delair-tech
AIRBORNE SENSORING

White paper

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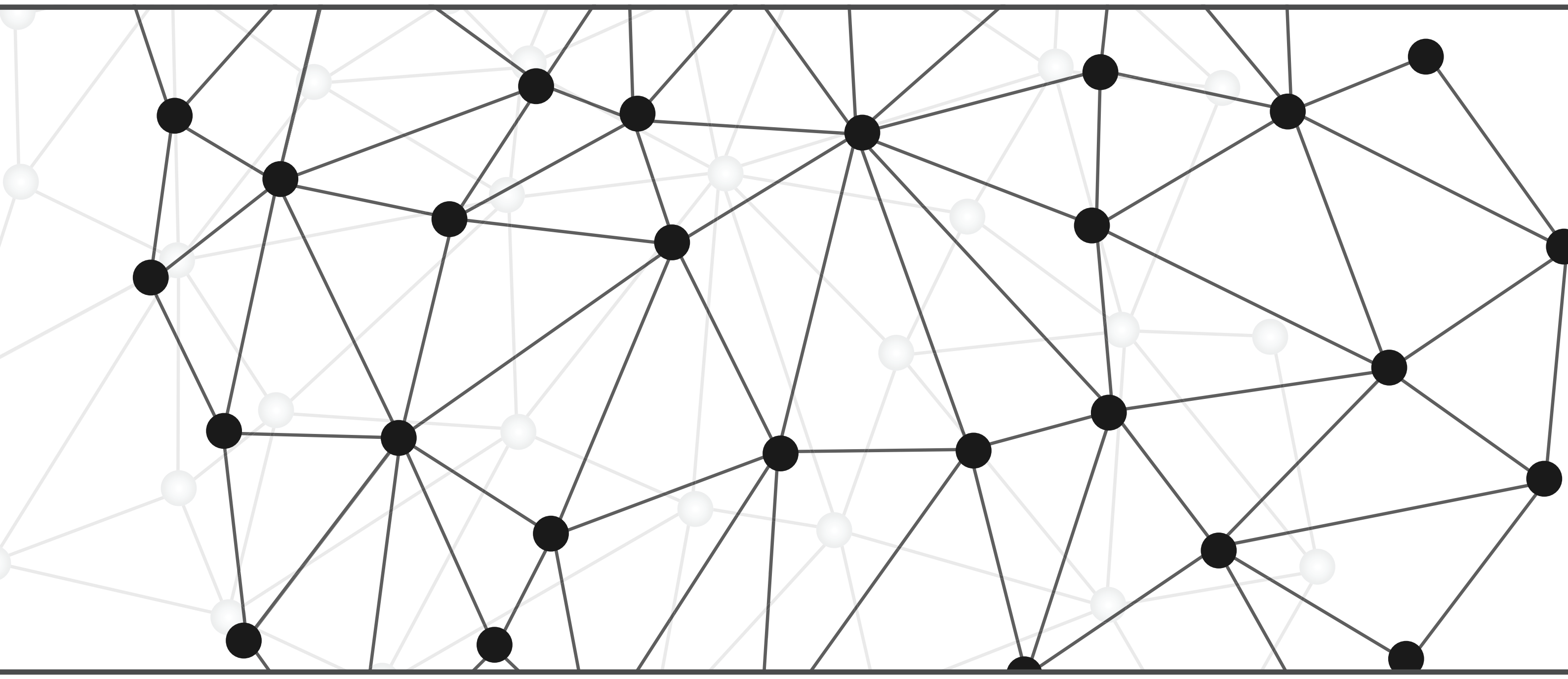
Get "the Z" right: methodology for achieving centimeter accuracy using drone-acquired data for mapping and topography purposes.



Content

1. Introduction

The purpose of this document is to analyse the benefits of a precision GNSS/IMU combination on the accuracy of products obtained by photogrammetry (DSM, DTM, orthophotography, stereoscopic restitution, 3D model) with Delair-Tech UAVs.

