Piksi™ for UAV Aerial Surveying

RTK Direct Georeferencing with Swift Navigation's Piksi GPS Receiver

Dennis Zollo, Rai Gohalwar
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swift
NAVIGATION

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1.0 Abstract

This whitepaper presents the results of using Piksi™—a carrier-phase differential GPS sensor—to georeference images from micro aerial vehicles (MAVs) in surveying use-cases. It presents sensor integration, data collection methods and real-world surveying results as processed by the Pix4D photogrammetry software. In addition, the benefits of using RTK GPS for aerial surveying are evaluated.

2.0 Overview

The use of MAV aerial surveying is of great interest and growing in popularity in industries such as precision agriculture, mining and forestry due in large part to its capabilities and low-cost.

In a typical aerial surveying use-case, an aircraft is outfitted with a high-quality camera and overflies an area of interest while capturing a series of images. The images are then processed in software to produce Digital Elevation Models (DEMs), Orthomosaics, and/or 3D point clouds which can be used for photogrammetry applications, volumetric measurements or crop health analysis to provide business value for users.

Commercial software tools for photogrammetry have the ability to stitch together aerial images through visual features with techniques such as bundle adjustment. Additionally, these software packages often require rough location and orientation of the lens when the photo was taken.

To facilitate post-processing, most low-cost MAV control systems used for photogrammetry have the ability to geotag photos as required by the processing software through Autonomous GPS combined with microelectromechanical systems (MEMS) sensors. The typical sensor technology, however, combined with uncertainty in timing of the camera's shutter, limits the precision and accuracy of geotagging information and therefore requires post-processing software to rely heavily on image processing techniques. Additionally, large amounts of sidelap and overlap between images and ground control points (GCPs) are often required to allow post-processing software to utilize imagery information given the inaccuracy of the georeferencing information. Lastly, survey sites lacking in visual detail (such as agricultural land) or where overlap is minimal (such as corridor mapping), often yield poor results with traditional techniques and sensors.

It has been demonstrated that Real Time Kinematic (RTK) GPS—also called carrier-phase differential GPS—can improve the location accuracy of georeferencing[2]. In the sections that follow, we will demonstrate methods and results of one such RTK sensor, Swift Navigation's Piksi, to geotag aerial photos for aerial surveying. It is expected that precise and accurate geotagging information can reduce the need for GCPs for typical survey missions, reduce the amount of overlap and sidelap required and improve the quality of ultimate photogrammetry deliverables.

3.0 Equipment and Setup

A camera, vehicle and an image-tagging system incorporating Piksi were made with careful design considerations to conduct experiments. Available and low-cost commercial off-the-shelf (COTS) equipment was chosen to highlight that these results can be replicated without exotic or expensive equipment.

A Sony NEX-5t mirrorless DLSR Camera with a fixed 20mm lens and a 16 MP CCID sensor was used as an imaging system. See Table 1 for detailed camera specifications. The application also required the ability to electrically sense the shutter which was achieved through the use of a Fotasy SANEX Hot Shoe Adapter Prontor/Compur (PC) socket for external flash synchronization. The digital flash signal was routed from the PC socket to the "external event" trigger feature of the Piksi receiver (pin 0 of Piksi's debug connector).

Specification	Value
Camera	Sony Nex-5T
Lens	Sony SEl_20F28
Weight (with vehicle amount)	424 g
Sensor	16 MP: 4912x3264
Hot Shoe Adapter	Fotasy SANEX (ASIN: B00DE4T4E2)

Table 1: Camera Specifications

The vehicle was designed and sized to carry the camera payload for a typical surveying mission. While a fixed-wing aircraft may be more applicable to surveying missions for their increased range, a quadrotor configuration was chosen for low-cost and ease of implementation. The test vehicle is based on a 680 Tarot quad frame and uses four TigerMotor anti-gravity 4006 motors with 15 inch propellers. The Pixhawk autopilot controls the aircraft and a 10.4Ah 6S battery pack powers. Fully-loaded, the vehicle has a flight time of about 30 minutes. The Sony camera is attached pointing down via custom-designed, 3D-printed housing. Communication to both a base-station Piksi and a UAV ground control station was accomplished via two 3D Robotics point-to-point radio modems. See Table 2 for a summary of vehicle configuration.

