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Falcon Unmanned Aerial Vehicle

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Project Report:

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Abstract

Missionary aviation pilots often must land their planes on remote airstrips that might be unsafe due to runway obstructions such as encroaching vegetation or large objects that were unknowingly placed on the runway. The Falcon Unmanned Aerial Vehicle (UAV) team partnered with Indigenous People's Technology and Education Center (ITEC) to develop an imaging system using a UAV to scan these airstrips to detect these obstructions. ITEC was founded by Steve Saint, the son of martyred missionary Nate Saint, to develop technologies to aid missionaries and indigenous peoples in their work. This document highlights the work of the Falcon UAV team and the basic terms and definitions for understanding the work of the team. The Falcon UAV team focused primarily on the use of automated 3D mapping and photogrammetry by drones to help identify obstructions to pilots landing on remote airstrips. This document explores different options for drones to purchase and software to use. Through our research and experimentation, the team is recommending the DJI Mavic Platinum Pro in combination with the DroneDeploy 3D mapping software.

Problem Definition

In remote areas of Ecuador, where ITEC has requested mapping to be done, airstrips are not regularly maintained and often can become overgrown with vegetation and obstacles that might be unsafe for arriving or departing aircraft. In these areas the airspaces, approaches, and airports are poorly documented and mapped. Many new, and even experienced pilots must use approach plates made over 50 years ago to fly into these small uncontrolled airports. This puts the pilots at risk of encountering overgrown trees, unmaintained vegetation, and obstacles which may not have been there since the last operation. The Falcon UAV team is tasked with creating a solution for high-resolution maps, as well as a process for the collection of data required.

Overview of Project

The Falcon UAV team at Messiah University began research various methods of solving the problem as previously described. In discussions with ITEC it was fairly clear that a drone solution seemed like the most affordable and promising way to map the runways. The team investigated using LIDAR which is a laser based system used for high resolution mapping but these systems are too costly (see the Additional Research section of this report for more information). The team determined using a drone along with third-party 3D modeling software was the best approach for several reasons including cost, ease of use, greater adoption by organizations, as well as continued advanced in drones and sensors for drones. The team began researching various drones and software vendors to determine their capabilities and pros and cons. After determining that we would use the DJI Mavic Platinum Pro drone system along with using Drone Deploy 3D mapping. The team then began testing the system to see how effective it would be at detecting small objects, holes, and trees and determining the size, shape, and height of each of these.

After better understanding the capabilities and limitations of this system, the team began creating how to videos and documents to help train ITEC and other future users of this system. See the document entitled "Creating effective 3D maps" for more information as well as tutorial videos. Finally, in May of 2021, the team was able to travel to ITEC in Florida to do further testing and training of this system.

Drone Decision

The Falcon UAV mapping system uses a DJI Mavic Pro Platinum quadcopter for taking pictures of the desired airstrip. The decision to use the DJI Mavic was made using a decision matrix that compared price, weight, size, flight time, battery life, top speed, obstacle avoidance, and camera quality of many of the top competing drones on the market. Examples include Mavic Pro Platinum, Mavic Pro, Mavic Air, Inspire 2, Phantom 4 Pro, Yuneec Typhon, and the Walkera Voyager 4. The Mavic Pro Platinum was chosen because it had the best combination of the above criteria with respect to how valuable each criterion was to the goal of the mapping system. Some of the drones in this list were not compatible with the software the team ended up using. The Mavic performs well in the most important categories such as price, camera quality, and battery life. It is also compatible with DroneDeploy. See table 1 below for an abbreviated comparison, and see document entitled, "Comparing selected drones" for a more in-depth comparison. The team recommends confirming that DroneDeploy supports the desired drone before purchasing said drone as there are a few drones that are not supported.

Figure 1- Shows Mavic Pro Platinum used for the Falcon UAV mapping system

Drone	Mavic Pro Platinum	Phantom 4 Pro	Mavic Air	Mavic Pro
Price	$ 1,150.00	$ 1,200.00	$ 919.00	$ 899.00
Weight (drone+battery+props)	1.6 lbs	3.06 lbs	0.95 lbs	1.64 lbs
Flight Time (claimed)	30 mins	30 mins	21 mins	27 mins
Range	7 km (4.35 miles)	4.35 miles	2.48 miles	4.3 miles
Camera Specs	4k (video) 12MP (resolution)	4k/60 video, 20MP camera	4k HD ,12MP camera	12 MP/4K

Table 1- Shows an abbreviated comparison table for drones

Software Decision

The Falcon UAV team utilizes Drone Deploy as the software service for all mapping operations. This decision was made after evaluating different factors between different software options. The two main software services that the team compared were Drone Deploy and Pix4D. The main factors for software comparison were software specifications, drone compatibility, price, and ease of use.

