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# THREE PHOTOGRAMMETRIC SOFTWARE ARE COMPARED USING FOUR DIFFERENT ALTITUDE UAV DATASETS

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**ABSTRACT**

Photogrammetric software utilizing Structure from Motion (SfM) have been extensively used with drone-acquired imagery. SfM software, such as Agisoft PhotoScan and Pix4D, use computer vision techniques to solve for aero-triangulation. This study attempts to compare these two software with traditional software such as Trimble Inpho using a dense ground control field. Since AgiSoft and Pix4D show increased robustness in their analyses and provide visually appealing three-dimensional (3D) models, they are used by many. Nonetheless, the details of these software, predominantly through statistical analyses of results, are not well understood. On the other hand, careful selection of initial settings combined with a rigorous check and analysis of the output are prerequisites for obtaining the best possible results in photogrammetry. For the companies which are producing photogrammetric products, bringing Agisoft and Pix4D into play might result in significant cost savings over time. Nevertheless, to make this major move, these software must be vetted. Thus, in this project, these three software (Agisoft, Pix4D and Trimble Inpho) were analyzed using four Unmanned Aerial Vehicle (UAV) datasets, and the results were compared in terms of precision and accuracy. It is found out that Inpho results were the least precise and accurate among these software. This is because Inpho is not sensitive to the biases created by reverse strips. Hence, the same data sets were processed without reverse strips and the errors got smaller, and systematic bias was removed. In addition, Inpho results deteriorated with flying height. Additionally, 90 m real-time network solutions showed the same performance as 90 m solutions without real-time network solutions.

**Keywords:** Photogrammetry, Structure from Motion, Agisoft, Pix4D, Trimble Inpho, UAV.

**Cited As:**

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## INTRODUCTION

Structure from Motion (SfM) is a computer vision technique which solves for the geometry of the scene, camera interior and exterior parameters without providing known 3D point positions (Agüera-Vega et al., 2017), and nowadays it is widely used because it provides greater flexibility and high quality results (Chiabrando et al., 2013).

The digital photogrammetry software mostly cited in the literature is Agisoft PhotoScan Professional Edition and Pix4Dmapper Pro. AgiSoft uses Python script interface that can be used to establish an automated process (El Meouche et al., 2016). Otherwise, the photogrammetrist has very little control over the data processing. Both software show increased robustness and visually appealing 3D models (Rumpler et al., 2017). Yet, they do not provide a thorough statistical analysis of results; however, a mean re-projection and the RMS values from check points are given in the report. The lack of details means that it is not possible to fully understand the underlying sources of error (James et al., 2017; Cramer, 2013). Careful selection of initial settings, combined with a thorough check and analysis of the output, are prerequisites for obtaining the best possible results in UAV (Unmanned Aerial Vehicle) photogrammetry (Reshetyuk and Mårtensson, 2016). Another drawback is that manual digitizing of GCPs (ground control points) and check points is required (Rumpler et al., 2017). AgiSoft and Pix4D are examples of a black box approach (Reshetyuk and Mårtensson, 2016). However, there is another software commonly used in the industry which is Trimble Inpho. Unlike AgiSoft and Pix4D, Inpho allows photogrammetrists to make changes along the process e.g., setting camera parameters, adding or removing GNSS/IMU data, creating strips etc.

To the best of the authors' knowledge, SfM software has not been compared extensively using UAV datasets. This is the main reason that authors worked on this project. To this date, there are two publications: one is a journal paper, and another is a conference proceeding. In the journal paper by Visockiene et al. (2014), Pix4D and PhotoMod are compared. In the conference proceeding by Qureshi et al. (2022), it is concluded that Agisoft Metashape, and 3DF Zephyr are the most suitable photogrammetry tools for close-range construction elements.

Although there are a number of digital photogrammetric software available on the market, with new ones constantly becoming available, for this project, these three software (AgiSoft, Pix4D and Inpho) were considered. In the literature, it is stated that accuracy tends to decrease as the flying height increases and lowering the flight altitude demands a longer acquisition time (Nasrullah, 2016). Thus, in this study, four UAV data sets with varying flying heights were used and the results were analyzed.