Specification	Value
Frame Type	Quad-Rotor
Frame	Tarot FY650
Flight Controller	3DR Pixhawk
Motors x 4	T-Motor MN4006
Motor Controllers	X-Rotor 40A OPTO
Propellers x 4	Tarot 1555CF
Batteries x 2	Multistar 6S 5200mAh
Weight	2942 g

Table 2: Vehicle Specifications

Specification	Value
Primary GPS	Piksi v2.3.1
Primary GPS Firmware	vo.21 (STM) v0.16 (NAP)
Secondary GPS	u-blox NEO 7N
Primary Antenna	Tallysman TW2412
Secondary Atenna	Taoglas gp.1575

Table 3: Vehicle GPS Specifications

As an autopilot and flight controller, the Pixhawk flight controller running Arducopter version 3.3.2 was used. A u-blox NEO 7N GPS receiver functioned as a backup GPS sensor and as a control against the Piksi sensor. See Table 3 for more information about the GPS sensors and antennas integrated on the aircraft.

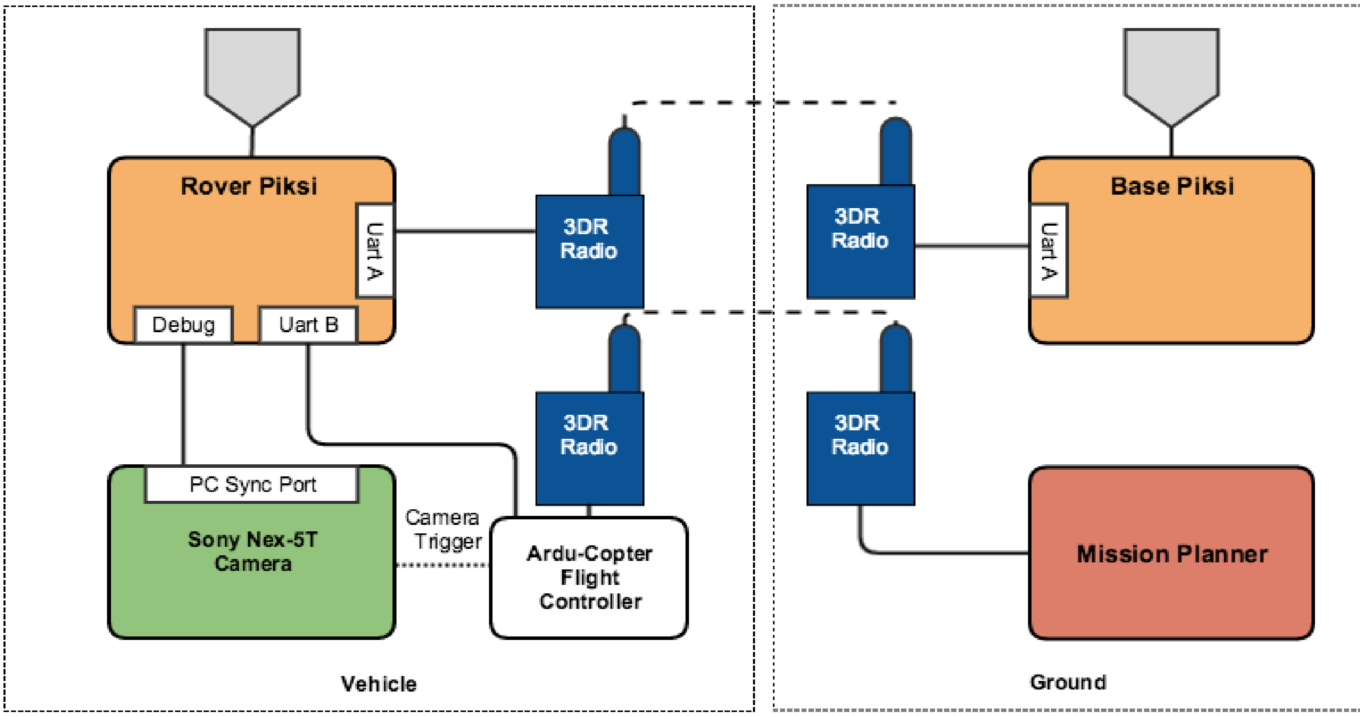
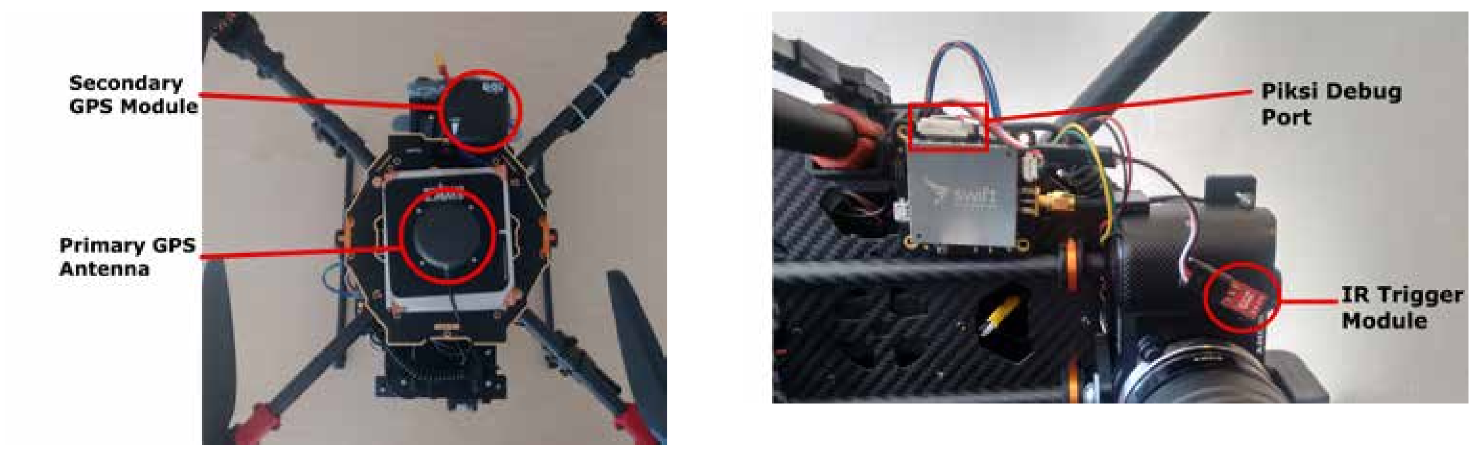


