we will explore the background of photogrammetry, followed by a short review of the piloting necessities required for UAV based photogrammetry, as well as the technical aspects of the capture flight. We will then move onto an exploration of the various uses of the technique, along with the post-processing rundown of how the software is able to create the *Orthomosaic*.

Our last section will include an in-depth review of the author's experience, along with the case study provided by hurricane Fiona, which will demonstrate how the ability to produce orthomosaics on demand proved useful. We will then conclude with a reflection of the learning experience.

Photogrammetry

Drone base photogrammetry uses numerous elements to achieve the goal of a completed orthomosaic - it requires a camera to capture the images; a GPS locator to maintain location bearings; the UAV itself to reposition the camera systematically; and enormous computing power to complete the post-processing of the images. Without each element, UAV based photogrammetry would not be possible. yes

The innovative technologies which have made UAV based photogrammetry possible were developed on a lengthy time scale, as the required technologies evolved independently, beginning with the advent of cameras in the 1800's, which brought along the possibility of "analogue photogrammetry" in the mid 1800's (Schenk, 2005.) At the time, photogrammetry was simply the alignment of numerous photographs, to create a 3D model of an object.



Major photogrammetric phases - a timeline of technological innovations required for modern photogrammetry. (Schenk, 2005, p.8)

The word *photogrammetry* comes from the Greek *Photos* meaning light, and -*metry*, meaning to measure. The definition of the word itself is the capturing of images (or data) without touching the object (Schenk, 2005). UAV based photogrammetry is the science of obtaining reliable information about the properties of surfaces and objects without physical contact (by taking pictures), then measuring and interpreting the data obtained (by creating orthomosaics.)

Using UAVs is simply a technological extension of the established process, but it unlocks massive capabilities in terms of geography, scale of capture, and variations of uses. Programmable GPS enables UAVs to use software features such as automatic grid capturing, meaning that a very large portion (if not all) of the mathematical legwork is also automated, while ensuring the captured data is labeled accurately with the coordinates, and that the drone flies in an efficient pattern.

Software has essentially automated the entire process, which means the user can completely skip the level of knowledge previously required to successfully use photogrammetry via triangulation calculations. The main skills required to complete our own photogrammetry project was learning to pilot the UAVs, and the (relatively low) learning curve to use the software application.

Once the photographs have been captured, powerful computing power is used to link the images together. Prior to this, the human eye and mathematical calculations were used to stitch a few pictures together, one at a time. The same type of system was used during World War 1, when images captured via airplane were interlaced manually by finding common points (mapware.com, 2022).

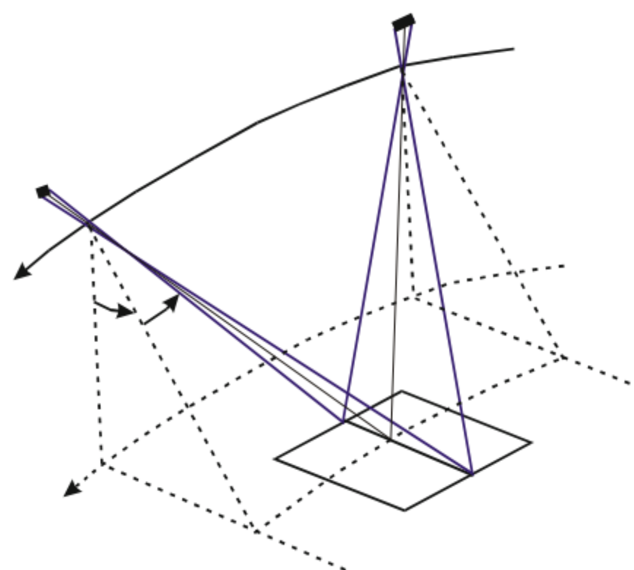
Advanced computing capacity has now provided the ability to combine hundreds of images, by matching thousands of "tie points." Tie points are the same identified object or precise location on two separate images, or "*3D points that are automatically detected and matched in the images and used to compute their 3D position*" (pix4d.com, 2022.) Once the computer can find the multiple common points between images, it is able to tie, or "stitch" the images together, (hopefully) creating one large seamless image which we call the orthomosaic.

Adding a grid of GPS coordinates onto a massive earth sized orthomosaic map has created powerful navigational tools, which have drastically changed our world, thanks to programs such as Google Earth Pro - with the visual map elements made possible by photogrammetry. Although they use satellite imagery instead of drone-based images to create their orthomosaic maps of the entire planet, the base mathematics remain the same, but the scale of each “tile” is much, much larger.

Linder provides an example from Jacobsen (2007) of “stereo image” overlays from satellite pictures.
(Linder, 2016, p. 116)

116 9 Two Final Examples

Fig. 9.1 Geometry of stereo images from satellites. From Jacobsen, 2007



Although visuals are already available such as on Google maps, these are often months, or even years old; based on satellite pass times. Their advantage is updated versions of large-scale areas, while photogrammetry focuses on much smaller areas, but can be captured at will, as needed. UAV based Photogrammetry allows for near-immediate results of a specified spatial area; thus it can be a great tool in post-event surveying.

Unmanned Aerial Vehicle (UAV) technology has enhanced the earlier capabilities of photogrammetry by allowing for accurate and relatively easy capture of the photographic data required to complete large scale photogrammetry projects.

Numerous technologies inter-combine to allow this low-barrier entry to new users. Most of the software is now streamlined with step-by-step processes implemented, with cloud based algorithmic rendering processed automatically, and self-flying UAVs perfectly capturing images at the push of a button.

In other words, UAVs are used as versatile, efficient, and precise camera tripods, while the meta-data keeps track of the location of each image, and satellites provide the GPS data required for picture taking in precise grid-life fashion, resulting in impressive final products, with little specialization apart from UAV piloting.

The technical process

In *Digital Photogrammetry a Practical Course Fourth Edition*, Wilfried Linder explains the mathematical principles behind the triangulation on three scalar planes of the captured image, which allows the user to use geometry to ascertain height points from the surface, along with sizes of objects in each plane (Linder, 2016). Drones have essentially unlocked (or expanded) a new axis for humans and the ability to see from above, while using the same mathematical principles. Photogrammetry uses the Oriented Stereo Model to create 3D objects from two or more photographs.

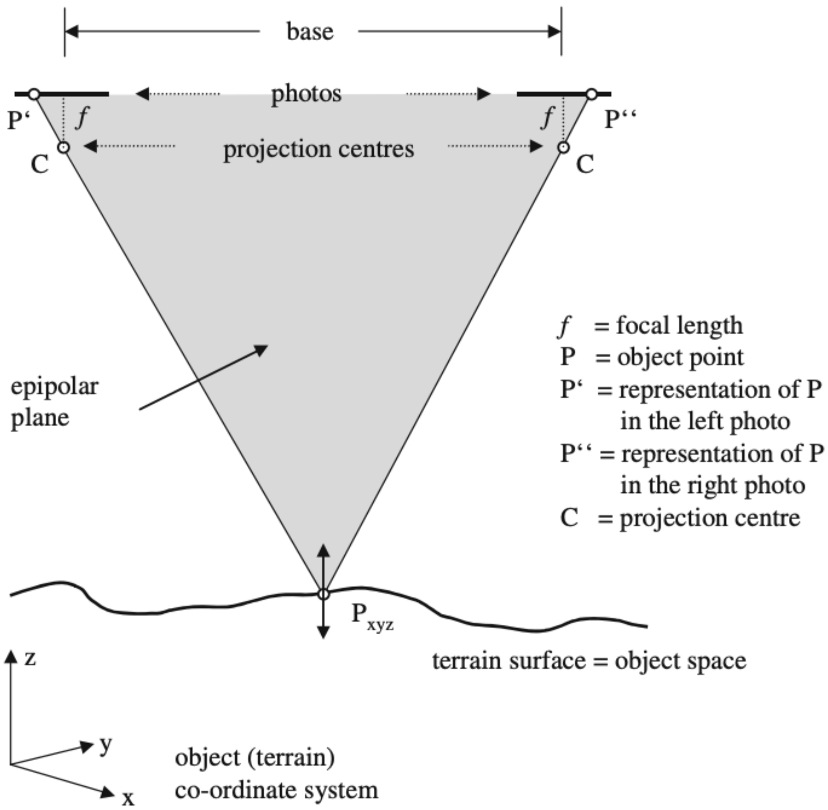


Fig. 1.1 Geometry in an oriented stereo model. Changing the height in point P (on the surface) leads to a linear motion (*left—right*) of the points P′ and P″ within the photos along *epipolar lines*

The oriented stereo model, from Linder, 2016.

The difference between photogrammetry and remote sensing is in the application; while photogrammetrists produce maps and precise three-dimensional positions of points, remote sensing specialists analyze and interpret images deriving information about the earth’s land and water areas. As depicted in Fig. 1.2 below, both disciplines are also related to Geographic Information Systems (GIS). Quite often, the core of topographic information is produced by photogrammetrists in the form of a digital map (Schenk, 2005).

The remote sensing > GIS > photogrammetry connection, graphic from Schenk, 2005.

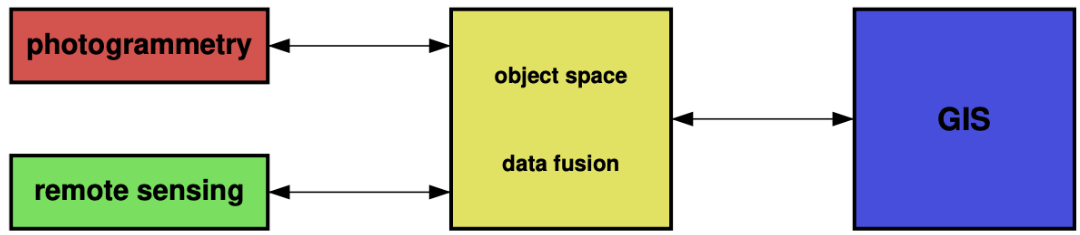


Figure 1.2: Relationship of photogrammetry, remote sensing and GIS.

