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GEOG3170: Geospatial Field Methods

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Final Project Part 2: Elevation Mapping

Introduction

In the class Geospatial Field Methods, students learned about methods for mapping, including getting accurately georeferenced data and models. The primary method and focus of the class was a method called Structure from Motion Photogrammetry (SfM). In SfM, a geographer is able to generate an accurate 3D model of a landscape from a set of images without needing to know the positions and angles of the camera for each image. This is done algorithmically, and has been realized as a cheap and effective method for mapping, particularly in areas where traditional surveying equipment and methods are impractical or unfeasible. The second half of the final project for this class was divided into two parts. Part A involved comparing models created with and without georeferencing. Part B involved comparing and contrasting two different flights with different parameters and their produced results. The data for both of these parts comes from the same flights and locations. This paper will discuss the methods, results, and a discussion of each of these parts of the project.

Methods and Tools

Data Collection

To collect data for this part of the project, students went to Granite Park in Sandy, UT. Here, each of our groups found a location that they were interested in mapping. My group chose to map an area that had both short-groomed grass, and unkempt wild grasses, divided by a sidewalk. We chose this area as it had multiple identifying features, a variety of vegetation, and no tall obstructions such as trees, powerlines, or buildings. Once we had determined our location, we laid out nine ground control points with relatively even dispersal through our target area. These points were then all georeferenced using a handheld Trimble Juno Sb device, where we could post-reference the points in analysis.

After we had readied our mapping zone, it was time to fly. Initially we had wanted to compare the SfM models produced using different types of cameras, but due to equipment problems we had to make a last-minute change to our plan. We instead decided to fly the drone at different altitudes to see if this had a significant effect on the models produced. For our two flights we used a Phantom 4 Pro drone. The first flight was at 70 ft above ground, and the second flight was at 40ft above ground. Both flights were flown in a checkboard pattern to attempt to get the most accurate overlapping imagery. One complication noted during our flights was that we were fighting the weather and getting intermittent snow flurries, which had not fully subsided during our flight times. We predicted this could lead to complications, but proceeded due to time and battery constraints.

Post-Processing

To process the data, there are a few notable steps. First off, the GPS data points need correction in order to be accurate. To use the GPS data, we had to compile, correct, and export the GPS points using the *Trimble GPS Pathfinder* software and the base station data provided to us. Using this we were able to export corrected the corrected data points for use in referencing the images. These GPS points were then imported into *Agisoft Metashape*, the program we used to generate the SfM elevation models and orthophotos. Using this software and the images captured by the drone, we were able to generate these elevation maps and orthophotos, with and without georeferencing them, to build the models we needed. This was then all imported to *ArcGIS Pro* for further analysis and use in making the final map results.

Results and Initial Observations

Part A – Referenced and Nonreferenced Models

For Part A, we responsible for producing 3 figures and any extra that we felt helped with our analysis, in comparing the models produced with and without georeferencing. The flight we used for this information was called flight 8 in our data and is referenced as such on the maps and figures. This flight was the lower altitude flight, starting at 40ft above the launch position.

For this flight, there was a significant error in the SfM models for the area where there was denser and less even vegetation. This will be discussed further later on but it did significantly reduce the size of the models from the actual size they should have been. Even so, we were still able to produce models that showed the most significant feature, the sidewalk, and so some analysis on the geo-accuracy can still be performed.

For the non-referenced data, the error from the processing report generated by Metashape shows an average error in the X (Longitude) of ~1.04 meters, Y (Latitude) of ~2.13 meters, and Z (Altitude) of ~0.121 meters. This gives an average margin of error of approximately 2.37 meters. The referenced data was similar, which makes sense given they use the same imagery. These came to X ~1.08 meters, Y ~2.19 meters, and Z ~1.14 meters, with a total margin at approximately 2.70 meters. It was surprising that the margin of error was higher for the referenced models, rather than the non-referenced model, but I think this is primarily because three of the ground control points were not included in the models generated, likely due to SfM complications that will be mentioned in the discussion section.

Once the elevation models and orthophotos were imported into ArcGIS Pro, there are some other interesting observations. Even though the margin for error was technically lower on the non-referenced models, there is some more significant warping of the image, particularly in the NW and SW corners where there is a bubble-like shape. This is especially noticeable on the elevation map (Figure 1), where is appears there is a significant depression in the model on these parts, that does not exist in any of the other models or the satellite imagery.