Figure 1: Vehicle Diagram



Top View

Bottom View

Figure 2: Surveying UAV

4.0 Method

4.1 Site Selection and Ground Control

A site was selected that combined high detail features—such as structures and roadways—with low detail features—including grassland. A series of 8 GCPs were surveyed using Piksi receivers and a base station located at a USGS survey marker, located about 2.2km away. One GCP ended up outside of the survey area. See Figure 3 for more information.

Figure 3: Flight Plan Visualization

4.2 Mission Planning and Camera Configuration

When conducting a surveying mission, it is very important to configure the vehicle, camera and flight parameters. To set flight and other surveying parameters, Mission Planner GCS was used. Mission Planner provided flight status during the mission and tools to convert user defined surveying parameters (ground sampling distance, overlap, sidelap, area of interest, flight time and camera direction) into an autonomous mission for Pixhawk.

The mission analyzed in this paper was designed with UAV surveying standards in mind. With a 75 percent overlap and 60 percent sidelap, the vehicle flew for approximately 22 minutes, capturing 218 images. The vehicle in this mission was flown at 20m altitude which in theory gives a 2.37mm ground sampling distance (GSD). Pix4D reported an average GSD of 4.9mm due to the terrain change and altitude variations of the vehicle during the mission.

To get the best quality possible, it was necessary to configure the camera settings appropriately. In order to avoid blur, and to compensate for the vibration and continuous movement of the vehicle, a constant shutter speed of 1/1250 sec was selected. The aperture settings and ISO were selected automatically by the camera. This resulted in sharp and detailed images.

5.0 Post-Processing Techniques

Post-processing tools were developed in-house for this project. Images captured from the camera were not individually tagged. Instead, a file with the image names, Piksi geolocation coordinates, orientation data (omega/phi/kappa) and accuracy (default of 5m horizontal and 10m vertical) was generated. This file was consumed by Pix4D with the aerial images.