## 1. TEST SITE AND FLIGHT

A UAV photogrammetry campaign was flown over the San Joaquin Experimental Range located in Fresno County, California in the foothills of the Sierra Nevada mountain range located about 32 km north of the California State University, Fresno campus. There were 81 control points (see Fig. 1) laid out in a 9-by-9 grid spaced approximately 40 m apart throughout a 320 m by 320 m area. The terrain of the area is rolling hills with sparse vegetation, structures and roads. The control point flight targets were designed to be circular, black and white, and measured about 47 cm in diameter (see Fig. 2). These control points were surveyed to 1 cm horizontal and 0.3 cm vertical accuracies, both at one sigma confidence level. The horizontal positioning was established using static GNSS at two different times on February 10-17, 2018 and July 12-18, 2018. For this purpose, six Trimble-R8 Model-2 receivers were employed to collect the measurements. Antennae and receivers were mounted on fixed-height 2-m range poles. Each point was occupied for a minimum of 30 minutes with a 1 second interval; however, while moving from point to point, some stations collected longer data. To determine the elevations of the points, differential levelling was performed using the Trimble DiNi digital level with an adjustable level rod. Local vertical control was surveyed in from a National Geodetic Survey (NGS) benchmark west of the project site just north of the intersection of Highway 41 and Road 406. After establishment of the project vertical benchmark (point 22), the remaining 80 control locations were then measured. A vertical network was created with a total of 154 observations to establish the elevations of each control point. The difference in elevation along each link between each individual control point was measured. Interior control points were measured with a minimum of 4 observations, exterior control points were measured with a minimum of 3 observations, and the corners of the site were measured with a minimum of 2 observations. All of these measurements were input into STAR*NET for a simultaneous least squares adjustment.

The aircraft platform used was a Phantom 4 RTK UAV, a vertical-take-off-and-landing platform with a quad rotor. The camera model was FC6310R, with a focal length of 8.8mm, pixel size of 2.4 microns, and an electronic/global shutter. As can be seen in Table 1, four data sets are used in this study. Additionally, 65-75% side/forward overlap is maintained throughout the survey.

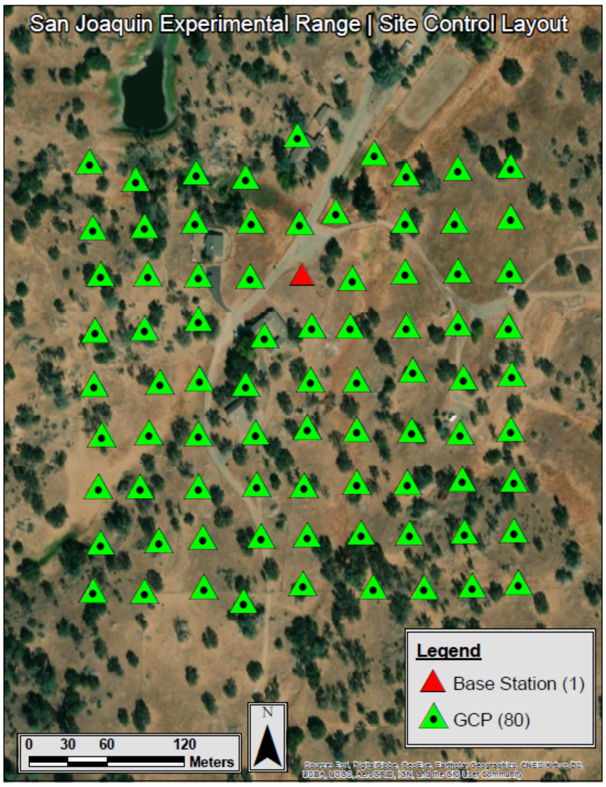


**Figure 1.** Control points established at the project site (image is prepared using ESRI ArcMap).

**Figure 2.** Ground target image.

**Table 1.** Flights used in this study (m).

| Flying height above ground level | Number of photographs |
|---|---|
| 60 | 947 |
| 90 | 485 |
| 90 RTN | 485 |
| 120 | 296 |

## 2. RESULTS

The images that were acquired by the four flights described above were processed using Agisoft, Pix4D, and Inpho software. In order to do so, the images were added to a software project and matched and aligned to create the initial block to be adjusted according to the surveyed ground control. Camera positions in the bundle adjustment were assigned an a priori uncertainty of 0.05 m both horizontally and vertically. The ground control points were all constrained by uniformly assigning a priori uncertainties of 1.0 cm horizontally and 0.5 cm vertically according to the accuracies of the survey. Finally, a bundle block adjustment was performed applying camera self-calibration (focal length, principal point, and lens distortion parameters). For the analyses, 5 ground control points were used, and the remaining points (see Table 2) were employed as check points (see Fig. 3).