While remote sensing is a similar application, photogrammetry allows the user to produce precise maps in real-time (Schenk, 2005), which are very literal visual records of the location at the given time.

The photogrammetric products fall into three categories: photographic products, computational results, and maps (Schenk, 2005). Although understanding the base geometric knowledge used to be crucial to properly project objects in 3 planes, or 3D, it quickly became apparent for our purposes that we now benefit from modern day apps and devices, which simply allow us to skip this requirement.

As we discussed earlier, the current barrier to entry does not require the user to learn the finer details of the mathematics behind the angles of the captures, but anyone wanting to read more is encouraged to read either Linder's work for more recent uses, or Schenk's *Introduction to Photogrammetry.* It is a bit dated from 2005, but the work really explores the mathematical bases.

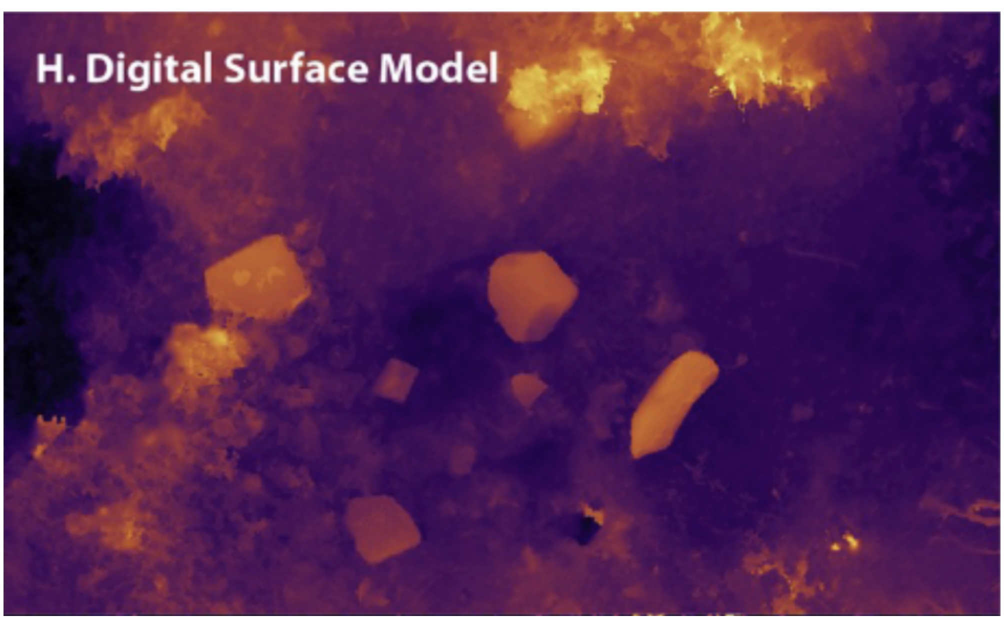
Modern Uses

At first glance, photogrammetry appears to provide a tool which apart from mapping and creating 3D models is somewhat limited. However, numerous uses for photogrammetry continue to emerge. Some uses save time for researchers, while others provide additional tools and potential avenues for analysis.

One niche where photogrammetry is used as a time saving measure is highlighted in Orengo and Garcia-Molsosa's research *A brave new world for archaeological survey: Automated machine learning-based potsherd detection using high-resolution drone imagery*. In this paper, they demonstrate how photogrammetry can replace traditional fieldwalking. They define *fieldwalking* as the "*systematic walking by teams of archaeologists to record surface-visible material culture, usually pottery fragments*" (Orengo and Garcia-Molsosa, 2019). This technique usually requires many hours of work.

Using photogrammetry, the researchers instead took pictures using the UAV, and then created an ortho-photomosaic Digital Surface Model (DSM). As we can see from the Digital Surface Model on the left, the capture allows the shards to emerge from the surrounding terrain, which is conveniently located on a GPS enabled grid. Instead of wasting many hours visually scanning the

should mention a special camera to detect temp difference is necessary



The Digital Surface Model Orthomosaic created by Orengo and Garcia-Mososa, 2019. You can clearly see the Shards that emerge within the picture thanks to the different heat signature than the surrounding ground. Simple, yet effective.

surface manually, researchers can use a single UAV pilot to complete a digital model, and a single researcher can then document or retrieve the shards at will.

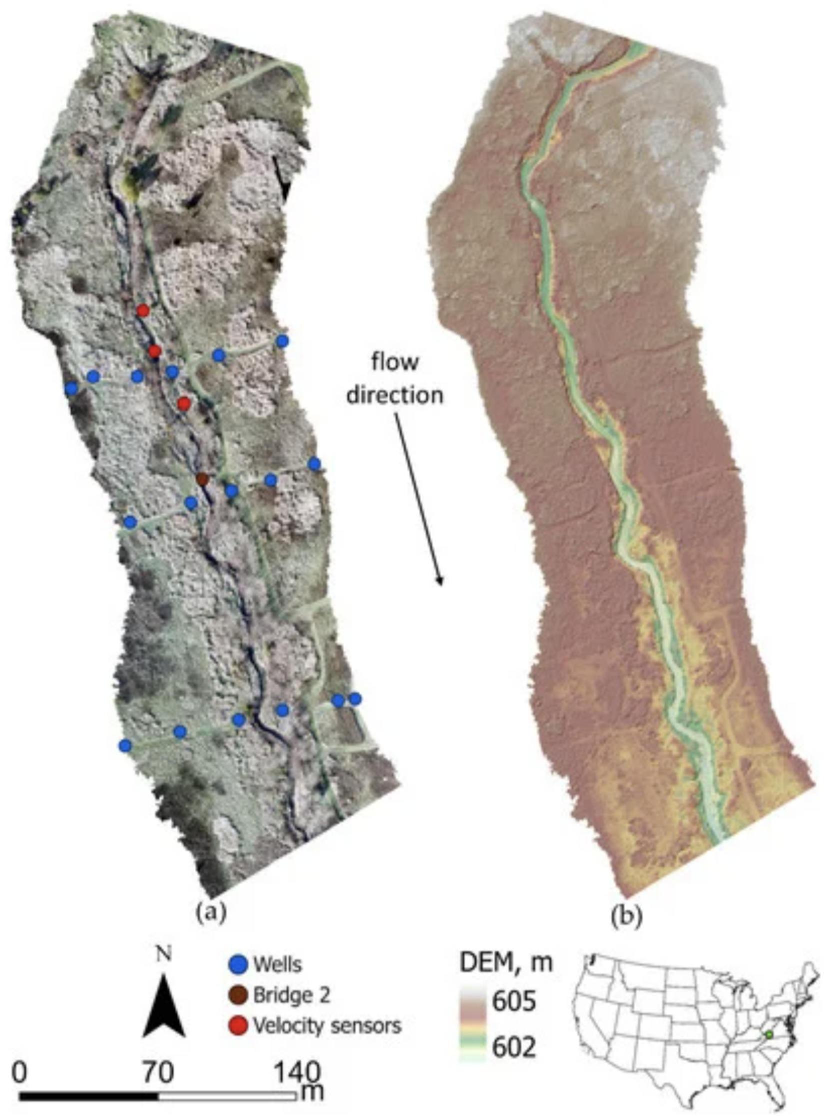
Photogrammetry provides a layer of real-time information in visual form. A huge potential is the current ability to overlay the resulting imagery from the process into existing maps, or tools such as GIS, for a single end-product. It is also possible to produce various forms of other visual tools, such as digital surface models, relief, and even heat-maps using thermal imagery. Using photogrammetry, some processes can also help expedite, and alleviate delays created by archeological surveys required prior to construction projects.

Overall, the authors conclude that the cost is a fraction of the traditional survey method, with faster results, and they even claim that the process has higher analytical capabilities than traditional surveying methods; after all, a finished visual product which can be analyzed at will is more useful than a single visual pass of an area where items may be missed during the field walk.

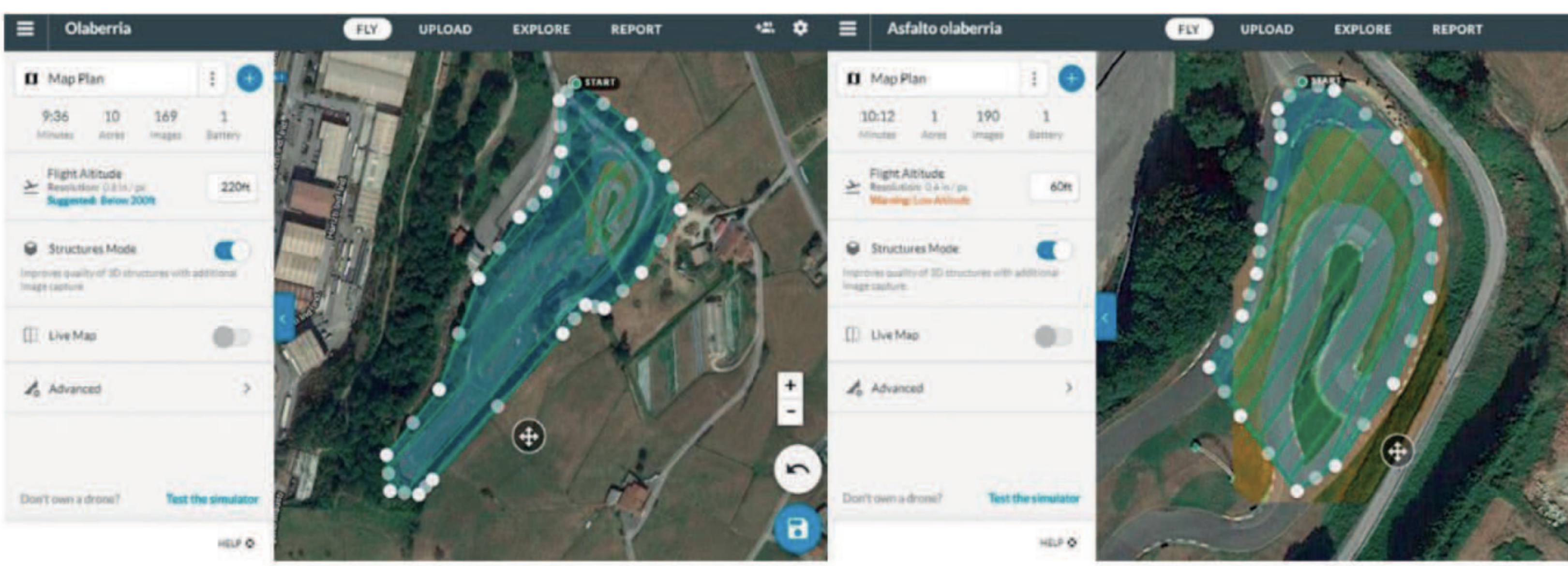
It should also be noted that the paper itself is from 2019, and even in just the past three years, the technology has advanced dramatically, and as such many of the limitations listed by the authors, such as camera quality and resolution, longer flight times of UAVs, and faster capturing (Orengo and Garcia-Molsosa, 2019), all continue to improve as technology advances.