Figure 4 shows the basic layout of the post-processing routines as to allow the methods to be reproduced. Georeference-process.py is a top-level python script that processes the data and generates a .csv file with image geolocations that can be consumed by Pix4D. There are other scripts within that carry out individual tasks. Mavlink-decode.py extracts the Piksi log file (SBP JSON) from the dataflash BIN log file created by the Pixhawk. Interpolate-event.py linearly interpolates the position data at the trigger points using the SBP log file. Query-mavlink.py is used to interpolate attitude data at each shutter time. This attitude data is converted from aircraft Euler angles to the “Image coordinate system” (omega/phi/kappa) specified by Pix4D in a Georeference-process.py subroutine. All this data is then compiled into a .csv file format specified by Pix4D with a Geolocation and camera attitude for each image. All scripts are open-source and available from Swift Navigation’s Github repositories, located at http://github.com/swift-nav

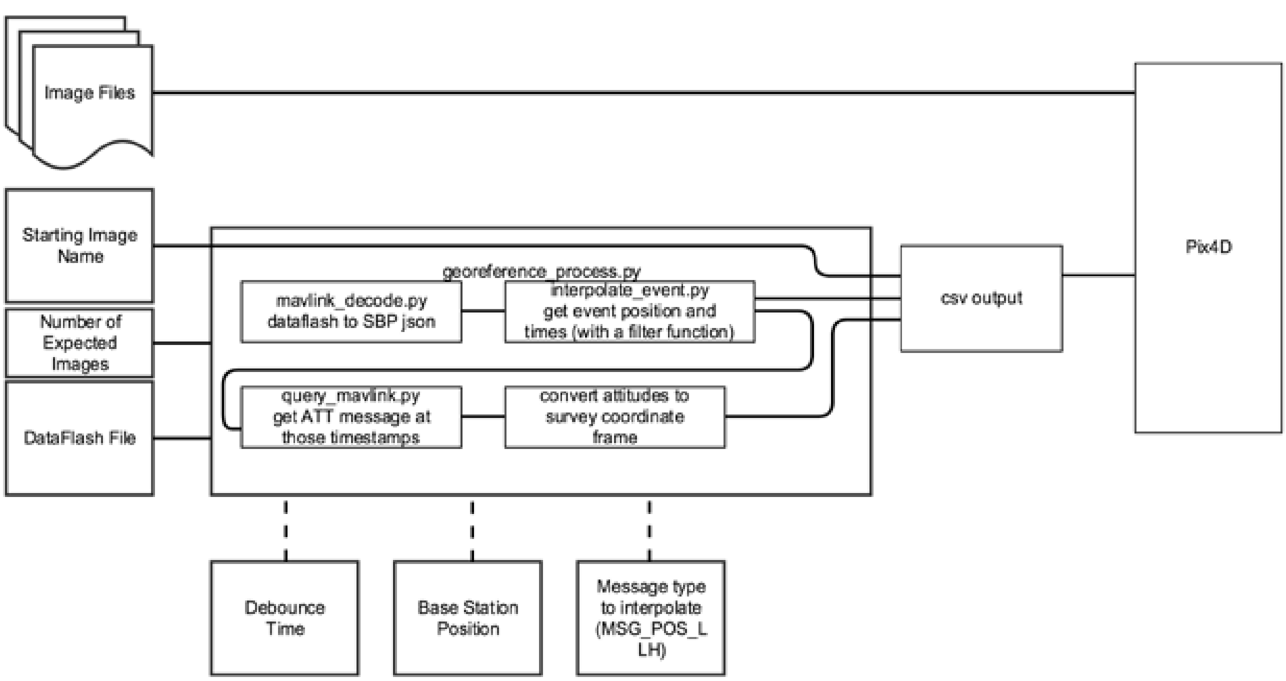


Figure 4: Post-Processing Architecture

5.1 Photogrammetry Parameters

To compare and analyze results from Pix4D, a total of 6 variations of settings and data were selected for rendering as described in Table 4. The calibration method column refers to whether the "Standard" calibration method in Pix4D or the "Accurate Geolocation and Orientation" methods were used. According to Pix4D help documentation, the "Accurate" setting is "Optimized for projects with very accurate image geolocation and orientation. This calibration method requires all images to be geolocated and oriented."[3] The Included Images column refers to which images were used for post-processing (see section 6.3 for more information). The entire parameter space was repeated for the primary GPS (Piksi) and control GPS sensor (u-blox sensor) as to make 12 total possible post-processing parameter sets.