Looking at Figures 3 and 4, it can also be seen that there is a difference in the physical location these images think they should be placed. Figure 3 shows the referenced orthophoto laid on top of the nonreferenced. Figure 4 shows the computed change between the two orthophotos. To understand Figure 4, the green parts of the image are where the referenced image lays, and the red parts where the non-referenced image lays. It is most noticeable between figures 3 and 4 that the image has been shifted in the North East direction during georeferencing. When measuring this difference in ArcGIS Pro, we see that it has shifted about 2.99 meters East and 0.76 meters North.

Part B – Comparing Different Flights

For Part B, we compared the models produced by flights using the same Phantom 4 Pro drone (same camera), but flown at different altitudes. The first flight was flown at 70 ft above our launch position. This flight is referred to as flight 7 in the data and figures. The second flight was flown at 40 ft above the launch position and is referred to as flight 8 in the data and figures. Flight 8 is the same flight used for Part A as well and some of the data shown here will be the same as discussed prior.

Looking at the processing reports for the data from the flights, Flight 7 had an average error in the X (Longitude) of ~46.35 centimeters, Y (Latitude) of ~71.98 cm, and Z (Altitude) of ~26.33 cm, giving a total margin of error at approximately 89.57 cm. As seen before, the errors for the referenced Flight 8 were X ~1.08 meters, Y ~2.19 meters, and Z ~1.14 meters, with a total margin at approximately 2.70 meters.

Using the information from these flights, many figures were produced. All of the data for this part was georeferenced prior to processing. For each flight, an elevation map, a hillshade map, and a slope map were all generated. A map showing the elevation difference between the two flights was also generated. These can be seen in the Figures section below, and are figures 5 – 11.

Looking at the elevation difference map (Figure 11), the majority of the image is yellow, meaning there is no significant elevation difference between the images. If Flight 8 had managed to build a better model of the long grass portion there may have been a bigger difference in this area. The only parts there are significant differences are on the southern portion. The green section means that flight 8 calculated as much as 8.3 ft lower than flight 7 did. There is also one section that can be seen as having a lot of red in it, which would mean that flight 7 was calculated at 22.6 ft higher than flight 8 did, a very significant error.

Discussion

Part A: Location and Georeferencing Uncertainty

Prior to this project I would have assumed that the models produced with more accurate georeferencing would be better images. As I have seen the SfM methods though I realized that the model building and georeferencing are almost separate processes that only come together once the models are placed on an actual map. This is most clearly seen by comparing the DEMs built off of flight 8 with and without georeferencing (Figures 1 and 2).

In looking at the models in Figures 1 and 2, the non-referenced model at first glance appears to be a fuller image with fewer holes in it. Figure 2 has a lot of gaps in the data particularly east of the sidewalk, and neither figure was able to build the area around the 3 most eastern ground control points. Since they are built off of the same set of images from the drone, it would seem that the introduction of georeferencing data confused the software and did not allow as many tie points to align during the SfM process. While it would seem that the georeferencing did cut down on the quality of the image produced, it did help to correct the bubble-like warping that is seen on the north west and south west corners of the non-referenced DEM in Figure 1.

Looking at figures 3 and 4, where the images are directly compared, there are a few conclusions that could be drawn about georeferencing and structure from motion. It seems as though the georeferencing may have cause the software to build a poorer image, likely from location data conflicts involving the location from the drone. That said, the data that is present in the referenced models does seem to be of higher accuracy and is more reliable. I think the reason we see such a high margin of error calculated by the report is that the model is full of holes, but these holes are the result of remission due to conflict, whereas the non-referenced model did not need to remove any images due to geodata conflicts. To boil that down into not so many words, the addition of georeferencing creates a more accurate and more precise image, at the cost of visual quality.

Part B: How Flight Parameters Impact SfM

Going into this part of the project I had made the prediction that the flight with the lower altitude would produce a significantly better image. My intuition led me to believe that a camera closer to the ground would get better individual images, and therefor the end result would be higher quality. This intuition is built mostly off of my own experience using my phone's camera, but didn't really take into account the SfM process. Looking at the results, my prediction for how these two flights models would compare seems to have been inverse to the reality.

The most obvious metric for determining the accuracy of these models would be looking at the margins of error for each flight. The model produced from flight 7 (70 ft) had a margin of error of just under a meter (~89.57 cm). The lower elevation flight (flight 8, 40 ft) had a margin almost 3 times this at about 2.70 meters. This is quite striking but, there are a few explanations as to why this would happen.