**Table 2.** Number of check points used for each processing.

| Flying height above ground level | Agisoft | Pix4D | Inpho |
|---|---|---|---|
| 60 | 36 | 37 | 35 |
| 90 | 38 | 38 | 36 |
| 90 RTN | 38 | 38 | 36 |
| 120 | 38 | 37 | 34 |

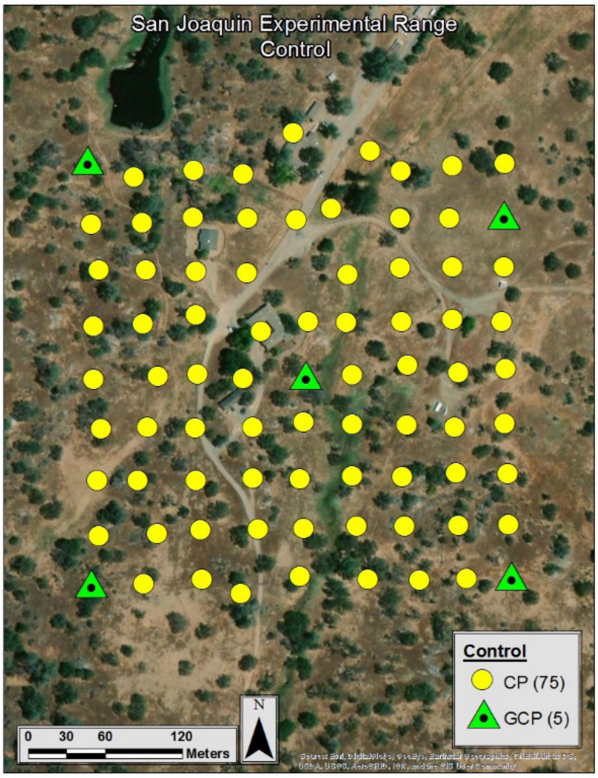


**Figure 3.** Control points and check points (image is prepared using ESRI ArcMap).

In the Introduction section it is stated that a drawback of these software is manually digitizing GCPs and check points. To eliminate digitizing error from software to software, a Python script was written to translate the control and check point image coordinates that were digitized in Agisoft to Pix4D and Inpho.

Four UAV data sets with varying flying heights (60, 90, 90 RTN and 120 m) were processed and the results were produced. As the name indicates, 90 RTN uses a Real-Time Network. A RTN is a network of permanent GNSS receivers whose combined data is used to generate RTN corrections for a rover and these network generated RTN corrections are used by any receiver which is capable of receiving these corrections to determine position instantly. Thus, a base station setup is not needed.

## 2.1. Results and Analysis of All the Strips

Results are analyzed using RMS, Standard Deviation, Mean, Minimum, Maximum and Range, see Tables 3-6.

**Table 3.** Results of the 60 m flying height (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 1.1 | 1.2 | 2.5 | 1.0 | 0.9 | 1.1 | 2.0 | 1.0 | 2.4 |
| Std Dev | 0.9 | 0.8 | 2.1 | 1.0 | 0.9 | 1.0 | 2.1 | 1.0 | 2.4 |
| Mean | -0.5 | 0.9 | 1.3 | -0.2 | 0.2 | -0.4 | 0.0 | 0.0 | -0.7 |
| Min | -2.1 | -0.7 | -2.9 | -2.2 | -2.1 | -3.6 | -3.7 | -2.0 | -5.3 |
| Max | 1.5 | 2.6 | 5.8 | 2.6 | 2.4 | 1.3 | 4.8 | 2.3 | 6.3 |
| Range | 3.7 | 3.3 | 8.7 | 4.8 | 4.4 | 4.9 | 8.5 | 4.3 | 11.6 |

As can be seen in Table 3, the RMS values for the X coordinate for Agisoft (1.1) and Pix4D (1.0) are very close to each other. Yet, the RMS value for the X coordinate for Inpho (2.0) is almost double that of the Agisoft and Pix4D values. The RMS results for the Y coordinate are almost the same for all three software. Although the RMS results for the Z coordinate for Agisoft (2.5) and Inpho (2.4) are close to each other, the RMS value for the Z coordinate for Pix4D (1.1) is much smaller. These results indicate that there is bias with the Z coordinate of Agisoft and Inpho and the same can be stated for the X coordinate of Inpho. Ratios of standard deviations for the results of these three software are more or less the same. This means that the Z coordinate of Agisoft and Inpho, and the X coordinate of Inpho are less precise compared to the other results. As can be seen in the table, ranges are rather large for these coordinates as well.