The team ultimately decided to select Drone Deploy. This is because there wasn't a distinct advantage to using Pix4D over Drone Deploy. Both software packages support DJI drones, so our drone recommendation of the DJI Mavic Pro would be compatible with either. Additionally, Pix4D's feature of being able to upload a maximum of 2,000 images was not being fully utilized. The largest map the team had conducted was of an airstrip and surrounding area that took up 200 acres but, at an altitude of 390 feet, the image count was only 809. This made Drone Deploy just as viable to use even with its limit of 1,000 images per upload.

In terms of ease of use, Drone Deploy is much more user friendly than Pix4D. This combined with Drone Deploy's track record of having accurate data presentation made it desirable for the team. It is also important to note that Pix4D had issues with producing Digital Surface Models (DSMs) that were easy to read or be analyzed. Drone Deploy on the other hand had DSMs that were easy to view and displayed elevation changes prominently. Seeing that the DSM is one of the most crucial tools in order to analyze mapped areas, this feature took the highest priority in the software decision.

In terms of price, Drone Deploy has a basic plan starting at $149 per month ($449 per month for the full plan), and Pix4D starts at $42 per month for a basic plan, and $291.67 per month for a full plan. While Drone Deploy is more expensive than Pix4D, the basic plan for Drone Deploy was capable of servicing the needs of the team during testing and analysis. As mentioned before, Drone Deploy also had superior usability, better data presentation, and didn't seem to be at much of a disadvantage compared to Pix4D.

This is not to say that Pix4D isn't a viable software product for mapping; from the perspective of the team, Drone Deploy was the better option. Pix4D may still be worth experimenting with in the future. See Appendix for a comparison table of Drone Deploy versus Pix4D.

Capabilities and Limitations of the System

General Capabilities and Limitations of the Drone

Drones are a great way to get stunning aerial images and footage at a low cost-point, but with that being said there are certainly limitations to what it can accomplish. These limitations can impact how the overall system performs, but it was found that the system was still successful despite these limitations.

Battery Life

The biggest limitation the drone has is its battery life, and therefore flight time. The DJI Mavic Pro Platinum is listed as having a battery life of up to 30 minutes, but in order to ensure that the battery never runs out while the drone is still in the air, DJI has a default setting where the drone controller alerts you when the drone battery hits 30% to give the user ample time and warning to land safely. The battery life is also affected by the weather (wind speeds, temperature, etc.) so returning to the home position and landing may take longer than usual which is why it is important to keep an eye on the drone's battery while flying. Battery life is the biggest limiting factor to drone flight currently, but thanks to the manufacturer's safety precautions, this factor has been optimized as much as possible for the needs of the project.

Rectangle (Width of 150 m x Length)			
Length (m)	Altitude (ft)	Pixel Density (in/pixel)	# of Batteries
800	100	0.4	8
800	150	0.4	4
800	200	0.5	3
800	300	0.8	2
800	400	1.1	1
700	100	0.4	6
700	150	0.4	3
700	200	0.5	2
700	300	0.8	1
700	400	1.1	1
600	100	0.4	6
600	150	0.4	3
600	200	0.5	2
600	300	0.8	1
600	400	1.1	1
500	100	0.4	5
500	150	0.4	3
500	200	0.5	2
500	300	0.8	1
500	400	1.1	1
400	100	0.4	4
400	150	0.4	2
400	200	0.5	2
400	300	0.8	1
400	400	1.1	1

Table 2- Variance of Map Area and Altitude on Battery Life

Flying in Wind
Another factor that greatly impacted the system was the drone's ability to fly in the wind. DJI recommends not flying in winds greater than 10 m/s or 22mph and this is a good rule to stick to. If you fly in winds higher than this, you risk your drone being blown into an obstruction and crash. These wind numbers are for when the user is in control of the flight and the path of the drone is more fluid. For the purposes of drone-mapping, the drone needs to fly at a certain speed in a specific pattern so the user will need to fly in much lower winds than 22mph in order to get the best results. During testing, it was found that the drone was blown off course and the flight had to be abandoned when flying in winds of around 15mph with gusts of closer to 20mph. The drone was flying at 390 feet in this case so the winds may have been higher at that height than on the ground as well. What the Falcon UAV team recommends is to fly your drone when the winds are as low as possible, but if you need to fly in winds, try to fly in winds under 10mph, and avoid conditions where there will be large gusts of wind as much as possible to ensure the best quality maps.