High accuracy makes it possible to work without Ground Control Points (GCPs), thus reducing overall costs.

The following case study was carried out from December 2015 to March 2016 with our DT18-PPK & DT26X-PPK models.

2. Vector and Payload

For this study, DT18-3bands PPK and DT26X-3bands XL PPK UAVs were used.

2.1 DT18-3bands PPK

The main specifications of the DT18 are :

- ◊ 2 kg
- ◊ 2h of autonomy
- ◊ 1.8 m wingspan
- ◊ 1.2 m length
- ◊ 60 km/h cruising speed

Figure 1 - DT18 UAV

The payload consists of a precision IMU/GNSS Applanix APX-15 and an industrial grade camera, with the following specifications :

- ◊ Sensor installed in landscape mode in the drone's direction of flight
- ◊ 3.45 microns (physical size of the pixels), ensuring good image quality
- ◊ 2448 x 2048 pixels
- ◊ Fixed, stable lens, with 12mm focal length.
- ◊ 1 s maximum frame rate
- ◊ At 150 m, coverage on the ground of 105 m x 88 m and a pixel on the ground of 4.3 cm

It should be noted that unlike consumer cameras, the industrial grade camera used in DT18 provides accuracy better than 10µs in timestamping the pictures.

2.2 DT26X-3bands XL PPK

The main specifications of the DT26X are :

- ◊ 15kg
- ◊ Payloads of up to 4kg
- ◊ 2h30 of autonomy
- ◊ 3.3 m wingspan
- ◊ Cruising speed 50 km/h

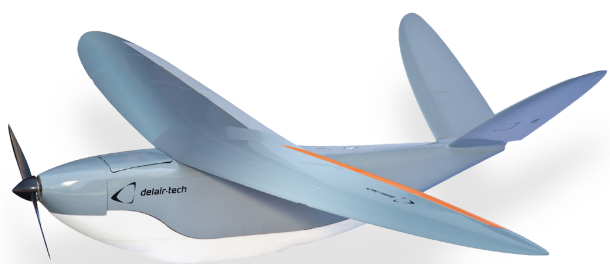


Figure 2 - DT26X UAV

The payload it carries is the DT3Bands-XL PPK. This consists of a Sony Alpha 7R coupled with an Applanix APX-15 GNSS/IMU, with the following characteristics:

- ◊ 7392 x 4920 pixels
- ◊ Pixel pitch 4.9µm
- ◊ Focal length : 35mm
- ◊ 1.4s maximum frame rate
- ◊ At 150 m ASFC, coverage on the ground of 155 m x 103 m and a pixel on the ground of 2.1 cm

2.3 GNSS/IMU APX-15

Applanix has been recognized in the aerial mapping field for many years, and its APX-15 UAV model was chosen. The position and attitude characteristics, once the data have been post-processed with POSPac software, are specified as:

- ◊ 2 to 5 cm in position
- ◊ 0.025° in pitch and roll
- ◊ 0.08° in heading

This system is autonomous, i.e. its results can be obtained without establishing any base on the ground, thanks to the permanent network used by Applanix for post-processing and calculating the trajectory.

It uses carrier-phase tracking, in addition to differential and bi-frequency technology. Furthermore, the GPS data is fused with the IMU data.

The "lever arms" between GPS antenna, IMU and camera are known from the design specifications.

3. Test fields

Several test fields were used, and for each of them, control points were measured on the ground with a Trimble R6 (post-processed using the fixed base shifts) guaranteeing accuracy of the checkpoints to within 2-3 cm.

Figure 3 – Example of one field with control points

4. Flights

Two types of flights were tested:

◊ Cover zones: because they contain several axes, the whole system is more constrained. In order to resolve ambiguities (camera, lens, distortion and principal point of autocollimation, as well as the angles related to the set-up between the Applanix map and the camera), a 90° cross-flight was performed at two heights above the ground. Side coverage of the axes was set at 60% in order to increase the overlap of images and obtain more autocorrelation points.