The biggest complication involved with Structure from Motion tends to be where calculating tie points breaks down due to too much noise, or unidentifiable features. The situation that tends to meet these conditions is when getting imagery of an area with lots of foliage or vegetation. This was a concern brought up by Javernick et al., 2014, and Westoby et al., 2012. In both of their studies, the authors note that noise created by vegetation was the biggest complication for SfM, and led to significantly higher margins of error. To me, it seems to make sense that this would cause identification confusion, as lots of vegetation is difficult to distinguish, and could easily create a lot of noise. Even in different pictures of the same area of vegetation, if wind or a critter has moved the plants, this could mean the images will no longer align as the leaves or grass will no longer look like the same object since it has moved.

Since the two flights took place over the same area, with the same vegetation, the altitude difference of the flight has the be the differentiating factor. As it turns out, flying at a higher elevation does a few things that has helped improve the models generated. The first change would be the effective grain/pixel size of the camera. Because the cameras/drones are exactly the same, and the images taken did not have any zoom, the higher altitude flight actually has a larger grain size, meaning that the size of a single pixel in the picture is physically larger than the size on the lower altitude flight. This means that it does not pick up as much fine detail, so small things like vegetation may not cause as much noise or are simply not in high enough detail to cause interference.

On top of the change in pixel size, there is also a change in the amount of overlap between the images. Both flights had the same path and image rate, just at different heights. This would mean that each image from the higher altitude flight will have both more frontlap, and sidelap, leading to higher accuracy in the SfM process. This increases the ease of identifying major features significantly. Both the explanation of grain size, and overlap helps to explain the higher quality model created by flight 7, less missing spots/holes in the flight 7 model overall, and why the flight 7 model was able to map much more of the vegetation than the flight 8 model.

The last notable difference between the flights, was that due to weather complications, flight conditions were not ideal. The weather was cold and cloudy, but stayed mostly clear for flight 7. For flight 8, however, the snow flurries did resume, and although it isn't obvious in any of the original images or models, I fear that the snow flurries could have impacted both the drone and the camera, cause lower quality images, noise, or instability during the flight. This could have easily impacted the models that were created, but without the ability to go attempt it again in the same location with better weather it is hard to say how much of an impact it really had.

Conclusion

Overall, this project did a lot to help me learn about the methods, complications, and correct my own assumptions involving georeferencing, mapping, and Structure from Motion photogrammetry. I was certainly surprised by the amount of inaccuracy seen in the flight 8 models, both referenced and georeferenced, but still can see how the georeferencing is important for location accuracy, as well as helping to remove distortion from the models. I was glad to have my intuitions about SfM challenged, and force me to realize why certain flight parameters are better and what effect they actually have on a flight and the model produced afterward. I think that flying with parameters appropriate for the location is certainly important. If I were to do this project again, I would like to do it in an area with even more low-lying vegetation to see if flying at a higher altitude would continue to help reduce noise and create a better model, and to see at what point the loss of resolution by flying at a higher altitude will hurt more than it helps in the SfM process.

Figures:

Figure 0: Field Notes

Figure 0 - Field Notes Granite Park.jpg

Part A:

Figure 1: Elevation model without ground control points

Figure 1 - F8 No GCP.pdf

Figure 2: Elevation model with ground control points

Figure 2 - F8 With GCP.pdf

Figure 3: Overlaid orthomosaics with satellite base imagery

Figure 3 - F8 Ref Over Nonref.pdf

Figure 4: Computed change between referenced and nonreferenced orthomosaics

Figure 4 - Compute Change F8 Ref to Nonref.pdf

Part B:

Figure 5: Flight 7 elevation map

Figure 5 - F7 Referenced.pdf

Figure 6: Flight 8 elevation map

Figure 6 - F8 With GCP.pdf

Figure 7: Flight 7 hillshade map

Figure 7 - F7 Hillshade.pdf

Figure 8: Flight 8 hillshade map

Figure 8 - F8 Hillshade.pdf

Figure 9: Flight 7 slope map Figure 9 - F7 Slope.pdf

Figure 10: Flight 8 slope map Figure 10 - F8 Slope.pdf

Figure 11: Elevation difference from flight 7 to flight 8

Figure 11 - Elevation Difference F7 - F8.pdf

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