Config	Description	Callibration Method	Included Images	GPS Sensor	Ground Control
1	Piksi RTK Std	Standard	All	Piksi RTK (Fixed)	None
2	Piksi RTK Std low sidelap	Standard	Every Other Line	Piksi RTK (Fixed)	None
3	Piksi RTK Std low overlap	Standard	Every Other Image	Piksi RTK (Fixed)	None
4	Piksi RTK Std GCP	Accurate	All	Piksi RTK (Fixed)	7 GCPs
5	Piksi RTK Acc	Accurate	All	Piksi RTK (Fixed)	None
6	Piksi Acc GCP	Accurate	All	Piksi RTK (Fixed)	7 GCPs
7	u-blox Std	Standard	All	u-blox	None
8	u-blox Std low sidelap	Standard	Every Other Line	u-blox	None
9	u-blox Std low overlap	Standard	Every Other Image	u-blox	None
10	u-blox Std GCP	Standard	All	u-blox	7 GCPs
11	u-blox Acc	Accurate	All	u-blox	None
12	u-blox Acc GCP	Accurate	All	u-blox	7 GCPs

Table 4: Post-processing Parameterization

6.0 Results

The survey mission and the various post-processing techniques provided typical UAV survey results. Most images were calibrated and stitched together to create survey outputs such as orthomosaics, digital elevation models and point clouds. In the section that follows, the resultant outputs are analyzed to better understand how improved GPS accuracy, ground control and different post-processing strategies can affect output quality.

6.1 Accuracy

Accuracy in surveying data can be defined as both the relative accuracy between locations in the scene and absolute accuracy in placing the data on Earth. GCPs and accurate image geotagging can help post-processing software with both aims. To evaluate the software's ability to correctly scale an image, the distance between 2 GCP markers in the post-processed image was used. This measurement could be a proxy for many surveying outputs as well as volumetric measurements. For this analysis, the distance between GCP 1 and GCP 8 was used. This distance was surveyed in advance to be 54.83 m. There was little to no difference between the distance as calculated from the survey outputs between any of the post-processing configurations. It is hypothesized that if geolocation information quality is within a threshold, Pix4D does not weigh the image geolocation data and most image scaling information comes from image processing. Thus there were no clear gains from an RTK GPS sensor with respect to relative measurements in images. The GCPs used as 3D Checkpoints were attempted to be used to evaluate the absolute positioning of survey outputs with respect to the earth. However, this method yielded inconclusive results suggest problems in the surveyed positions of GCPs.

6.2 Accurate Calibration Method

A technical contact at Pix4D suggested using the "Accurate Geolocation and Orientation" calibration methods to configure Pix4D to weigh more heavily image geolocation information. Configuration 5, 6, 11 and 12 (shaded in Table 5) were rendered using "Accurate Geolocation and Orientation" settings in Pix4D. It was expected that this calibration method would produce better orthomosaic and point cloud results, but the results were qualitatively worse. Observing Table 5, both Piksi and u-blox show increased errors. The RMS errors increase to a point that configuration 11 doesn't produce DSM or orthomosaic and configuration 12 cannot perform initial image calibration and thus are omitted from the results. In Figure 5 the orthomosaics of Piksi clearly show that the orthomosaics with the accurate calibration method cover less area compared to default settings. The digital elevation models produced from the accurate calibration method yielded strange artifacts.

One possible theory to explain the behavior is that the inaccuracy of the orientation data starts to dominate with this calibration method. Since the Pixhawk flight controller in the experiment has a relatively low quality MEMS IMU, it cannot be expected to have highly accurate attitude measurements during the flight. Moreover, it is possible that an error persisted in the conversion from aircraft Euler angles to the surveying frame (omega/phi/kappa) required by Pix4D. The exact reason that this calibration method yielded poor results is unknown, but it is presented as a finding should the question arise.

6.3 Overlap/ Sidelap

Surveying missions are typically flown with high overlap to yield high-quality photogrammetry results. Tools such as Pix4D are designed to favor image processing over geolocation information due to lack of accuracy in the commonly used GNSS systems on MAVs. The hypothesis is that with accurate geolocation data, the overlap percentage can be dropped without affecting the performance.