**Table 4.** Results of the 90 m flying height (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 1.1 | 1.0 | 2.1 | 1.0 | 1.0 | 1.5 | 3.1 | 1.1 | 3.2 |
| Std Dev | 1.0 | 0.9 | 1.9 | 1.0 | 1.0 | 1.5 | 3.1 | 1.1 | 2.9 |
| Mean | -0.4 | 0.5 | 0.9 | 0.3 | 0.2 | 0.0 | 0.1 | -0.1 | -1.4 |
| Min | -2.4 | -1.6 | -4.2 | -2.0 | -1.8 | -3.1 | -6.7 | -2.7 | -6.2 |
| Max | 1.7 | 2.5 | 4.3 | 2.7 | 2.7 | 2.7 | 6.9 | 2.0 | 8.2 |
| Range | 4.2 | 4.1 | 8.5 | 4.7 | 4.4 | 5.8 | 13.6 | 4.7 | 14.4 |

Almost similar ratios are apparent in Table 4 i.e., as well as the X coordinate of Inpho, the RMS values for the Z coordinate of Agisoft and Inpho are larger compared to the other results. Same scenario exists for standard deviations. This means that there is bias with the Z coordinate of Agisoft and the X and Z coordinate of Inpho. Similarly, the Z coordinate of Agisoft, and the X and Z coordinate of Inpho are less precise as opposed to the other results in the table. It should be pointed out that RMS and standard deviation of the Z coordinate in Pix4D solutions got slightly larger as well.

**Table 5.** Results of the 90 m flying height using real-time network solutions (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 1.8 | 2.5 | 1.5 | 1.1 | 1.0 | 1.0 | 2.9 | 1.1 | 2.7 |
| Std Dev | 1.0 | 0.8 | 1.5 | 1.1 | 0.9 | 1.0 | 2.9 | 1.1 | 2.7 |
| Mean | -1.6 | 2.4 | -0.3 | 0.0 | 0.3 | 0.1 | -0.2 | 0.0 | -0.4 |
| Min | -3.5 | 0.1 | -4.1 | -2.6 | -1.6 | -1.6 | -6.0 | -2.7 | -5.2 |
| Max | 0.6 | 4.2 | 2.3 | 2.0 | 2.9 | 2.8 | 6.0 | 1.9 | 6.0 |
| Range | 4.1 | 4.0 | 6.4 | 4.6 | 4.6 | 4.5 | 12.0 | 4.6 | 11.2 |

Although the same pattern is apparent with Pix4D and Inpho results in Table 5, the RMS value of the Y coordinate for Agisoft is larger with the 90 m flying height using real-time network solutions. However, ratios of standard deviations for the results are the same as the results in the previous two tables. Thus, with the 90 m flying height using real-time network solutions, the Y coordinate for Agisoft is less accurate along with the X and Z coordinate of Inpho results. In terms of standard deviations, the Z coordinate for Agisoft, and the X and Z coordinate for Inpho are less precise in contrast to the other results in the table.

**Table 6.** Results of the 120 m flying height (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 1.0 | 1.3 | 1.7 | 1.0 | 0.9 | 1.3 | 3.8 | 1.8 | 3.5 |
| Std Dev | 1.0 | 0.8 | 1.5 | 1.0 | 0.9 | 1.3 | 3.8 | 1.8 | 3.3 |
| Mean | 0.1 | 1.0 | 0.8 | 0.2 | 0.2 | -0.1 | -1.0 | 0.0 | 1.2 |
| Min | -1.9 | -0.6 | -3.5 | -2.1 | -2.3 | -2.2 | -8.2 | -3.7 | -4.2 |
| Max | 2.1 | 3.0 | 3.0 | 2.2 | 2.1 | 3.0 | 5.3 | 2.9 | 8.6 |
| Range | 4.0 | 3.5 | 6.6 | 4.3 | 4.4 | 5.2 | 13.5 | 6.6 | 12.8 |

Almost similar ratios are apparent in Table 6 i.e., as well as the X coordinate for Inpho, the RMS values for the Z coordinate for Agisoft and Inpho are larger compared to the other results. Same scenario exists for standard deviations. This means that there is bias with the Z coordinate of Agisoft and the X and Z coordinate of Inpho. Similarly, the Z coordinate of Agisoft, and the X and Z coordinate of Inpho are less precise as opposed to the other results in the table. It should be pointed out that the RMS and standard deviation of the Z coordinate in Pix4D solutions got slightly larger as well.