◊ Linear mapping: this was achieved with just one back & forth flight (2 axes separated by 10m).

In total 7 flights were made:

N	Date	UAV & Payload	Number of images	Type	Area (km2) or Length (km)
1	2015 December 18th	DT18-3Bands PPK	161	coverzone	0.14
2	2016 March 2nd	DT26-3Bands XL PPK	720	coverzone	0.42
3	2016 March 10th	DT18-3Bands PPK	2534	coverzone	1.67
4	2016 March 10th	DT26-3Bands XL PPK	3245	coverzone	4.81
5	2016 March 11th	DT18-3Bands PPK	969	linear	8.00
6	2016 March 17th	DT26-3Bands XL PPK	191	coverzone	0.27
7	2016 March 17th	DT26-3Bands XL PPK	457	linear	4.50

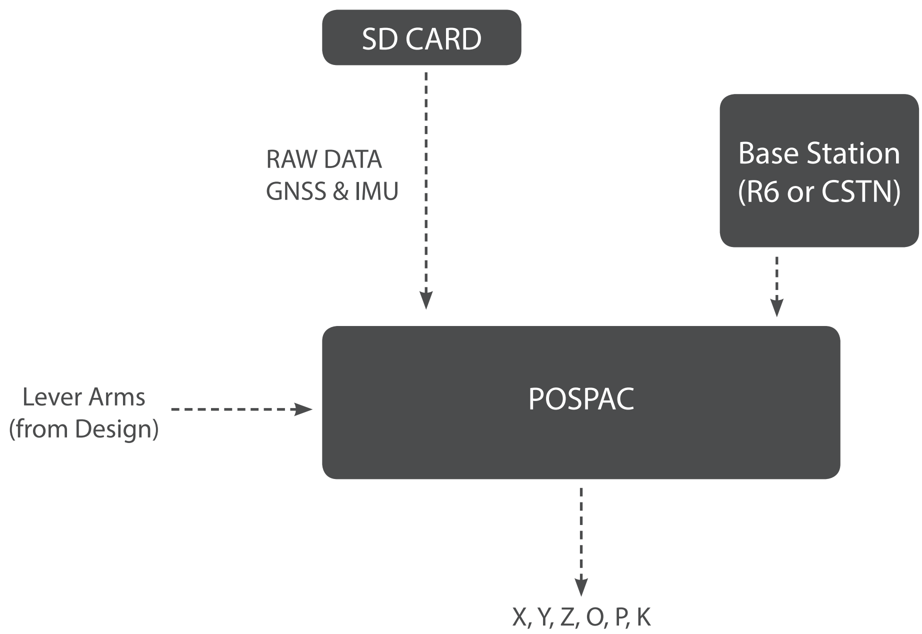
5. Processing

After the flight, the Applanix navigation data were post-processed using POSPac software in order to integrate the lever arms and calculate the precise trajectory (X,Y,Z,O,P,K).

Two bases were used in order to evaluate the influence of the distance on corrections and results :

- ◊ A local base station (located at the Ground Control Station, therefore close to the flight area). Here a Trimble R6 receiver was used.
- ◊ A network station, in this case a CSTN beacon, located 40km from the flight area

All data are in UTM 31N Projection and in EGM96 for altimetry.



Two photogrammetry softwares applications were used: Pix4D and UASMaster.