The mission was designed to have an overlap of 75 percent and a sidelap of 60 percent. As shown in the configurations on Table 4, post-processing was performed after removing lines and after ignoring every other image. The removal of lines would effectively halve the sidelap percentage while the removal of images would effectively halve the overlap percentage.

Figure 6 shows the mean RMS errors extracted from Pix4D quality reports for various configurations. As expected, both Piksi and u-blox experience significant increase in error when lines and images are removed. That said, the error of magnitude with Piksi's geolocation information is smaller than that with u-blox. Additionally, the number of images and the total area that was successfully surveyed is larger when Piksi's RTK geolocation information is used to georeference images. This analysis suggests that a more accurate GPS sensor can reduce the overlap and sidelap necessary for successful image processing and thus increase the area that can be surveyed in a given flight.

Config	X Error (m)	Y Error (m)	Z Error (m)	Image Calibrated Percent
1	0.185	0.136	0.274	84
2	0.653	0.552	1.056	64
3	0.847	1.182	1.202	59
4	0.076	0.089	0.011	85
5	0.556	0.619	0.989	99
6	0.277	0.073	0.723	95
7	0.202	0.840	0.563	82
8	3.075	1.842	1.255	64
9	2.191	3.028	1.897	57
10	0.086	0.096	0.024	81
11	0.500	0.625	0.959	99
12	Would Not Render			
Configurations with gray cells use the "accurate geolocation and orientation" calibration method				

Table 5: Post-processing Parameterization

(1) Piksi All Images

(2) Piksi Every Other Line

(3) Piksi Every Other Image

(4) Piksi with GCPs

(5) Piksi Accuracy

(6) Piksi Accuracy with GCPs

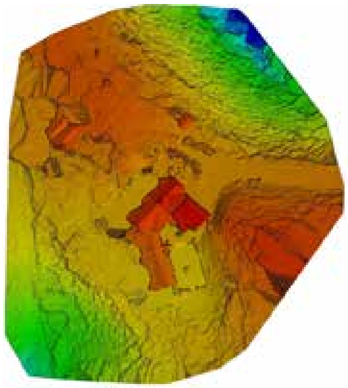
(7) u-blox All Images

(8) u-blox Every Other Line

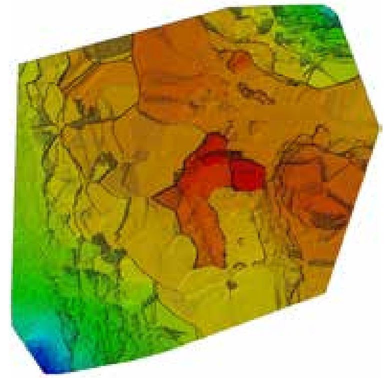
(9) u-blox Every Other Image

(10) u-blox with GCPs

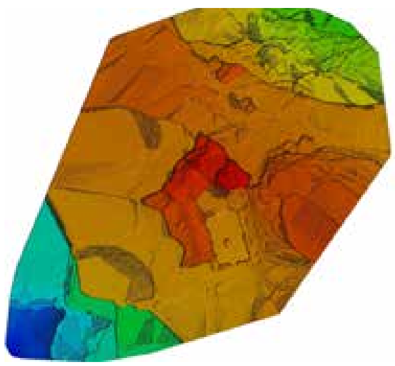
Figure 5: Orthomosaics of Different Configuration Rederings