good point

This is but one example of the capabilities that photogrammetry can provide, and many others exist. Another example includes the work of Prior et al. (Right), who used the same process to estimate floodplain vegetative roughness of a riverbed, as seen in the accompanying graphic (2021), while Salazar-Lozano's study used the 3D modeling technique (below) to map out a go-karting circuit (2021).



Prior et al,'s photomosaic of the floodplain, with a focus on vegetative roughness. (2021.)



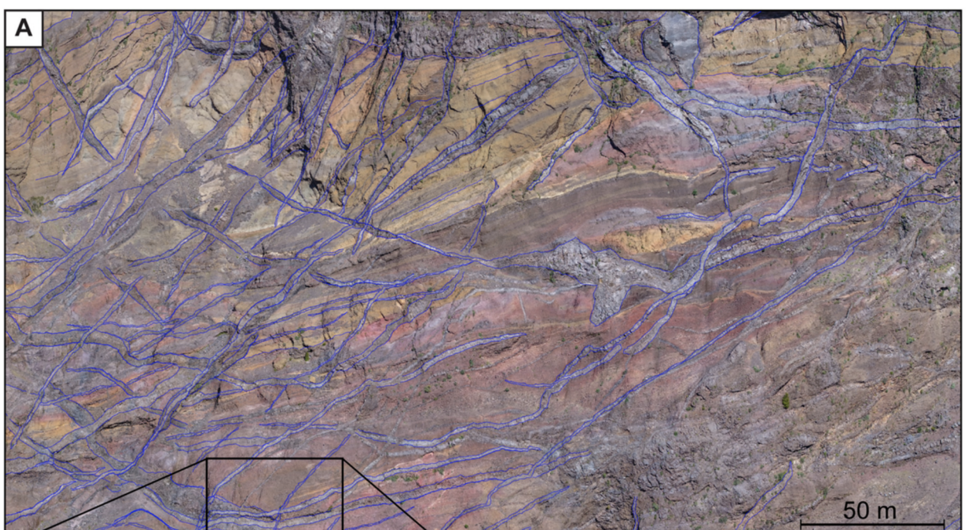
Solazar-Lozano's (2021) use of 3D modelling to lay out the go-kart course is a novel use of photogrammetry. You can see the flight paths being automatically provided by the software, dependent on the area chosen. The white points are manually adjustable to any spatial configuration. The user can simply tap the dots and move them at will, and the software will readjust the flight path.

The reasons for using the capture process of photogrammetry are as varied as there are fields of research (or creativity). From the work of Gillian et al. who used photogrammetry for *Estimating Forage Utilization with Drone-Based Photogrammetric Point Clouds* (2019), to predicting tree and oil palm water use, within the work of Ahongshangbam et al., entitled *Drone-based photogrammetry-derived crown metrics for predicting tree and oil palm water use* (2019), to monitoring the body size and body condition of Antillean manatees (Ramos et. al., 2022). The potential uses for photogrammetry continue to grow, as the process brings technological solutions for a variety of situations, where a visual record can benefit the process.

One study which stood out was the paper by Dering et al., who used photogrammetry to map and monitor volcanic dykes (2019), and another by Gomez and Kennedy, *entitled Capturing Volcanic Plumes in 3D with UAV-based photogrammetry at Yasur Volcano-Vanuatu* (2017).

These stood out, in that the use of drones appeared to have unlocked the ability to easily survey and capture areas of extreme danger, such as volcanoes.

G.M. Dering et al. / Journal of Volcanology and Geothermal Research 373 (2019) 148–166



Derring et al.'s photomosaic of volcanic dykes. UAVs are capable of flying in dangerous situations normally limited to humans.

Although Dering et al.'s work focuses on volcano dykes, it is easy to see how the application could be adapted to the ocean dykes surrounding the Tantramar marshes, as a local use example. The process can even be adapted underwater, such as the work of Walter et al. (2022), who used underwater photogrammetry to map the geothermal fields of Iceland! great

In Gillian et al.'s work discussed above, they detail how sampling techniques do not provide an entire picture of forage use of an area, while satellite imagery lacks the resolution and details required to be effective, and manned air flights can be cost prohibitive (Gillian et al., 2019). It is in these scenarios where photogrammetry finds its niche, and it is no surprise that there is emerging research focusing on validating the process, in lieu of many traditional methods.

It appears that the use of photogrammetry will continue to expand while the technology advances. In some instances, photogrammetry appears to be a tool that is replacing many traditional techniques, and is often faster, cheaper and requires a single pilot, rather than a large team. In other instances, it is a technical revolution.

One revolutionary example comes from the National Gallery of Canada, which has created a Virtual Reality Exhibit whereby users place a 360-degree virtual reality headset over their eyes and are then immersed in a conservation exhibit.

In this instance, the journey brings the users to Africa, where they can experience the horror of just how many elephant tusks and rhinoceros' horns were destroyed to deter poachers. The mound of horns is much more impressive to experience in virtual space which helps provide users with stunning scale-accurate visuals, versus a simple image that does not truly convey the size.

The immersive exhibit was described as being in a real-time 360 film, and the process to create the media encompassed the use of photogrammetry!

A picture of the team capturing the images which will be used to create the immersive orthomosaic - National Gallery of Canada

The Workflow

Orengo and Garcia-Molsosa provide us with a visualized snapshot of the workflow which applies to most photogrammetry projects. Apart from the geological motivation and features (top), the rest of the workflow is essentially unchanged from our own project. Removing the elements related to the UAV leaves us with a basic photogrammetry workflow.

The result is a highly precise 3D (or 2D) representation of a current, geographically present location, in a spatially based model.

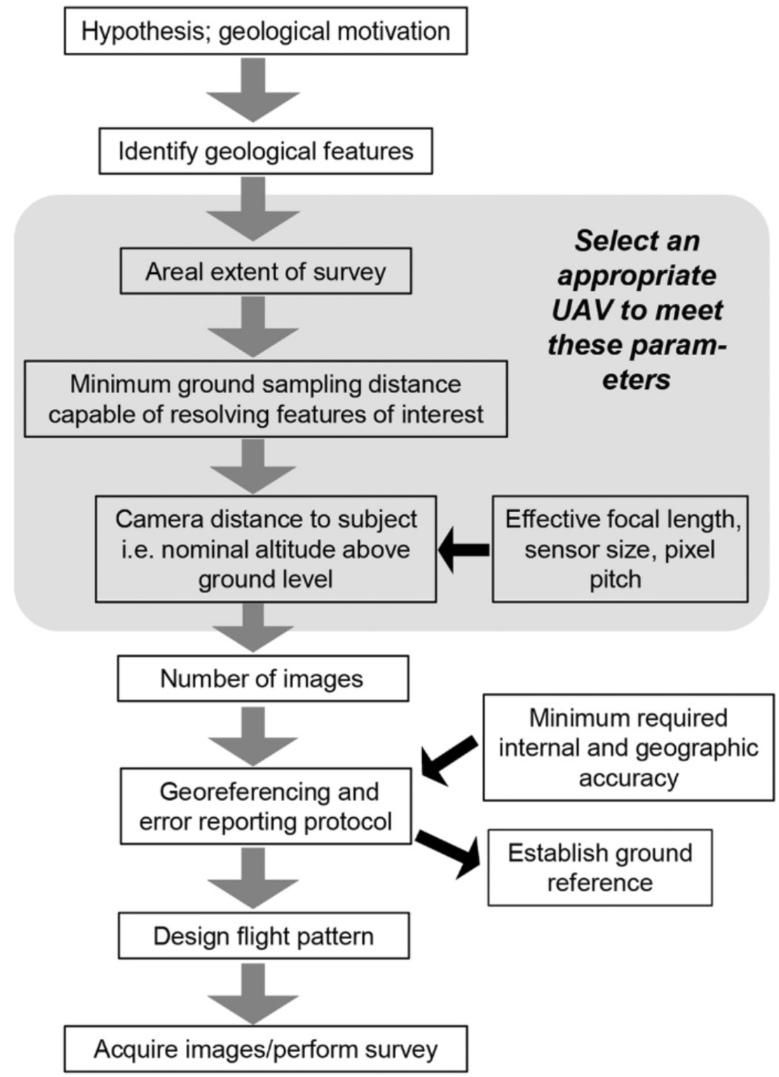


Fig. 1. A hypothesis-driven workflow for photogrammetry survey planning that incorporates geological parameters into the design.