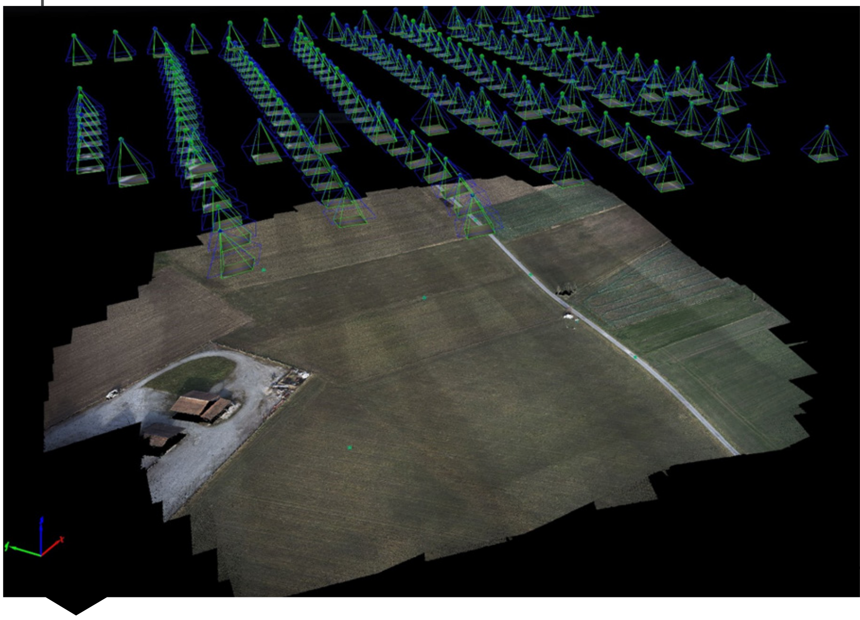


Figure 4 – Pix4d View