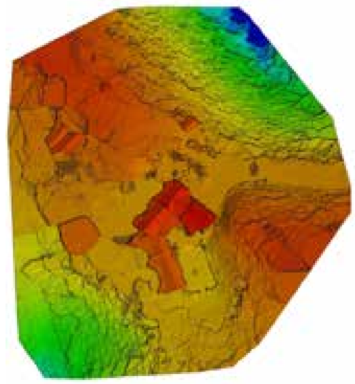
(1) Piksi All Images



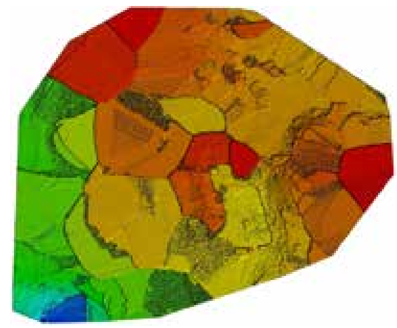
(2) Piksi Every Other Line



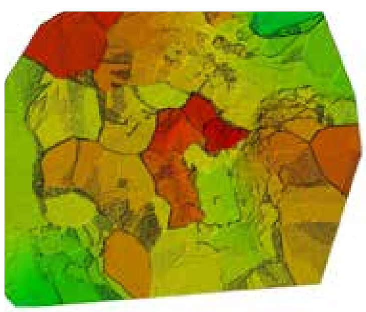
(3) Piksi Every Other Image



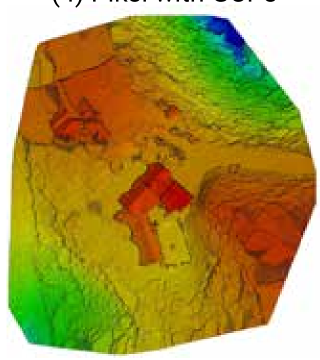
(4) Piksi with GCPs



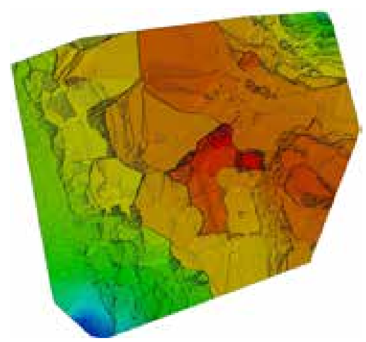
(5) Piksi Accuracy



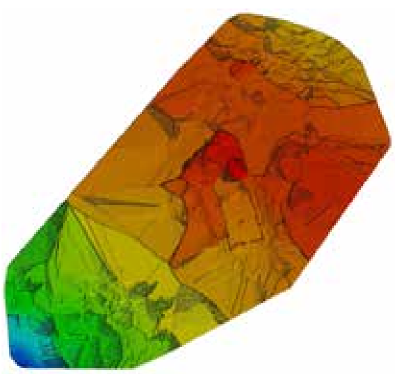
(6) Piksi Accuracy with GCPs



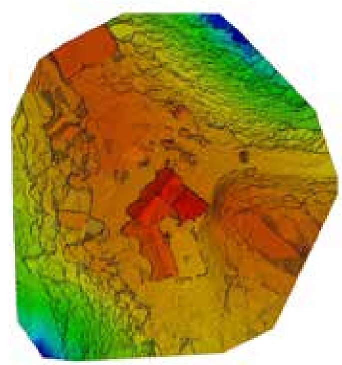
(7) u-blox All Images



(8) u-blox Every Other Line

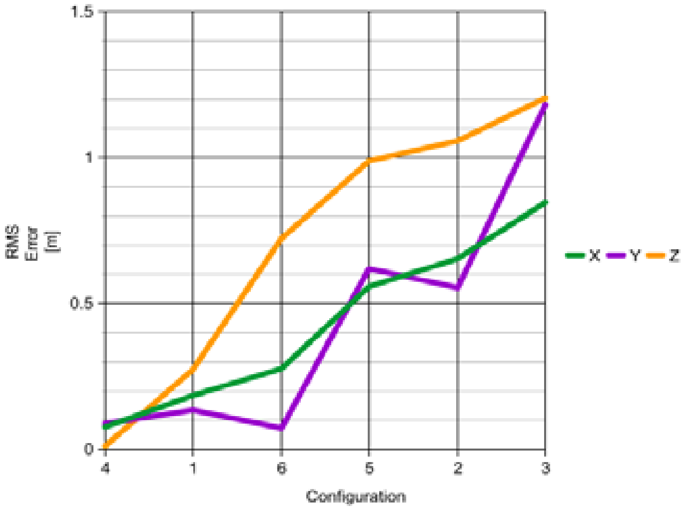


(9) u-blox Every Other Image

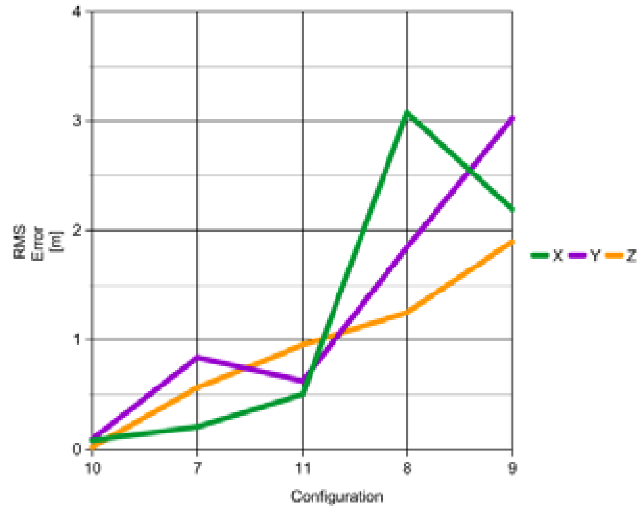


(10) u-blox with GCPs

Figure 6: Digital Surface Model (DSM) of Different Configurations



(a) Piksi



(b) u-blox

Figure 7: Piksi and u-blox RMS Error

6.4 Initial Accuracy Estimate Investigation

One potential output to measure post-processing quality is the RMS errors reported by Pix4D Software which come from the “Initial processing” step of the software. Indeed, this paper, and the marketing material of some vendors and other parts of the literature, uses this image processing output as a key metric in evaluating the quality of geolocation surveying data.

In this analysis, however, the RMS error values seemed highly affected by the image geolocation “accuracy” estimates that are initially provided to the software by the user as input. This outcome was peculiar and unexplained and is presented in Table 6. The table shows three identical post-processing runs where the only difference was the accuracy estimate. As this accuracy estimate decreased, the image location errors as reported in the Pix4D quality report decreased as well. This behavior suggests that the geolocation accuracy reported by Pix4D is reflection of post-processing itself rather than the physical geolocation accuracy. For this paper the default initial accuracies were used as a control for this behavior. In certain cases when these initial accuracy values are constrained to values below the accuracy of the sensors used for georeferencing, the software is unable to perform initial processing.

Label	Initial Image Accuracy (m)		Images Processed (%)	2d Keypoints	Mean RMS Error (m)		
	X,Y	Z			X	Y	Z
a	5	10	84	5902	0.184857	0.136434	0.273608
b	0.2	1	84	5907	0.126739	0.097678	0.163582
c	0.1	0.2	84	5887	0.062538	0.06066	0.111367

Table 6: Initial Accuracy Estimate Data

6.5 Issues