I like this = very clear.

Camera settings and lighting

To complete a photogrammetry process successfully, a firm grasp on camera usage is essential. Without getting lost in the details, it is important to understand how lighting affects the post-process while you are capturing images. There is a need to understand the ISO (film speed), F-stops (aperture), shutter speed, and focus attributes to capture the images correctly for use in post-processing.

ISO

The lower the ISO setting, the less "noise" (graininess) is present in a picture. To human eyes, the difference between ISO 100, and 200 (one exposure step higher) is almost imperceptible. However, as the software finds as many *tie-points* between pictures as possible, the non-perceptible graininess to humans can be extrapolated by the much more accurate computers, and higher ISO can result in an overall lower number of tie-points, and therefore a lower quality render. Thus, the best ISO setting for photogrammetry is always 100.

Shutter Speed

The Shutter Speed is an essential element for photogrammetry, as the speed of the UAV flight will affect the need for a faster Shutter Speed to reduce motion blur. If you are flying quite fast (25 km/h +), you are likely hindering your final product as the quality of the end orthomosaic depends on the quality of the data captured.

Accurate, crisp, and in-focus pictures are essential. For our purposes, we intended to fly slowly and deliberately, and so our Shutter Speed was set to automatic (depending on the exposure level). We then discovered that the software had an option called "safe capture" which meant the UAV stops moving and hovers, captures the image, then continues on its way. We used the feature extensively, especially in high winds, but it did drain the battery faster and slow our image capture speed significantly.

Trade off = good point about battery cost

F-stop

Given the ISO setting is predetermined, the F-Stop setting will be set to automatic, and heavily dependent on the Shutter Speed, to ensure an accurate exposure of each picture. The triangulation formula of photography, also known as the three pillars of photography (https://photographylife.com/, 2022) provides the correct F-stop, which is automatically adjusted by the camera for each image.

Focus

The focus is an intriguing element when using a UAV for photogrammetry, because the UAV is required to fly to a certain altitude, whereby the focus cannot be re-adjusted manually on our UAV and cannot be allowed to refocus automatically which may create differences of focus between images.

Two solutions are possible; the first is to use the infinity focus, which will result in overall consistent focus. However, for a more deliberate and crisper focus point, we can also use a secondary method as follows; first, we fly the UAV to the desired height (based on the recommendation from RH Precision, roughly 245 feet above ground level (AGL)), and then we use the auto-focus feature to set the correct focus by using our remote. We then disable the auto-focus, which “locks-in” the current focus on the camera by switching into manual mode. If we do not touch it again, the focus will remain correct for the designated height. When we then fly the UAV during the photogrammetry capture, the camera will maintain the same focal length, while the UAV will maintain the same height for all images, meaning all images should be in focus (in theory.)

This is a very similar type of exercise completed in everyday photography to solve a similar focus issue - when you want your focus locked into a specific setting but want the camera to automatically find that setting first, and then manually lock that focus. This is often used by photographers such as birdwatchers, since the birds are so small, and often surrounded by branches which constantly throws off the camera's auto-focus. Instead, they focus once on the bird, and switch to manual focus to stop the auto-focus from refocusing. The same workaround was efficient in our case.

Lighting and white balance

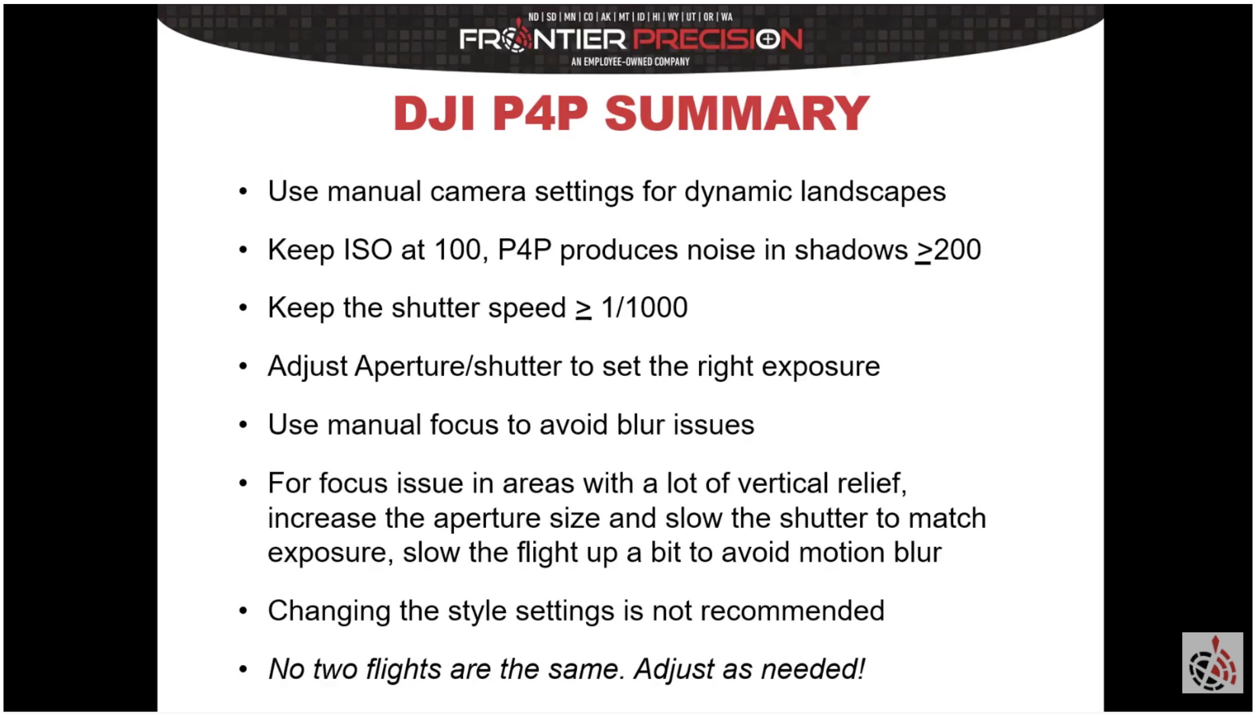
Despite the "golden hour" before sunset generally being known as the most common favorite time to photograph images thanks to the soft light and colors, for photogrammetry capture, this time of day is not the most desired as there are many shadows cast on the ground during golden hour.

For our purposes, the best time to complete the flight is midday when the sun is directly above the trees, limiting the shadows created. This resulted in better and more consistent data capture, and thus a better end model.

great product

In order to ensure similar white balance and exposure for each photograph, it is recommended to capture all photos in one session if possible, and the ideal conditions include mid-day overcast skies, so that there is an abundance of soft light, versus direct sunlight.

Here is a summary of all settings from the *Frontier Precision* youtube channel;



(Frontier Precision, youtube.com, 2018)

Our learning experiences

Our learning experience included 3 sections. Firstly, was the certification process to be able to fly the UAV. This learning curve took a few months from no experience, to obtaining our advanced pilot certification. The second part of the experience was the on-site learning in Ottawa where I was able to participate in a real-time capture, and lastly was our very own capture turned into case-study, the property in Cormier-Village.

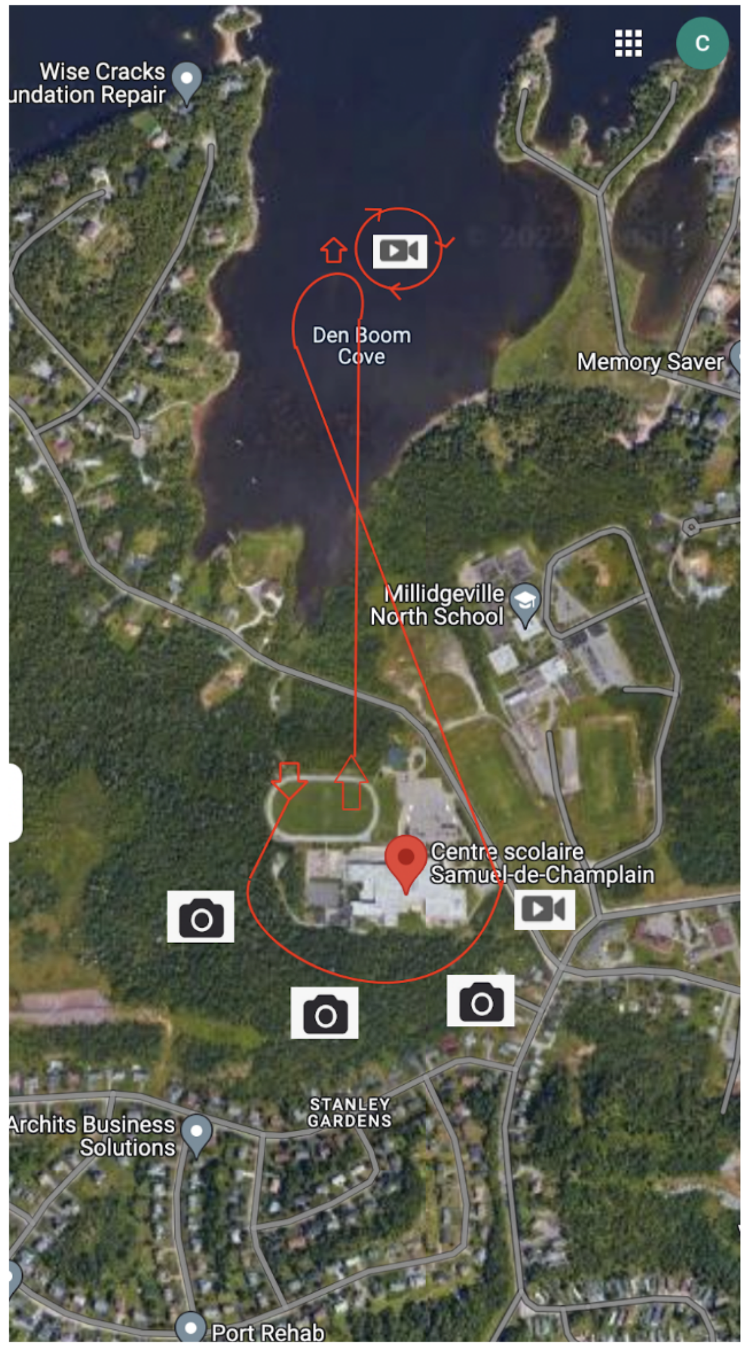
This is good! But should have been presented at the beginning of the paper

Flight training

Transport Canada is responsible for the flight safety of UAVs, and certification of pilots. The process of certification is tiered, with an online test being required for basic certification. This level allows the pilot to fly in unrestricted airspace, away from people, and comes with a host of restrictions. For most audio-visual reasons to capture photos, this is a sufficient license to get the shots required to complete most projects.