## 2.2. Results and Analysis Without Reverse Strips

At the end of the analyses, the residuals of the photo positions after the bundle adjustment were produced - see Figs. 4 to 9 as an example. Some figures depict systematic errors as a function of flight direction. In order to eliminate photo position errors due to flight direction, every other strip was eliminated i.e., images taken during backward flights are removed from the data sets. This creates fewer favorable number of looks. The results of this approach are shown in Tables 7-10.

**Table 7.** Results of the 60 m flying height without reverse strips (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 1.4 | 0.9 | 2.7 | 0.9 | 1.0 | 1.4 | 1.7 | 1.1 | 2.6 |
| Std Dev | 1.0 | 0.8 | 2.5 | 0.9 | 0.8 | 1.4 | 1.7 | 1.0 | 2.5 |
| Mean | -1.0 | 0.4 | 1.1 | 0.0 | 0.6 | -0.3 | -0.3 | 0.5 | -0.9 |
| Min | -3.0 | -1.6 | -7.0 | -1.8 | -1.3 | -3.3 | -2.9 | -1.4 | -4.6 |
| Max | 1.2 | 2.0 | 6.1 | 2.0 | 1.9 | 3.4 | 4.0 | 2.1 | 4.8 |
| Range | 4.2 | 3.6 | 13.1 | 3.9 | 3.1 | 6.7 | 6.9 | 3.5 | 9.4 |

The results in Table 7 are similar to the results shown in Table 3 except that the Z coordinate for Pix4D is a little larger. Hence, we can state that there is bias with the Z coordinate of Agisoft and Inpho and the same can be stated for the X coordinate of Inpho. In addition, the Z coordinate of Agisoft and Inpho, and the X coordinate of Inpho are less precise compared to the other results. With these results, it is expected that not much change would be experienced with Agisoft and Pix4D results, however, Inpho results would get better. Yet, some changes are experienced with Agisoft and Pix4D results and there is improvement with the X coordinate for Inpho but the Y and Z coordinates are not better.

**Table 8.** Results of the 90 m flying height without reverse strips (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 1.1 | 0.9 | 2.2 | 1.2 | 1.0 | 1.4 | 2.3 | 1.5 | 3.7 |
| Std Dev | 1.0 | 0.9 | 1.9 | 1.2 | 0.9 | 1.2 | 2.4 | 1.2 | 3.1 |
| Mean | -0.5 | 0.2 | 1.1 | 0.5 | 0.4 | 0.7 | 0.2 | 0.9 | -2.0 |
| Min | -2.6 | -1.8 | -4.2 | -1.7 | -1.6 | -1.8 | -3.8 | -2.0 | -8.2 |
| Max | 1.6 | 2.2 | 4.7 | 3.1 | 2.6 | 3.1 | 6.6 | 2.4 | 6.2 |
| Range | 4.2 | 4.0 | 8.9 | 4.8 | 4.2 | 4.9 | 10.4 | 4.4 | 14.4 |

The results in Table 8 are similar to the results portrayed in Table 4. Again, there is improvement with the X coordinate for Inpho but the Y and Z coordinates are not better.

**Table 9.** Results of the 90 m flying height using real-time network solutions without reverse strips (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 2.2 | 3.0 | 1.5 | 1.3 | 1.0 | 1.5 | 2.1 | 1.4 | 3.5 |
| Std Dev | 1.1 | 0.8 | 1.5 | 1.2 | 0.9 | 1.6 | 2.1 | 1.2 | 3.2 |
| Mean | -2.0 | 2.9 | -0.3 | -0.6 | 0.5 | 0.0 | -0.4 | 0.6 | -1.3 |
| Min | -3.9 | 0.8 | -4.0 | -3.1 | -1.5 | -3.7 | -3.6 | -3.3 | -7.2 |
| Max | 0.3 | 4.8 | 2.3 | 1.9 | 2.4 | 3.8 | 4.8 | 2.6 | 6.2 |
| Range | 4.2 | 4.0 | 6.3 | 5.1 | 3.9 | 7.4 | 8.4 | 5.9 | 13.4 |

In terms of precision and accuracy, the same scenario displayed in Table 5 is displayed in Table 9. Except for the X coordinate, the results for Inpho are not improved.