We present these issues and learning opportunities discovered during data collection and analysis in an effort to assist future researchers in avoiding common pitfalls. First, it is important to match flying speed and image triggering intervals with the imaging sensor's ability to buffer images. Part of the post-processing procedure involves comparing the number of triggered images (Mavlink CAM messages) to the number of shutters recorded (Piksi SBP MSG EXT EVENT messages). If there are more trigger messages than images, or recorded shutter events, the mission was most likely flown too fast for the camera to react to shutter triggers.

Moreover, while post-processing configuration with GCP markers, few tie points were found in images including the GCPs. Considering Figure 3, it is clear that most of the GCPs were placed on the edge of the mission range. This placement made it difficult for Pix4D to accurately define, and use, these points for the processing procedure. In a future data collection effort, GCPs should be placed in low-detailed portions of the scene and/or areas with high image overlap as opposed to the edges of the scene.

An additional issue was limited understanding and closed nature of the Pix4D processing software. Many of the results would be more clear with a deeper understanding of the algorithms and heuristics in the post-processing tool. Software inputs such as the initial accuracy estimates and orientation inputs (omega/phi/kappa) had unexplained roles in the rendering process. Different post-processing tools (Agisoft PhotoScan or Visual Surveyor) or a deeper understanding and/or partnership with Pix4D could improve future analysis work.

7.0 Conclusions

MAVs have the potential to greatly reduce the cost and complexity of aerial surveying and to arm end-users with actionable data. This paper presented methods and results of integrating Swift Navigation's Piksi RTK receiver into a MAV surveying system. From this we learned that improved geolocation accuracy information can improve aerial surveying results. Specifically, with increased geolocation accuracy, sidelap and overlap can be reduced and image location errors reported by image stitching software can be reduced.

8.0 Acknowledgements

Please acknowledge Andrew McIntyre from Pix4D for his technical support and Malcolm Morrison from Agriculture and Agri-Food Canada for his thoughts and advice. Also please extend a special thank you to Diana Schlosser (Swift) for access to her property for this use-case.

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