Photogrammetry often requires flying above or near buildings, and urban environments may not allow the ability to completely avoid persons below or may require flying in restricted airspace. Although airspace must be known to obtain the basic license, (so that the pilot knows he is in class G (unrestricted) airspace - the only one basic pilots are allowed to fly in), the knowledge leap between basic and advanced is significant in terms of expectations during emergency events, as well as the additional step of a practical exam.

I had previously completed the online written portions for both piloting levels during the pandemic, however the practical test had remained outstanding. On July 7th, 2022, I completed the testing required and obtained an advanced license. The testing procedures came with the requirement for an operational flight plan, as well as a Site Survey.



Our pre-planned flight path for our advanced license testing in St. John, NB. We focused on a North to South flight due to the nearby Aerodrome to the East – the helipad of the St. John hospital. We indicated where we would capture videos and pictures, before returning to land in the soccer field. We obtained permission from the school prior to the flight.

Site Survey

UAV Flight July 7th, 2022 18:00 hrs

UAV Pilot: Christophe Lirette (PC2023153505)
705-205-4828
chrislirette@gmail.com

✓

Proposed location:
Centre Scolaire Samuel-de-Champlain and surrounding Areas,
St. John, NB.

Actual operational zone

Take Off/Landing Zone:
Latitude/Longitude: ~ 45°17.70 N, 66°07.02W

The testing went well, and on the 18th of August, I obtained my advanced pilot certification. I was now ready to fly!

Transport Canada   Transports Canada

Pilot certificate

Small Remotely Piloted Aircraft System (RPAS), Visual line-of-sight (VLOS)

The individual indicated below may exercise their privileges to fly a drone subject to the rules and regulations listed below and set out under the Canadian Aviation Regulations (CAR).

Issued to:
Christophe H.P. Lirette
194 Charlotte St.
Sackville, NB E4L 2Y8

Date issued (YYYY-MM-DD):
2020-08-18

- [x] Basic operations
- [x] Advanced operations
- [ ] Flight reviewer rating

Certificate number:
PC2023153505

Transport Canada account number:
TC2023185097

Rules and regulations

2. Ottawa

On July 20th, 2022, RH Precision advised me that they had obtained clearance to fly for a contract located on Sparks St. in Ottawa, between August 2nd to 12th, 2022. Sparks Street is very near the parliament buildings, which initiated a host of challenges for this project. The parliamentary airspace is class F, meaning highly restricted, and the team was required to obtain clearance from Air Traffic Control (ATC), as well as parliamentary security. They also had to request a “geo-fence clearance” from DJI (the manufacturer of the UAV they were using) to be programmed within the UAV.

Modern UAVs are advanced enough with their GPS systems to “understand” where they are in term of airspace, and if the geo-fence clearance is not requested and approved, the UAV may actually “refuse” to fly within class F airspace - a fascinating challenge given it is the hardware which must be overcome, not the bureaucracy.

The total capture included 4 facades of the building, hundreds of photographs, dozens of battery flight times, and the process took two full days. Because the street below was busy with pedestrians, the team used a parachute system on the UAV, in case it ever came crashing down. Although this reduced the flight time considerably per battery, it removed the need to close the street, and was well worth the extra effort and safety. I was able to participate mainly by acting as a gopher on the site - carrying batteries back and forth as they were charged up at the designated base camp, and I also worked as a second spotter, ensuring no pedestrians bothered the pilot during flight, and explaining to any curious onlookers what we were doing.

The entire experience provided a real-life example of the workflow process, security requirements, reporting procedures, and the real-life hazards of flying a UAV in the middle of the city (low hanging wires, lampposts, traffic, building facades, etc.) and it was a fantastic learning experience.

Alex Healy (co-owner of RH Precision) is a great pilot, and it was certainly an asset to watch him work and learn his process. Matt Ryan (the other co-owner) is the post-processing wizard. Once the picture capture was complete, he demonstrated how to use the software to complete the orthomosaic. First backing up the data, then uploading all the images before review of the data to ensure the GPS data was correctly labeled. Followed by using the Pix4D Cloud processing software to complete the post-processing, which can often take hours.

Pix4D) reiterated some discussion

Overall, I was able to see the entire workflow from capture day to the post-processing and the end result that would be delivered to the client. The experience absolutely helped me when creating my own orthomosaic in Cormier-Village.

I feel.

3. The Cormier-Village Case Study

Currently underway in Cormier-Village is the construction of a 18 hole disc golf course on a ~30-acre piece of property next to the community center. Given we had permission and access to this piece of land during my learning experience, I decided to use it as a test ground for my own orthomosaic creation, to see if my capacities and experiences thus far would allow me to successfully pilot, capture and process a completed orthomosaic.

As usual, RH precision was instrumental in my success, and instructions before I took off included the following;

"1. overlap overlap overlap - Typically you will see that Pix4D and others will promote a 60-70 or 65-75 (side and long track between image overlap) - do more. 80-80 is the way to go. The more data you have on the front end.... the better."

Overlap means the amount of same ground captured by different pictures. Overlapping photos takes more time but provides a lot more data for the post-processing to connect the "tie points."

"If accuracy is not an issue, fly as high as possible - give yourself 10-15m of room from the regulatory requirements in case there are gusts of wind, or the drone does some erratic movements. The more terrain you can get per image the better so push for at least 100m to make a wicked terrain model…Shadows that are thrown by trees need to be as consistent as possible between images from day to day and is the biggest hurdle when doing this kind of work over large areas/merging the data (RH Precision Email, 2022)."

For my case, it was suggested that I overlap aggressively and fly as high as possibly to capture as much ground as possible. The more tie points, the more accurate the result will be, thus the more overlap, the better the end product should be.

This was especially important ~~when capturing forests, as~~ the greenery from above can often mesh. For this reason, their suggestion was also to try to fly as early as possible before the budding has begun. Unfortunately, we had little choice in the matter as the timing of most of the project was out of my hands. Upon receipt of the UAV from the company, the batteries were found to be unusable, and new batteries were ordered. By the time the UAV was in the air, the buds had fully matured on the trees, and the canopy was full, creating a somewhat challenging scenario.

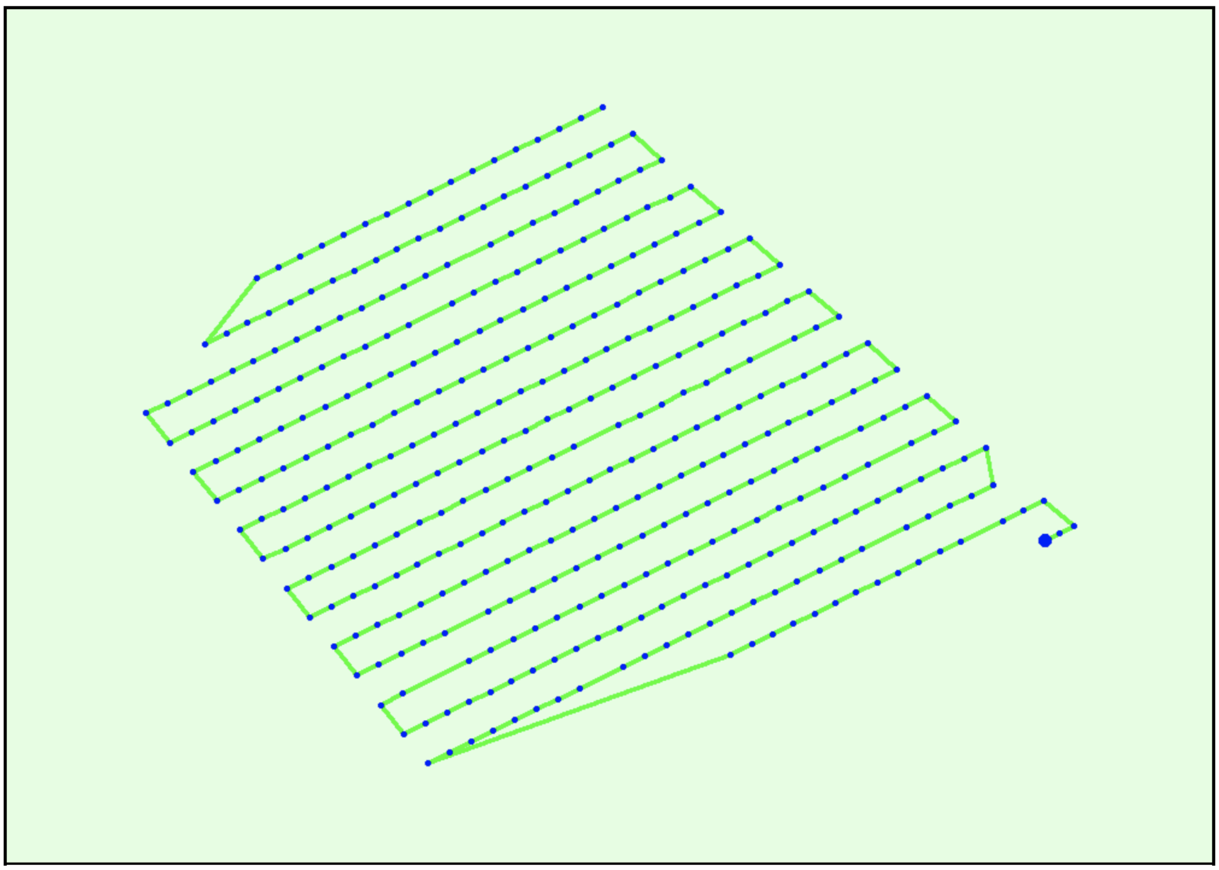
The Flight

The biggest factors in capturing usable images are lighting conditions and the ability to fly. Weather analysis quickly became a constant operational requirement, as UAVs are surprisingly often precluded from flying, mostly due to high winds or lack of satellite coverage, but also because solar radiation storms can affect radio frequency (RF) transmissions between the controller and aircraft. Perfectly timed flight windows had to be taken advantage of, as the perfect conditions were rarely available.