Obstacle Avoidance
The DJI Mavic Pro Platinum comes equipped with forward and downward obstacle avoidance to keep it from flying into any obstructions. Now while this feature is very handy to have, no sensor is perfect and small branches on the tops of trees could potentially be missed by the drone's sensors which would be the biggest impact to the drone's flight capabilities for the purposes of this project. There is no obstacle avoidance for flying sideways or backwards, but this is not a problem as the drone is always flying forwards when mapping. The obstacle avoidance on this drone is a handy feature to have, but this does not mean the pilot does not need to take necessary precautions to ensure that the drone does not crash. While mapping, the drone will fly at a specified altitude in comparison to the take-off point, so if there is an extreme change in terrain elevation, such as a cliff or steep hill, the drone could fly directly into it. Therefore, it is very important to plan your flight carefully and do a pre-mapping flight to confirm elevation data. These steps can be found in the How-To Manual Record. DJI drones can be switched into "sport" mode which makes them fly faster, but in order to do so, it disables all collision avoidance sensors. It is important to confirm that your drone is not in sport mode while mapping.

Camera
The last aspect of the drone that was looked at for this project was the camera and not actually the drone itself. Since these maps are generated mostly from the pictures taken by said camera, it is important to ensure that the camera quality will stand up to what is being asked of it. When researching drone cameras, the biggest difference that was found was the type of shutter: rolling or global. Rolling shutter is the standard shutter that is found on most drones and is what is on the Mavic Pro Platinum. Global shutter is a slightly different shutter style which is also more expensive which is why it is pretty much only found on the Phantom 4 Pro. Because of the style of drone and the fact that Phantoms have been discontinued, this choice was made for the team out of necessity and cost. Rolling shutter is supposedly slightly worse than global shutters, but only barely and so this problem is not one that has arose during the testing process and therefore has been deemed to be a non-issue for simple mapping functions. The drone research and decision-making process took place in fall of 2019. Since then, DJI has released the second version of most of their models. When looking at the new models, it was noticed that the Mavic Air 2 had a higher megapixel camera and a flight time that 4 minutes longer than the Mavic Pro 2 which made us start to rethink our decision. After looking into it further, it was found that Drone Deploy does not support the Mavic Air 2, so while the drone itself might be slightly better, it will not work for mapping so the team is

sticking with their original recommendation of the Mavic Pro and would recommend the Mavic Pro 2 now that it is available to the public.

General Capabilities and Limitations of the Software

When using the mapping software, there are several features and tools at the disposal of the user to aid in analyzing the map. There are two viewing modes, a Digital Surface Model (DSM) (see Figure 2) and an Orthomosaic (see Figure 3). The DSM is a 2-D representation of the mapped region, in which a color gradient displays higher elevations in red and lower elevations in blue. This gradient is matched with a range bar for specific elevations in Mean Sea Level (MSL), and the gradient can be edited for specific elevations to be displayed at the highest and lowest levels. The Orthomosaic view is a 3-D model of the mapped region and is comparable to the 3-D view that one might see in Google Earth. This view can be useful to look at the physical features of the map in a manner that is to scale.