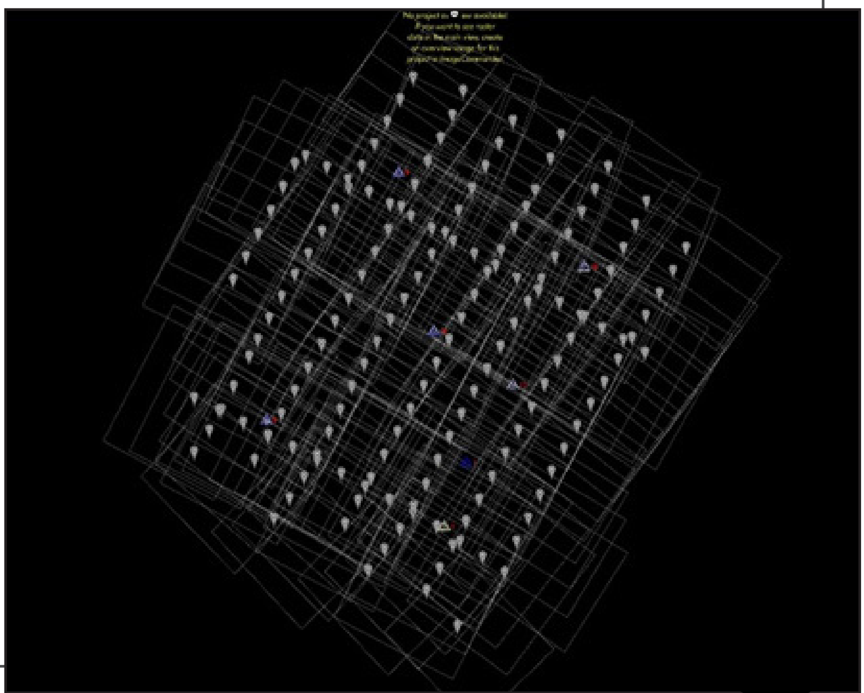
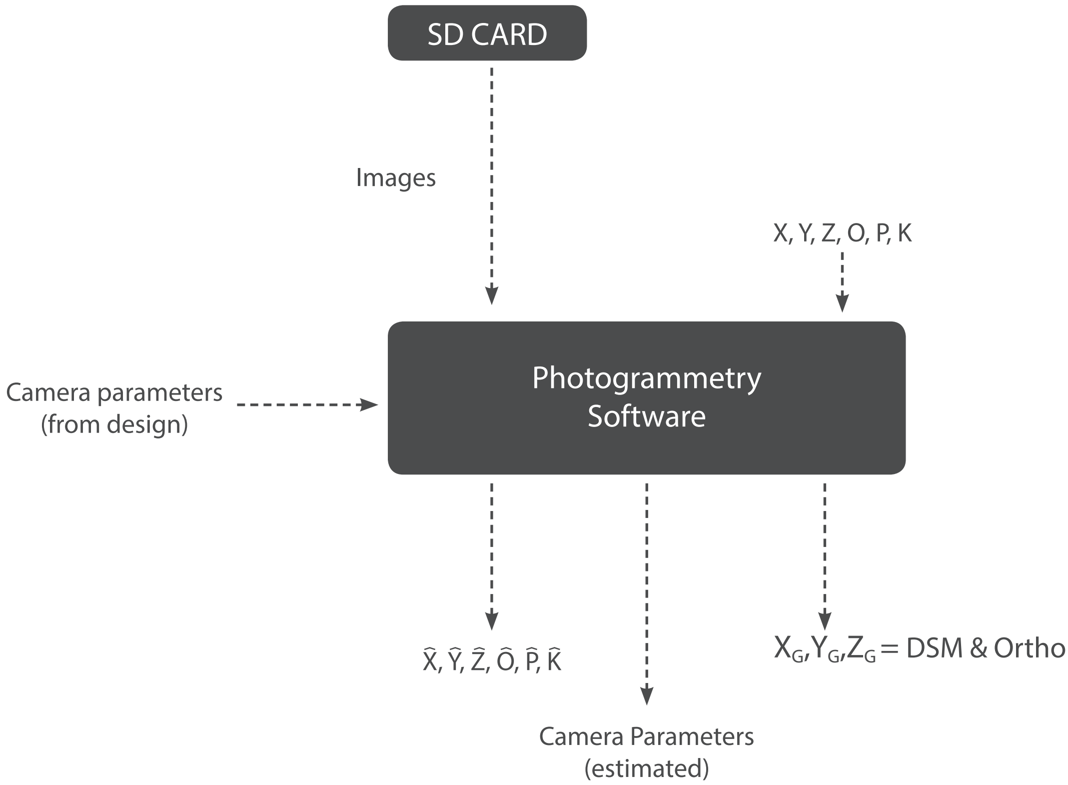