Sites such as uavforcast.com provide 24-hour advanced forecasting that encompass all elements of flying a UAV in an easy-to-use "yes/no" flight decision.

Current Conditions as of Wednesday 2022-07-20 13:29 ADT										
Time	*Wind*	*Gusts*	*Temp*	*Precip Prob*	*Cloud Cover*	*Visibility*	*Visible Sats*	*Kp*	*Est. Sats Locked*	*Good To Fly?*
13:29 ☼	15 mph→	32 mph→	76°F	-	6%	10 miles	12	3	11.1	no
Wednesday 2022-07-20: sunrise 05:46, sunset 21:03										
Time	*Wind*	*Gusts*	*Temp*	*Precip Prob*	*Cloud Cover*	*Visibility*	*Visible Sats*	*Kp*	*Est. Sats Locked*	*Good To Fly?*
14:00 ☼	15 mph→	31 mph→	77°F	-	7%	10 miles	11	3	10.6	no
15:00 ☼	15 mph→	30 mph→	78°F	-	15%	10 miles	9	4	8.8	no
16:00 ☼	13 mph→	27 mph→	78°F	-	17%	10 miles	14	4	13.3	no
17:00 ☼	12 mph→	25 mph→	79°F	-	18%	10 miles	13	4	12.9	no
18:00 ☼	12 mph→	24 mph→	78°F	-	20%	10 miles	17	4	16.5	no
19:00 ☼	9 mph→	20 mph→	77°F	-	12%	10 miles	19	4	17.9	yes
20:00 ☼	6 mph→	12 mph→	75°F	-	13%	10 miles	15	4	13.8	yes

Thankfully, we were able to find a break in the weather. The flight was pre-programmed within the software, and the mission was launched. In total, 386 images were taken. From the after-mission quality report, here is a schematic of the flight path. Each dot indicates a photo captured.

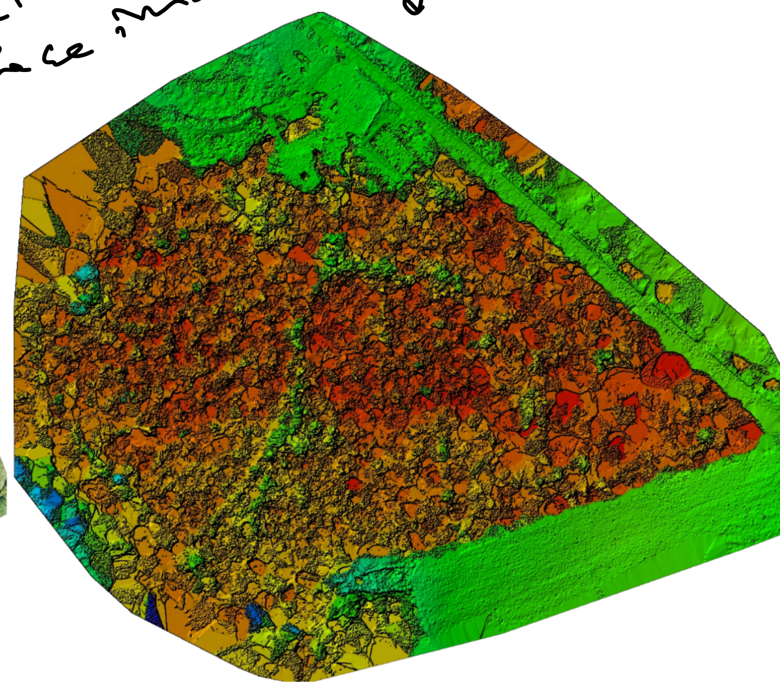


The flight capture is not perfect; some pictures are missing due to the UAV losing connection momentarily during flight, as well as instances of not returning to the exact position/skipping a photo following the return to home after a battery swap.

Following the flight, the data was uploaded to the software cloud and the model was rendered in 6 hours and 38 minutes using a MacBook pro with a relatively decent processor. Given the size of their projects, RH Precision uses a custom-built computer that was adapted for these specific tasks. Modifications include 128 Gigs of Ram, and a high-speed CPU for faster processing.

Lastly, the software processed the entirety of our photographs and created the final orthomosaic;

What's the total area of these images?



The colorful image to the right is the Digital Surface Model (DSM), which is similar to an elevation model, but is not as accurate. It does, however, provide a visual representation of the accuracy level of the end model based on tie-points, as well as detailed features of the surface, such as the small creek flowing North to South in the middle the forested area. The green areas are much better defined, while you can see the oversaturated section to the top left are stretched out and inaccurate in the DSM.

The left portion of the visual image is oversaturated; a result of the sun peeking out front the clouds during the capture phase. It is difficult to find perfect weather

The orthomosaic created by the author in August of 2022 of the property in Cormier-Village. The building to the top left next to the tennis court is the community center. Although not perfect, it does provide a visual model of the property. It would also be used as a comparative model to our post-hurricane assessment.

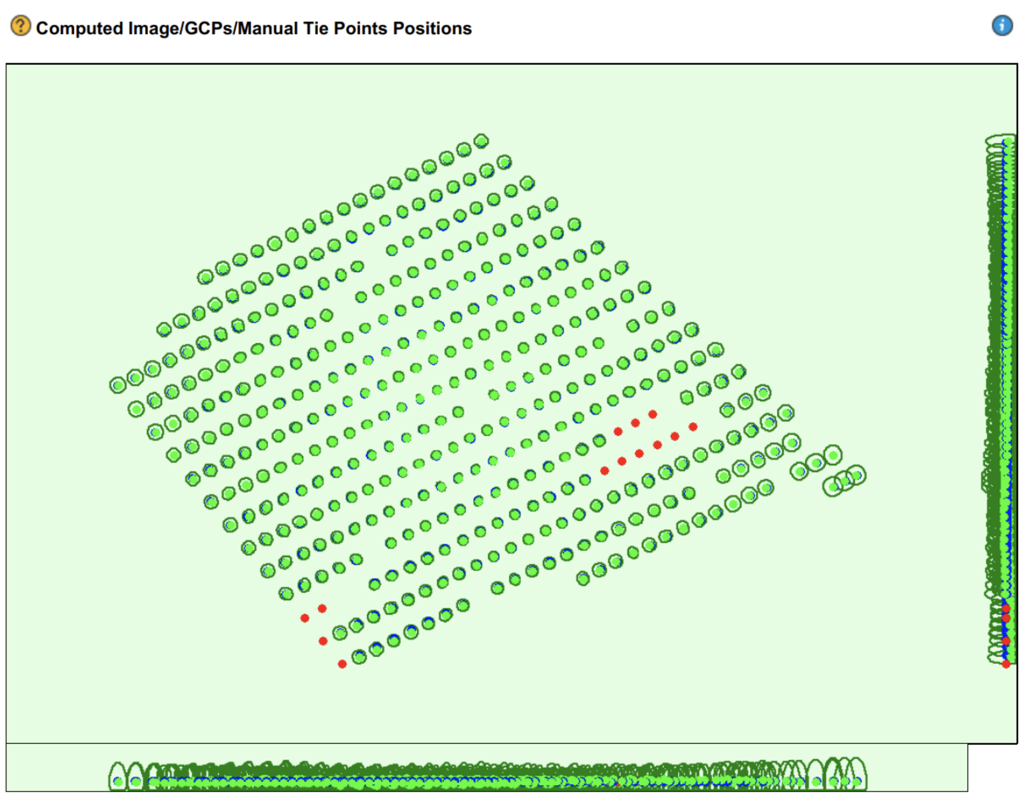
conditions. As our battery charged, the conditions from the noon-time overcast conditions changed to mid-afternoon direct sunlight.

GPS Coordinates and Ground GPS points

The post processing of data includes three steps. First the computer analyzes each image and ensures the metadata is attached. It then lays them out in a virtual geographical plane, and then it connects the tie points, creating a point-cloud. This is a virtual laying-out of sorts of all the images and the various tie points which will create the photomosaic. At this stage the model can be modified and edited within the software. One example of a modification is the creation of virtual GCP's.

GCP's

During certain capture missions when high precision is required, pilots can use Ground Control Points (GCP's), which are visual targets placed on the ground during capture, which are "attached" to their



From the author (2022.) The post review of the various tie points per position from the capture. The red dots are areas where there are little lie points, and some match up with missed pictures, or difficult capture areas. The right and bottom columns provide a spatial depth to the pictures taken (elevation).

verified GPS coordinates. Using very precise GPS points means the post-processing can use the GPS coordinates, and build the model from these points, ensuring an accurate representation.