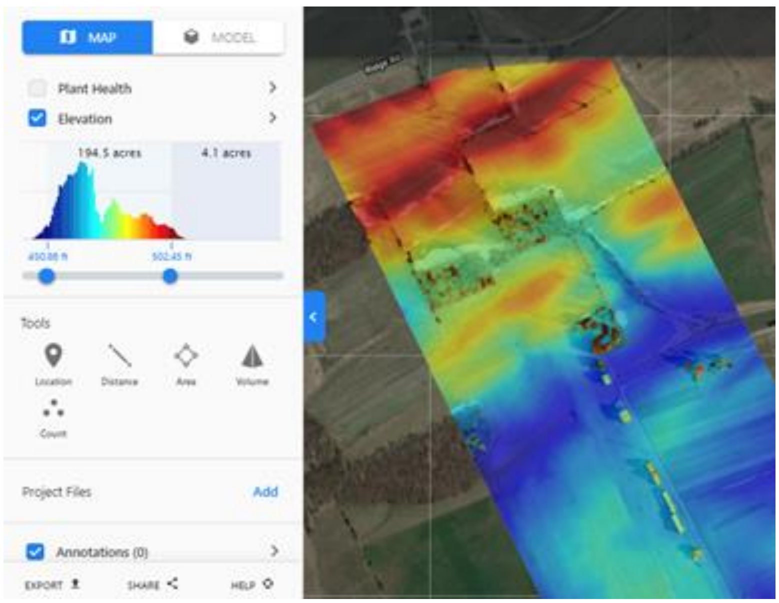

Figure 2: Airstrip DSM in Drone Deploy

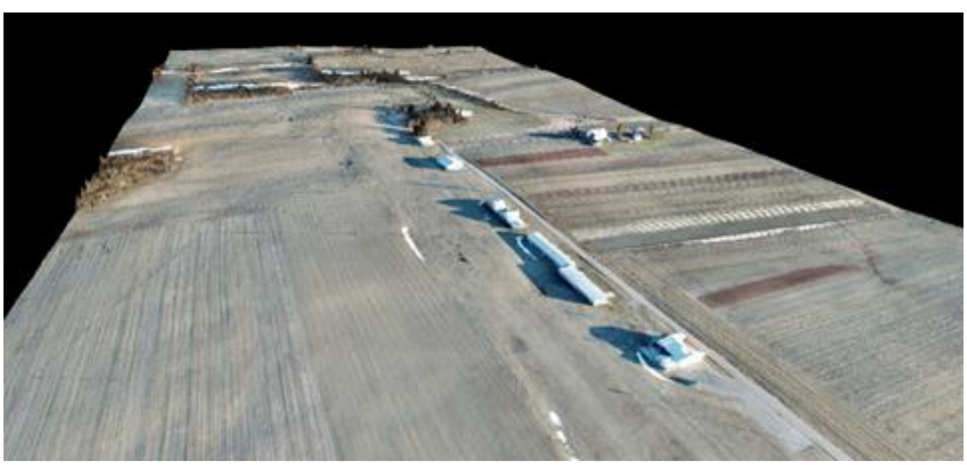

Figure 3: Airstrip Orthomosaic View in Drone Deploy

One of the tools that Drone Deploy offers is the ability to calibrate the elevation data in order to yield more accurate results. To do this, the user must have a separate device to measure the elevation at a specific point on the mapped space (a GPS that reads elevation would work). If the user inputs that elevation value at the specific point on the map using the "Calibrate" tool under "Map Details", the entire map updates to reflect this.

Another tool that Drone Deploy offers is the ability to change the opacity of the DSM. By increasing it, it allows for the gradient to stand out more, and subsequently allow for elevation changes and other unique characteristics to appear more prominently.

Another important feature of Drone Deploy's software is the ability to create an elevation profile (see Figure 4), which is a 2-D graph showing elevation changes along a path along with important data points such as slope, horizontal and surface length, as well as change in height. This can be done by using the "Distance" tool under the "Tools" tab and creating a path with 2 or more points. This line will have a unique elevation profile graph associated to it when the line is clicked on by the user.