Figure 5 - UAS - Master

The usual process was used, with no GCPs. From Positions (X,Y,Z), Angles (O,P,K) and Pictures, knowing the theoretical camera parameters (focal length, sensor size, principal point, etc…), the aerial triangulation process estimates the "real" positions of the camera ($\hat{X},\hat{Y},\hat{Z}$) as well as its "real" exterior orientations ($\hat{O},\hat{P},\hat{K}$). The photogrammetry software then estimates the DSM and generates a projection of the image points on the DSM to produce the orthophoto. At the end of the process, every point of each image has unique (X_G,Y_G,Z_G) coordinates.

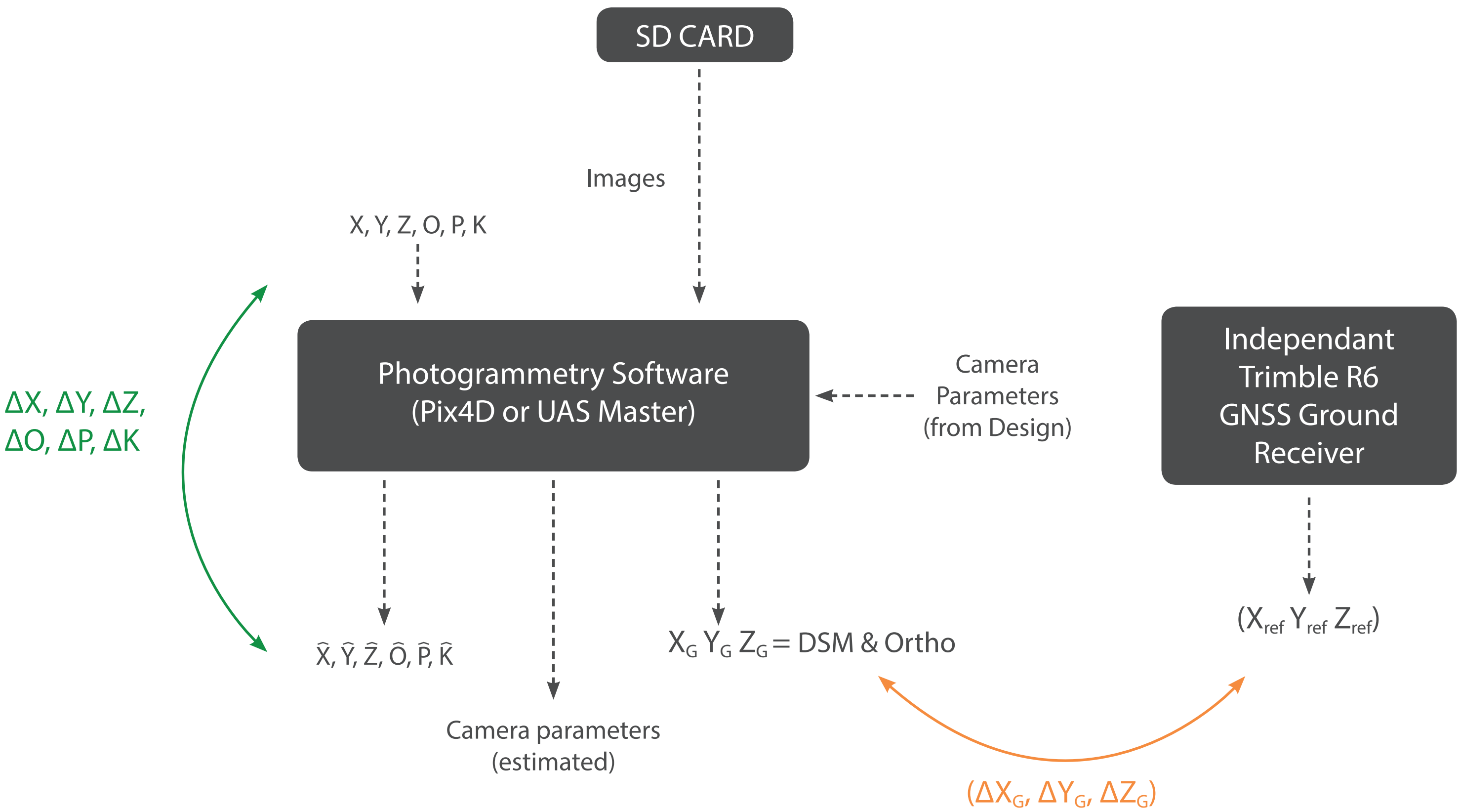


6. Comparison Method

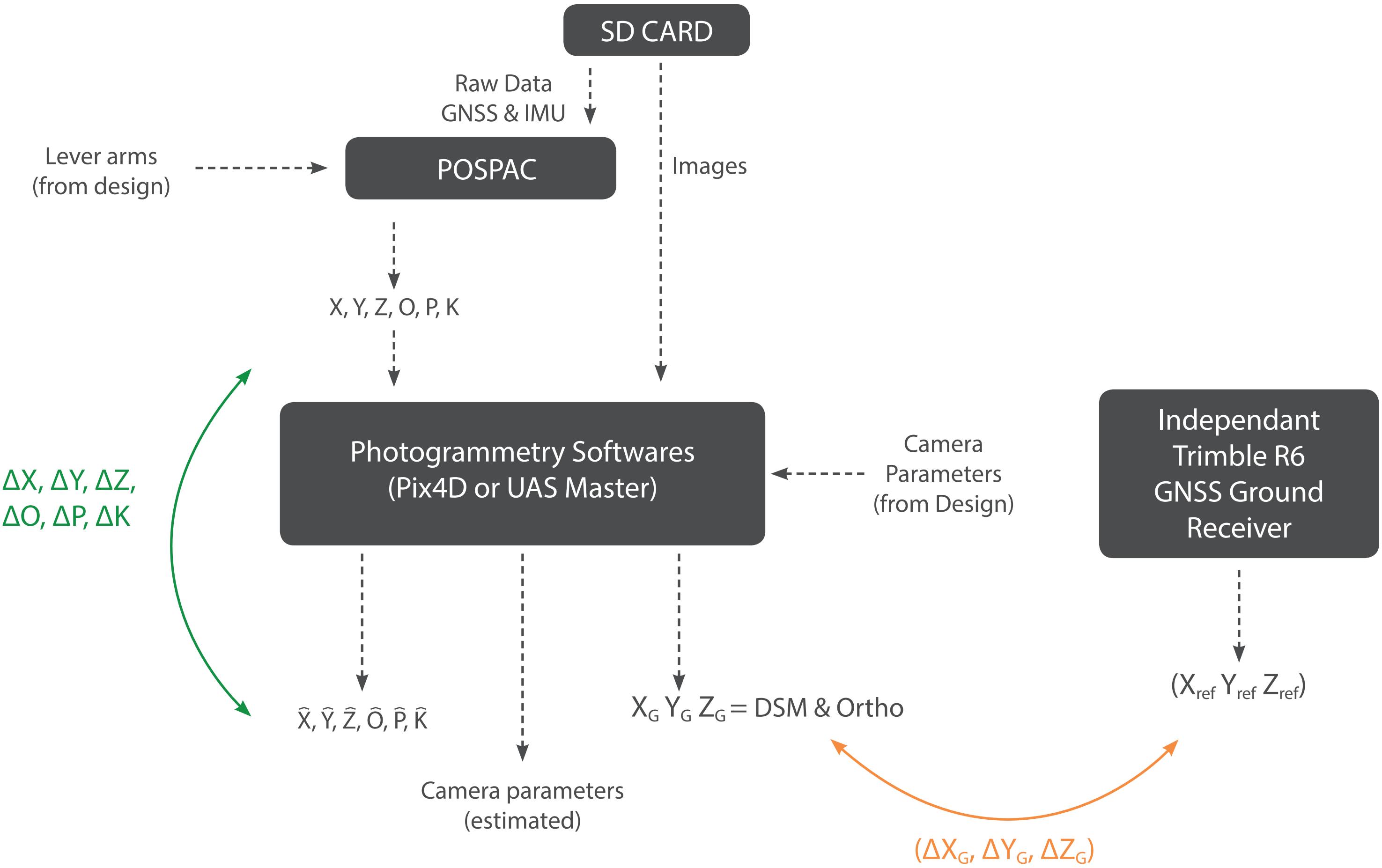
In the following tables we present the differences (RMS) between:

◊ Exterior Orientations of the camera as calculated by POSPac (X,Y,Z,O,P,K) and as estimated by the Photogrammetry software ($\hat{X}, \hat{Y}, \hat{Z}, \hat{O}, \hat{P}, \hat{K}$). This gives (ΔX, ΔY, ΔZ, ΔO, ΔP, ΔK)

◊ Coordinates (X_G, Y_G, Z_G) of specific points on the ground and their coordinates measured on the field by an independent method, in our case : a Trimble R6 receiver ($X_{ref}, Y_{ref}, Z_{ref}$). These reference points are called "CheckPoints". They should be distinguished from Ground Control Points (GCPs) in that they are not used during the photogrammetry process. In our case this gives ($\Delta X_G, \Delta Y_G, \Delta Z_G$)