**Table 10.** Results of the 120 m flying height without reverse strips (cm).

| | Agisoft | | | Pix4D | | | Inpho | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| RMS | 1.0 | 0.9 | 1.7 | 1.0 | 0.9 | 1.7 | 2.3 | 1.3 | 3.3 |
| Std Dev | 1.0 | 0.8 | 1.5 | 1.0 | 0.9 | 1.6 | 2.1 | 1.2 | 3.2 |
| Mean | 0.0 | 0.2 | 0.8 | 0.0 | 0.0 | -0.8 | -1.0 | 0.6 | -0.7 |
| Min | -2.2 | -1.7 | -2.3 | -2.5 | -1.7 | -3.9 | -5.2 | -1.9 | -4.8 |
| Max | 2.1 | 2.2 | 3.2 | 2.2 | 1.5 | 2.3 | 2.6 | 2.3 | 7.1 |
| Range | 4.3 | 3.9 | 5.5 | 4.7 | 3.2 | 6.1 | 7.8 | 4.2 | 11.9 |

With results of the 120 m flying height without reverse strips in Table 10, the results came out as expected (i.e., not much change was experienced with the Agisoft and Pix4D results); however, Inpho results improved.

About 120 m flying height results, it is mentioned that X coordinate for Inpho is larger compared to the other results (see also Table 6). In order to test this statistically, two tailed test is utilized because here the concern is whether the sample mean is statistically different from the population mean. Let us introduce the t-statistic:

$$t = (\bar{y} - \mu)/(S/\sqrt{n}) \quad (1)$$

where $\bar{y}$ is the mean value, μ is the true value, S is the standard deviation and n is the number of observations.

The null hypothesis, $H_0$: $\mu = \bar{y}$

The alternative hypothesis, $H_a$: $\mu \neq \bar{y}$

Using the test statistic in Eq. (1), $t=(-1+0)/(2.1/\sqrt{34}) = -2.777$

Agisoft and Pix4D mean values are considered as μ since both software mean values are 0.

$t= |-2.777| > t_{0.025,\ 33} = 2.036$

So, there is a reason to believe that Inpho mean value is different from Agisoft and Pix4D mean values. As can be seen, the result corroborates the above statement. Here, this test is done for one result as an example; however, it can be repeated for all the entries listed in the tables.

As can be seen in Tables 7-10, although some changes are experienced with the results time to time, some results, especially Inpho results, got better. In order to show GNSS photo position displacements in two dimensions (2D), displacement vectors are also displayed for flights with and without reverse strips. In total, 24 of these images are produced but only 6 of them are shown here; however, all these images are available upon request. 2D displacement vectors for the results without reverse strips got smaller and systematic bias is removed (i.e., arrows show a random pattern; see Figs. 4-9).