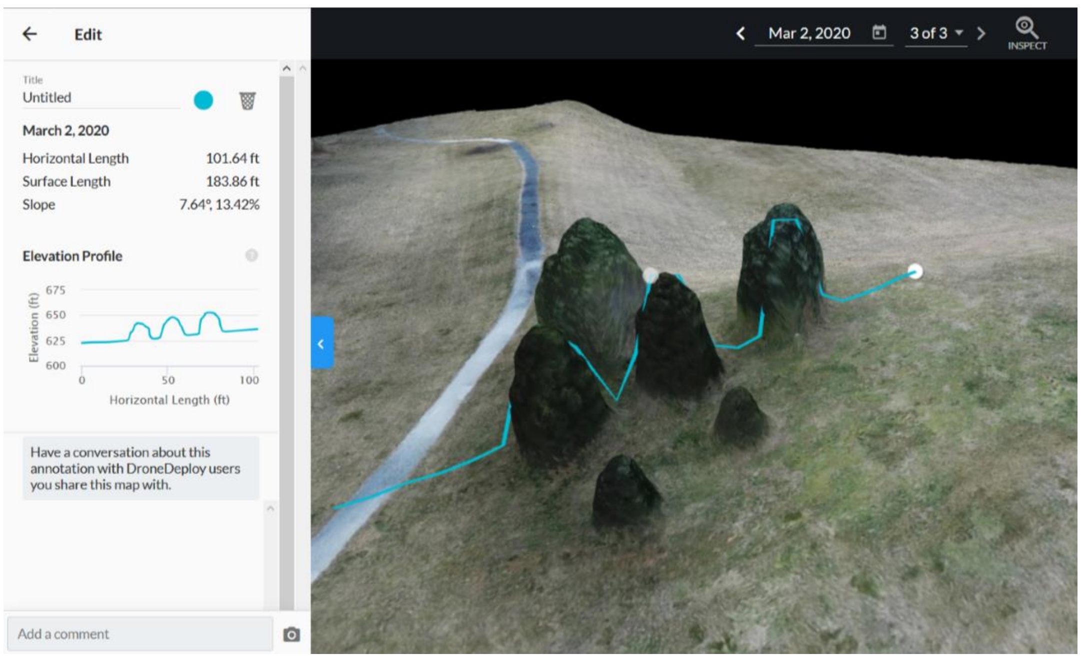

Figure 4: Utilizing the Elevation Profile via Distance Tool

In terms of object detection, it was determined that Drone Deploy can be very accurate at detecting and presenting height measurements for large objects such as trees, even if camera resolution is poor. For small objects, the software can detect the objects both on the elevation profile and the DSM, but the measurements tend to be less accurate compared to large objects.

General Capabilities and Limitations of the Mapping System

A large part of the Falcon UAV team's task was to determine the capabilities and limitations of the mapping system. In other words, the team spent quite a bit of time testing the system in order to generate data showing what the specifications of the system were. Accuracy of measured tree heights and large objects, ability to detect small objects, ability to detect holes and ruts, and largest possible size and length of map were four areas of testing that were focused on. This report gives a summary of the conclusions drawn from the testing. See document entitled, “3D Mapping accuracy testing” for more information about the details of the testing.

The Falcon UAV team found that the accuracy of measuring tree and large object heights depended on the resolution of the map. For a map resolution between 0.6 and 1.3 inches per pixel, the percent error of tree and large object height measurements was between 0.1 and 9 percent respectively. For an object to be classified as “large” and therefore follow the accuracy data above, the area as seen from above the object must be at least 2 square feet, and the height of the object must be at least 1 foot.

Flight Altitude (ft)	Pixel Density (in/pix)
100	0.4
200	0.5
300	0.8
400	1.1

Figure 5- Shows how the flight altitude of the drone affects the resolution of the map (the area of the map was held constant) (Should be Figure 5)

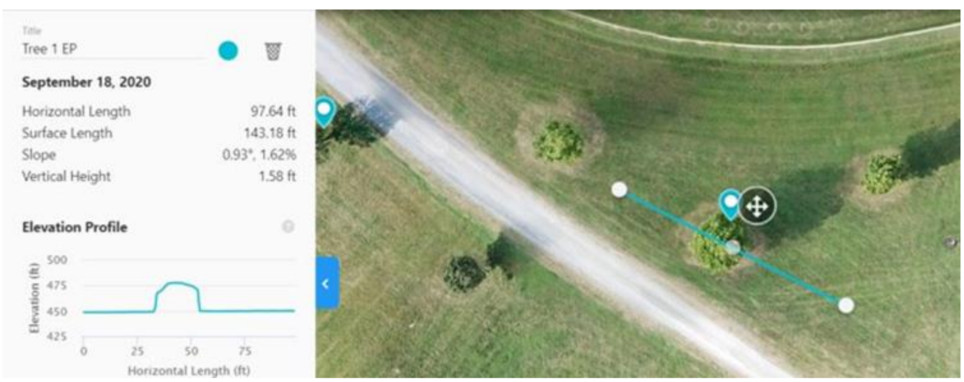

Figure 6- Shows an example of measuring tree height using DroneDeploy (Should be Figure 6)

The ability of this system to detect small objects, holes and ruts is directly related to the resolution of the map which is controlled by changing the flying altitude of the drone (see figure 5). The results from the testing show that a drone pilot should do a flight at an altitude of 150 feet or lower to catch all possible small objects, holes, and ruts in the runway. However, even flights at much higher altitudes (150-400ft) can detect most runway hazards that would be dangerous for small aircraft.