Virtual GCP’s are a similar concept, except you simply create the GCP digitally within the software, regardless of actual accuracy (when you don’t require real-world accuracy, that is), this then allows the computer to build off the GCP which can often help with warping or inaccurate rendering. In a sense, it is a digital, location-based anchor.

On the left is an example of a post-processed assessment of tie points and key point matches.

The notable aspect of the key point matches and how the terrain being captured will affect the post-processing is apparent within the diagram.

2D Keypoint Matches

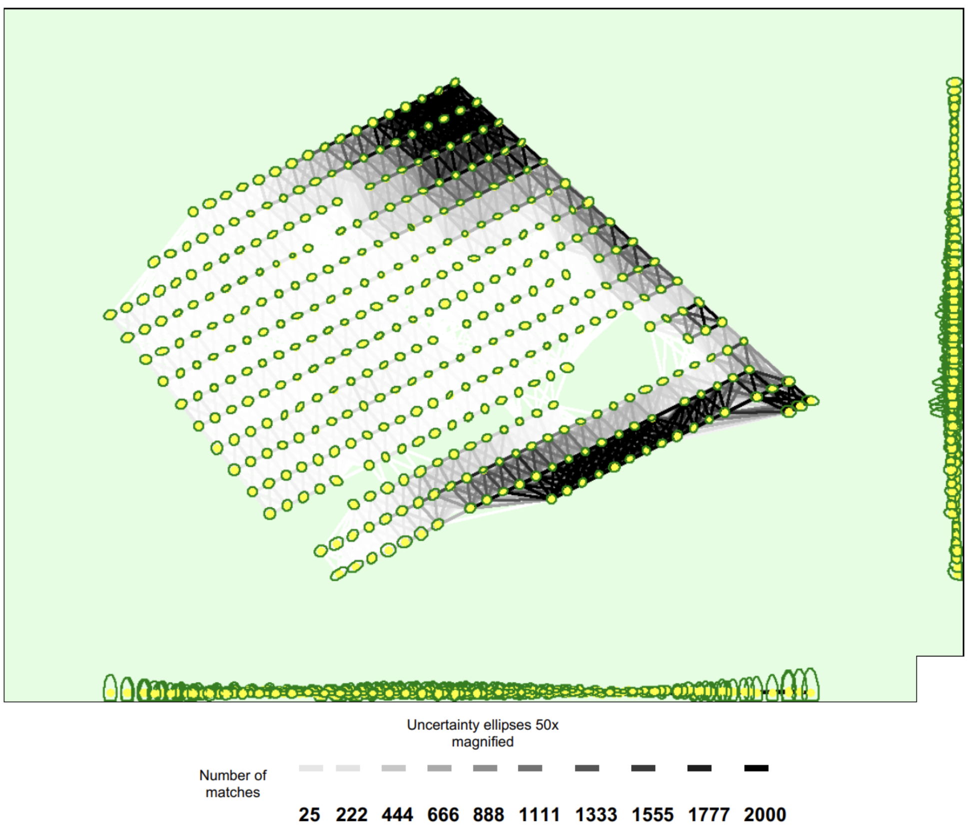


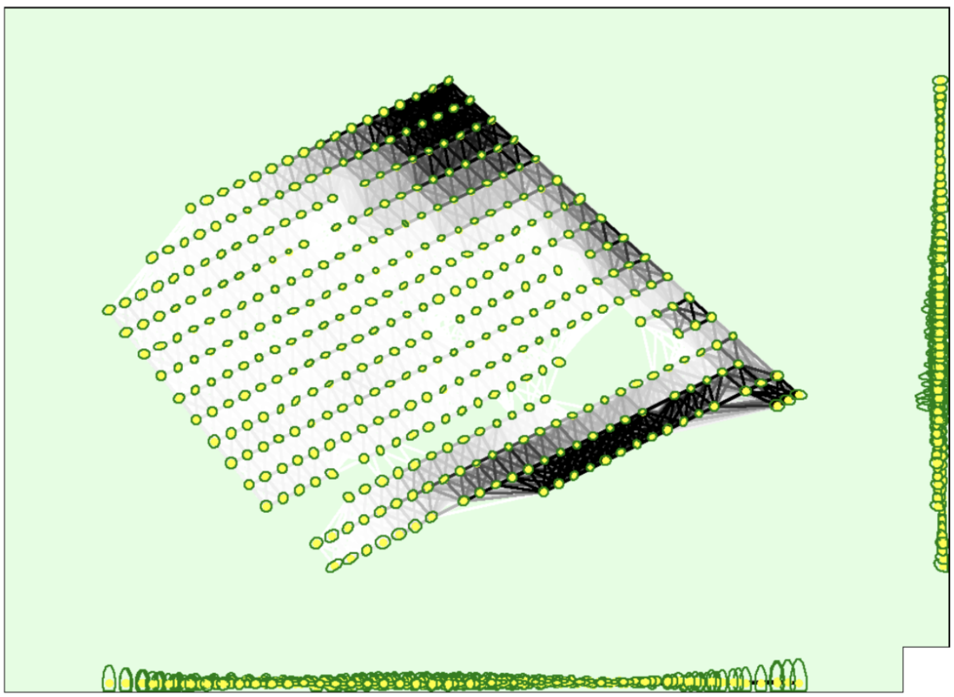
Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.078	0.070	0.089	0.076	0.072	0.019
Sigma	0.012	0.012	0.053	0.034	0.029	0.004

From the author (2022.) A visual representation of key point (tie-point) matches, displayed based on the terrain mapped. The dark areas of concentrations of many tie-points, the whiter areas and wider circles represent less certainty, and may result in warped or blurry imagery as the computer tries to match tie-points.

The dark areas are locations where there are a high number of tie-point matches, and within the image, these areas correspond to the roads, the parking lot, and the surrounding fields. The whiter areas within the image, are where there are lower numbers of matches, and it corresponds to the forested area, as we were warned about prior to our capture due to the foliage.



What this means, is that the software can find many more tie points within solid and unique (and unmoving) geography such as the parking lot, roads, or the tennis court, as compared to areas with dense trees, which may be moving in the wind, and are difficult to connect via tie points due to the foliage density.

yes, good point.

Our attempt

Overall, our attempt was met with success. One “major” technical issue encountered was the limitations imposed by battery life. Having 2 batteries at our disposal, we flew our first flight, and then while our second flight was ongoing, charged the first battery. However, as our batteries depleted faster than they charged, our third flight was delayed significantly by the charging time required, resulting in the image oversaturation. Purchasing additional batteries removed this restriction moving forward.

We were also able to successfully navigate the Pix4D software to process the images and programmed the flight details required to capture the data.

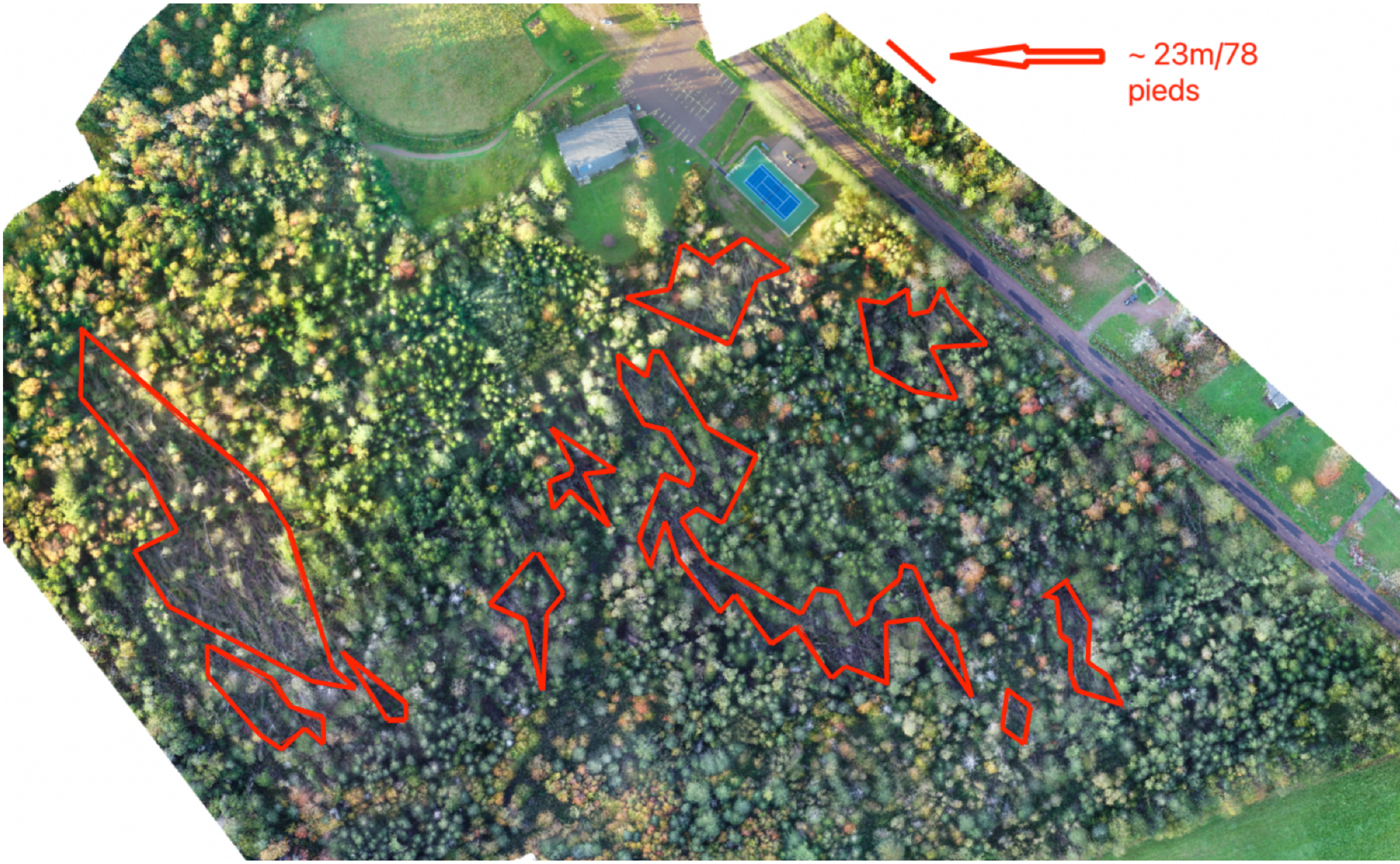
Hurricane Fiona

On September 24th, 2022, one of the largest hurricanes to strike the East Coast of Canada created massive destruction along the coast of New Brunswick (cbc.ca, 2022). Unfortunately (but fantastic for our project…), the same plot of land we had captured only a few weeks earlier was decimated during the hurricane. Despite the devastation, an opportunity arose to use UAV based photogrammetry to assess the post-damage. Given the urgent requirement for the assessment, we took the first available usable weather window, which resulted in late day capture. Batteries were charged, and before long the UAV was out over the property again.