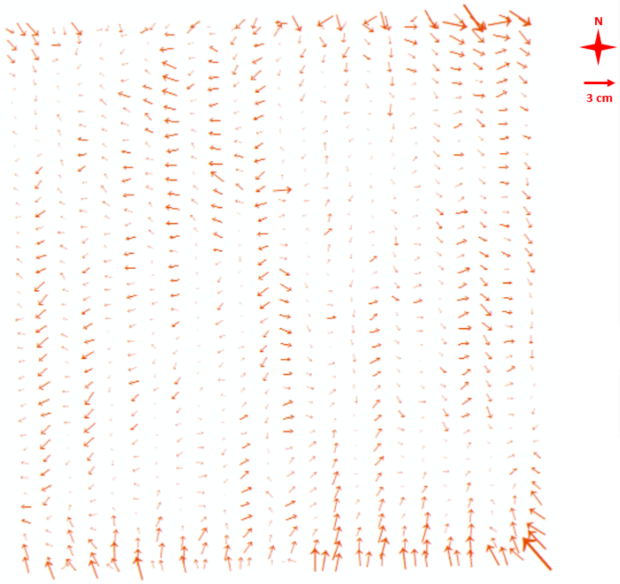


**Figure 4.** Agisoft 60 m GNSS photo position residuals.

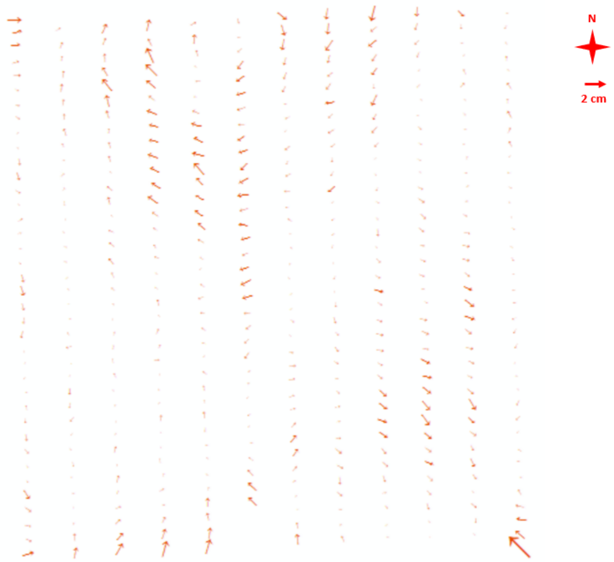


**Figure 5.** Agisoft 60 m GNSS photo position residuals without reverse strips.

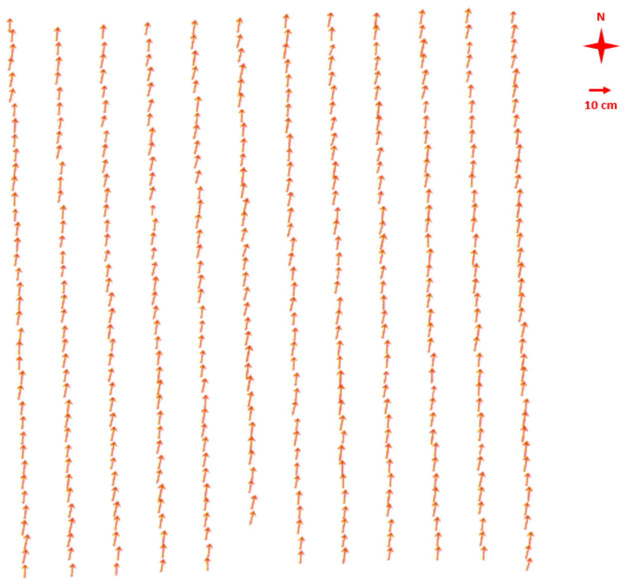


**Figure 6.** Pix4D 60 m GNSS photo position residuals.

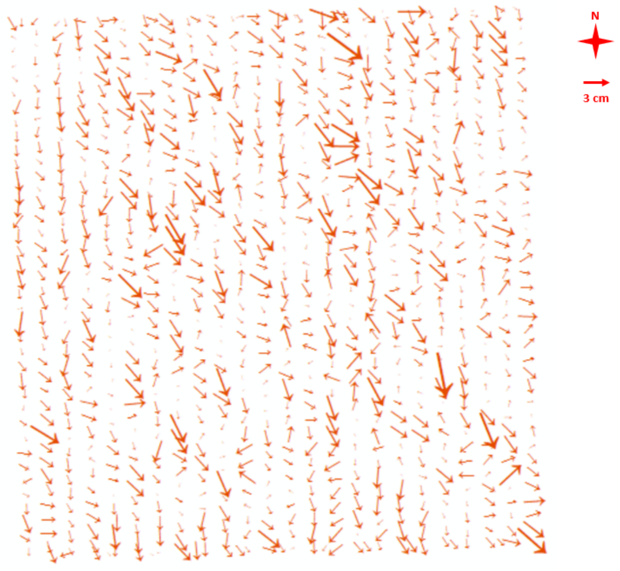


**Figure 7.** Pix4D 60 m GNSS photo position residuals without reverse strips.

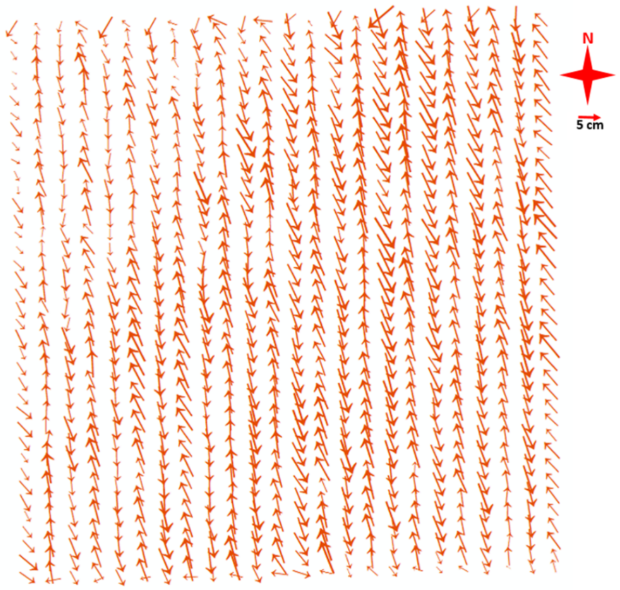


**Figure 8.** Inpho 60 m GNSS photo position residuals.

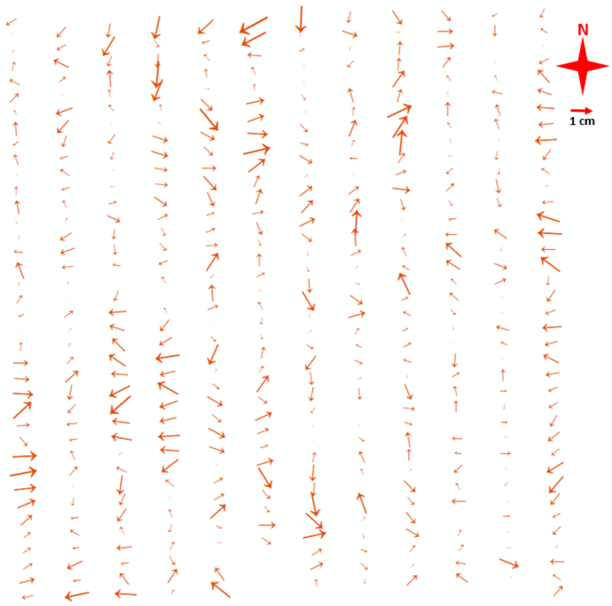


**Figure 9.** Inpho 60 m GNSS photo position residuals without reverse strips.

Even though the Inpho solution employs the block drift parameters in the processing, it does not resolve this issue. On the other hand, the SfM software did not display this behavior. In fact, their results look random. Further, the SfM software accuracy was more resistant to deterioration due to flying height than Inpho, see Fig. 10.

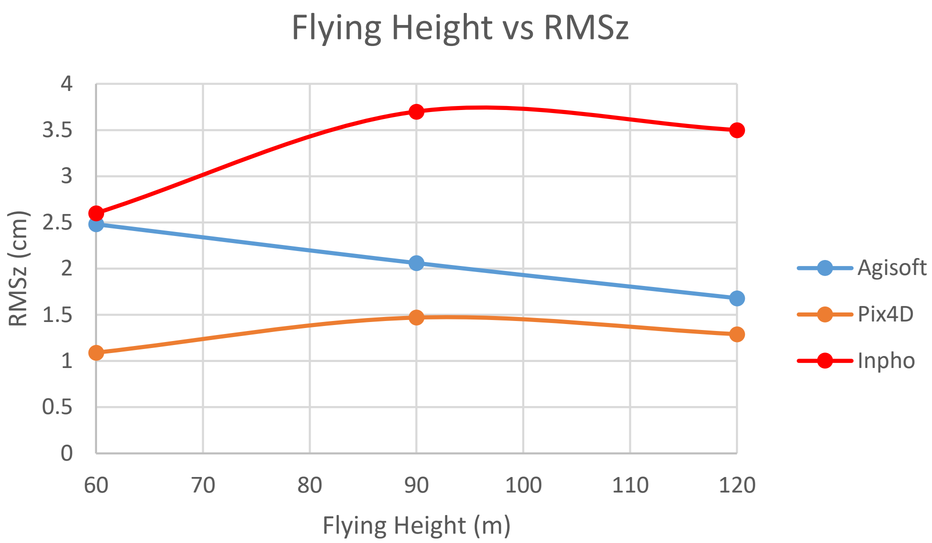


**Figure 10.** Flying height versus RMSz.

As can be seen in Fig. 10, Agisoft results accuracy increased with flying height, Inpho results accuracy deteriorated with flying height and Pix4D accuracy is almost flat.

## CONCLUSIONS

Agisoft, Pix4D and Inpho software were compared using four UAV data sets collected at 60, 90, and 120 m above ground level along with 90 m real-time network solutions. As the flying height increased, the results deteriorated. This was especially the case with Inpho. By analyzing the results, it was also found that Inpho is not sensitive to the biases created by reverse strips. Thus, the same data sets were processed without including the reverse strips. Although some changes were experienced with the results time to time, some results, especially Inpho results, got better. In order to show GNSS photo position displacements in 2D, displacement vectors were also displayed for flights with and without reverse strips. It was found that 2D displacement vectors for the results without reverse strips got smaller and systematic bias was removed. Moreover, Inpho results deteriorated with flying height. Furthermore, although some slight changes were experienced from software to software and coordinate to coordinate, 90 m real-time network solutions showed the same performance as 90 m solutions without real-time network solutions.

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