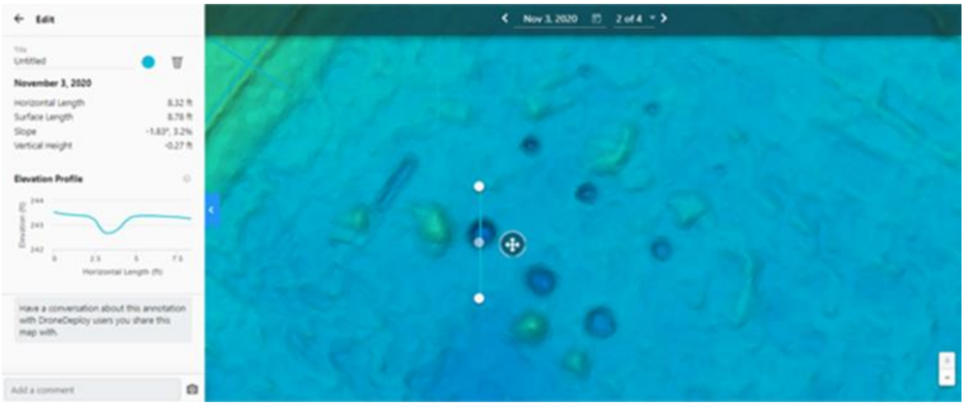

Figure 7- Shows an example of measuring holes using DroneDeploy (Should be Figure 7)

Potential Uses of Resulting Data

The main use of the Falcon UAV mapping system is to gather information needed for producing a substitute for an airport diagram and/or approach plate that would assist the pilot during landing. Specifically, a pilot would be interested in knowing the slope and geometry of the runway, the elevation and location of large objects and trees around the runway, and hazards on the runway. The testing referred to in the previous section was done to explore DroneDeploy's ability to accurately calculate these points of interest.

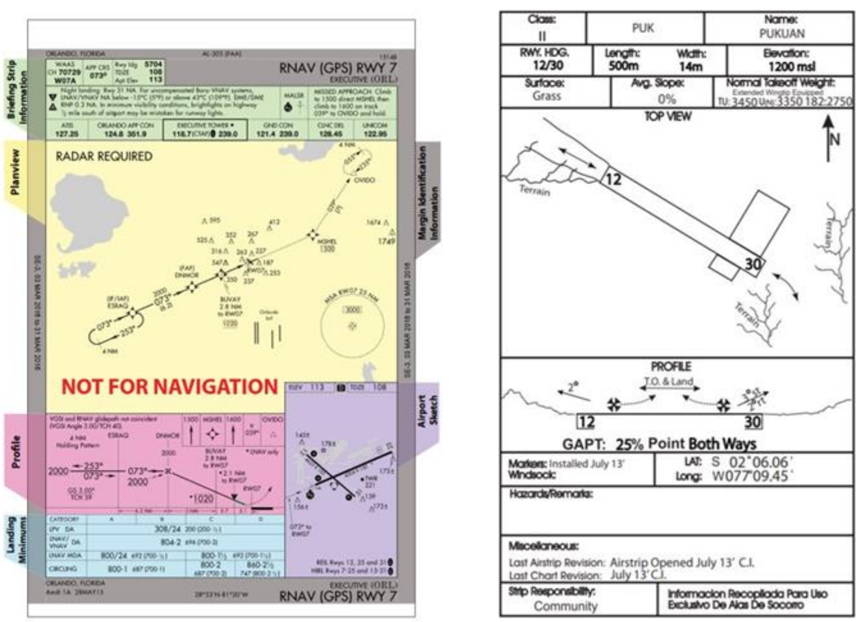

Figure 8- Shows an FAA standard approach plate, and a current ITEC approach plate

Additional Research

During the initial researching phase of the project, alternatives to drone-mapping, such as LIDAR, were looked into for comparison. LIDAR uses lasers to map and model compared to photos as used in the drone-mapping system. LIDAR would do a much better job mapping and can be mounted under a plane so that the airstrip could simply be flown over without having to land, but it is just too expensive right now to be a viable option for this project, as it currently costs around $10,000. When the price of LIDAR systems drops to a price where it is reasonable for ITEC and IAMA to buy one, the Falcon UAV team fully recommends using that instead of drones. Due to the fact that LIDAR is so expensive, the team was left to make the best system possible using commercially available drones and drone software. In the future, LIDAR prices may drop enough that it will become a viable option.