This is really cool

The software allowed us the ability to simply reproduce the exact same mission and flight as our previous attempt, and thus the process was even simpler than the first attempt. Despite having to accept a day with less-than-desirable weather and sunlight, our result was quite effective for our needs. The changing colors of some of the leaves also helped differentiate individual trees.

The following Orthomosaic was created;



We outlined in red the areas which suffered the most damage. Especially prominent is the large swath to the left, which by comparing with the tennis court as a scale, we can see is hundreds of feet long.

By using Google Earth Pro, we were then able to roughly estimate the total area of devastation (left).

Segment	Size (Acres)
1	0.24
2	1.46
3	0.1
4	0.1
5	0.11
6	0.1
7	0.7
8	0.1
9	0.15
10	0.46
total	3.52

For the construction of the disc golf course, most areas which have been flattened now need to be cleared. So far, section #10, which amounts to .46 acres, was cleared in roughly 4 full days of logging. We are also only planning to log about half of section #2. We can thus calculate how much we've cleared so far:

Section 10 divided by the total to clear (which is 3.52 acres - half of section two)

Sec10 / (3.52 - (Sec2/2) =

0.46/ (3.52 - 1.46/2) =

0.46/ (3.52 - 0.73) =

.46/2.79 =

16.48% of the total we need to clear has been cleared thus far.

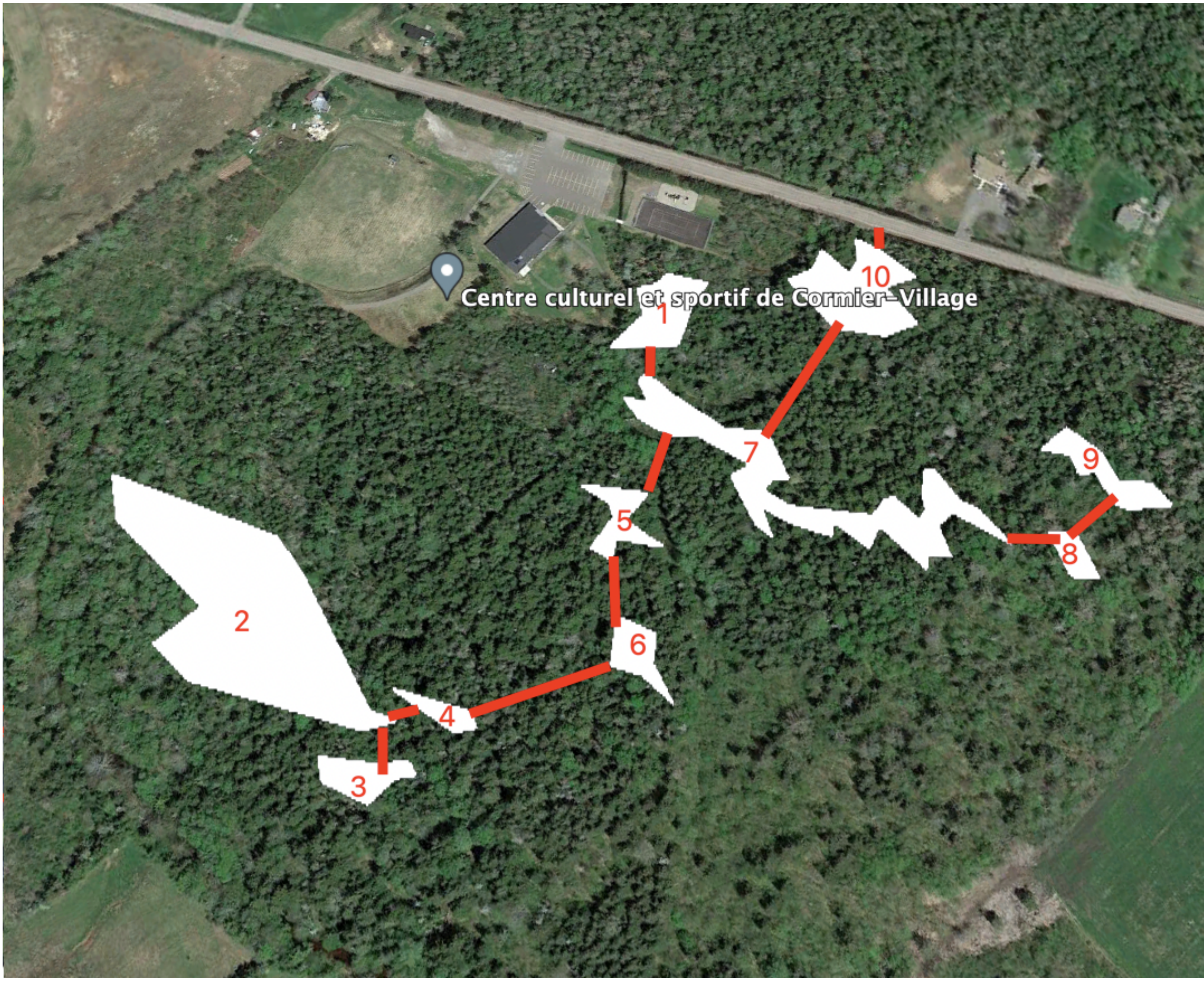
3,52 acre out of a total in your area of what?

Meaning, we require;

100%/16.48% = 6.0679, or roughly 6 times over the work already done, to complete the total clearing.

Given we know that we worked about 4 full days, this means we should be able to clear the sections of fallen trees in roughly (6x4 =) ~24 days of work.

We can add another few days or so for the roads we will be required to build in between sections, however this also highlights another advantage of the bird's eye view of our model. Thanks to our knowledge of where the damaged sections are, we can also strategically place our roads to limit tree cutting. We've clearly demonstrated two benefits of using photogrammetry for the disc golf project.



From the author (2022). A visual representation of the size of damaged areas, along with the likely roads to be built, which will allow for the least overall deforestation. Photogrammetry has provided a sharable, accurate, detailed and quite useful map of the property. The timing of the hurricane was impeccable for our project, despite the work remaining to be completed.

Personal Reflections

The partnership with RH Precision in Ottawa has developed into a wonderfully cooperative arrangement and a mentorship. Their interest in seeing this project succeed was highlighted by the hardware lent to the completion of our mapping. RH Precision was gracious enough to send us their “old” Phantom 4 Pro UAV. Our only cost was the purchase of the batteries required to power the UAV.

Despite being slightly dated compared to new technology the Phantom 4 pro is equipped with a gimbal camera and rolling shutter - both optimal features for capturing precise photographs. The intelligent batteries self-monitor their depletion level, with a typical flight time of approximately 30 minutes, depending on wind strength and speed. The controller which came with it plugged into any cellular phone or tablet, where the user downloads the apps required. It was a perfect aircraft to learn to fly for our project.

The experienced staff at RH Precision were fantastic to shadow during the on-site job in Ottawa. Their knowledge, comfort in difficult technical situations, piloting skills, and navigation abilities through the bureaucratic maze of Ottawa city and federal approvals was all clearly demonstrated during the project. The project undertook in Ottawa should not be minimized in terms of complexity, risk levels, and the potential for things to go drastically wrong. Despite all of these risks, RH Precision managed to seamlessly fly multiple UAV flights in a congested urban area with (as their name states) precision. The end photomosaic will be used to complete the mandated timeframes for building façade inspection, saving the owner of the building thousands of dollars as compared to traditional methods (which includes lots of time and scaffolding). Their services are not only technologically impressive, and modern, they are useful and efficient. RH Precision has done the same type of modelling with the Parliament of Canada buildings during the renovations they are currently undertaking, a testament to their abilities and professionalism.

Their support while I undertook my own small mission and milestones to familiarize myself with the aircraft and software was invaluable to my success. Their patience teaching me the technical skills required and answering questions was very appreciated, as were the after-mission lunches to discuss and debrief about the day's work while in Ottawa.

Following the entirety of the work experience, my comfort level at flying UAVs has grown exponentially. With further guidance, professional level photogrammetry captures are within y reach and this opportunity was a fantastic experience, far exceeding my initial expectations when the idea of a work experiential program occurred to me as a possible avenue to learn more about the technology.

Lastly, I thank Dr. Lieske, and the University of Mount Allison for their flexibility and support during this program. It would certainly be a recommendation from my part, for any student in the future who wishes to undertake the same type of learning.

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