Initially it was thought that the team may be able to develop approach plates from the data gathered during these drone flights. After further research, it was determined that the amount of knowledge needed to make an approach plate up to the desired standards is far above the heads of the students on the team. They did not feel they could make approach plates accurately enough within the timeframe of the project to be able to be confidently used by pilots. That was something that would need to be taken over by ITEC in the future if they still wish to have that as a deliverable.

Because drones connect to satellites for signal and GPS, it was decided that more research should be done on the GPS and elevation data gathered by the drone to see how accurate it truly is. The way GPS works is by triangulating the drone's location from any and all satellites it can connect to. By knowing the position of the various satellites and how each one receives a signal from the drone, the drone's precise location can be determined up to within just a few meters. Now, this is the location on the globe, not the altitude. GPS is very good at determining location, but not nearly as good at determining altitude or elevation. The elevation of a drone is determined using a combination of sensors on the underside of the drone as well as a built-in barometer to read the air pressure. This is how planes determine their altitude while flying. By doing this extra research, the team felt like they had a greater understanding of how drones fly and how accurate their maps truly are.

Conclusion

At this point in the project, it is believed that the Falcon UAV team has developed a system which will be successful in creating and analyzing maps of remote airstrips using reasonably-priced, commercially available, products. Due to the speed at which technology changes and updates, this system could easily be outdated with a few years, but the ideas and research gathered through this project should give the user a strong foundation and ample knowledge to be able to adapt the system to new technologies as they become available, such as LIDAR. The team will continue to fine-tune and develop the system they have created, but overall, the system seems to be a success and working just as it was believed to work.

Appendix A: Drone Deploy vs Pix4D

Software	Pix4D	DroneDeploy
Price	$42 monthly basic plan, $292 monthly full plan	$149 monthly basic plan, $449 monthly full plan
Supported Drones	DJI, I1, I2, MA, MP, M2P, P4A, P4P, Parrot Anafi, Yuneec H520, 3DR Solo	DJI only
Supported Inputs	JPG, JPEG, TIF, TIFF, EXIF data	JPG w/ geotagging in GPS EXIF format
Free Trial?	Yes	Yes
Photos per project	varies based on system specs found here (up to more than 2000)	minimum 30, maximum 1000 (Basic plan); Max 3000 (Full plan)

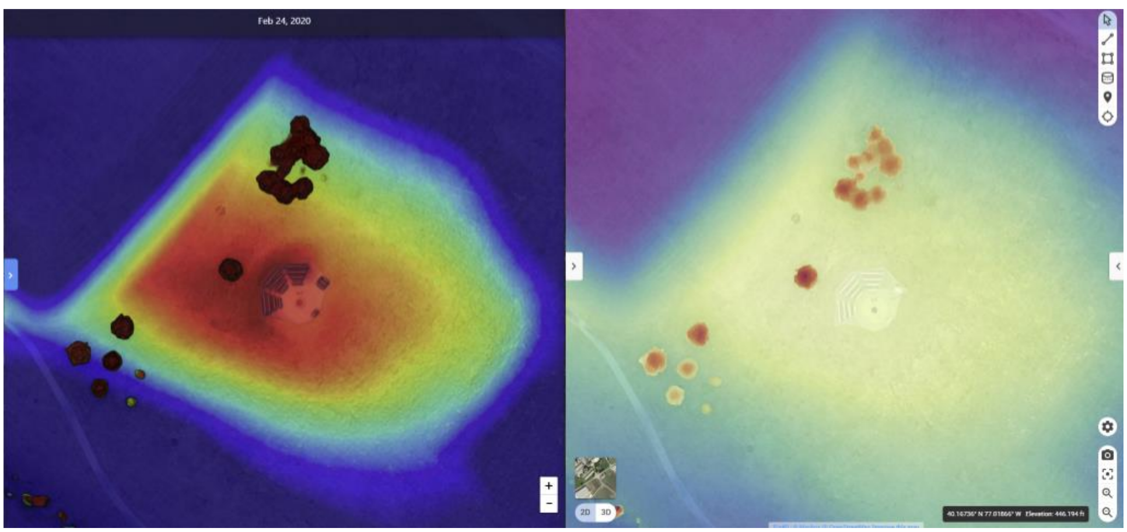

Figure 9: DSM Comparison (Drone Deploy on left, Pix4D on right)