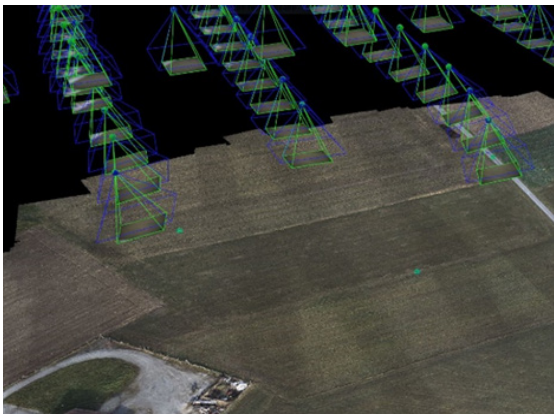


7. Global view



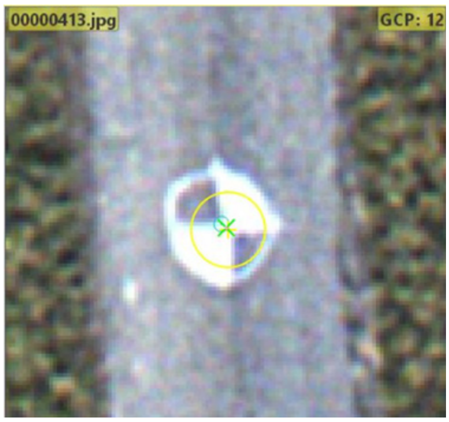
With images :

ΔX	ΔY	ΔZ	ΔO	ΔP	ΔK



The differences are calculated between the “green” and “blue” pyramids as seen here in Pix4D

ΔX_G	ΔY_G	ΔZ_G



The differences are calculated between the “real” coordinates of the Point as measured on the ground (center of the target) and the coordinates as seen in the reprojection from the photogrammetry software (here : Pix4D)

8. Example of Acquisition & Processing

For flight Number 1, acquisition took place on December 18th, 2015 in good weather conditions.
161 images were acquired.
The raw data were processed in POSPac in order to get exterior orientations.

The dataset was processed in Pix4D and UASMaster, without GCPs.

With UASMaster, the following results were obtained in comparison with checkpoints measured on the ground by an independent GNSS receiver (Trimble R6) :

Check point errors

	ID	Projections	X [m]	Y [m]	Z [m]	Total [m]
1	11	14	-0.0152	0.0234	0.0821	0.0867
2	12	11	0.0010	-0.0078	0.0279	0.0290
3	14	14	0.0028	0.0091	0.0362	0.0374
4	5	12	-0.0139	-0.0163	0.0179	0.0279
5	6	5	-0.0216	-0.0225	0.1234	0.1273
6	8	4	0.0137	-0.0535	0.1521	0.1619
	Mean		-0.0055	-0.0113	0.0733	
	Sigma		0.0134	0.0267	0.0553	
	RMS		0.0134	0.0269	0.0890	
	Maximum		0.0216	0.0535	-0.1521	

For this dataset, with UASMaster, the accuracy (RMS) in X,Y,Z on the ground is therefore :

- ◊ X : 1.3cm
- ◊ Y : 2.7cm
- ◊ Z : 8.9cm

With Pix4D, the following results (RMS on the ground) were obtained :

- ◊ X : 1.4cm
- ◊ Y : 1.8cm
- ◊ Z : 11.4cm

9. Results

All results are in RMS, and no Ground Control Points (GCPs) were used.

9.1 Linear flights

UAV	Base	Img	Length (km)	GSD (cm)	ΔX (cm)	ΔY (cm)	ΔZ (cm)	ΔO (°)	ΔP (°)	ΔK (°)	ΔXG (cm)	ΔYG (cm)	ΔZG (cm)	N CP	Soft
DT26	CSTN	457	4.5	1.7	2.6	3.1	2.6	0.233	0.188	0.493	9.3	34.7	12.9	5	Pix4d
DT26	CSTN	457	4.5	1.7	2.6	2.7	1.6	0.016	0.022	0.007	6.2	38.6	14.0	6	UASM
DT18	CSTN	969	8.0	3.3	1.2	1.2	1.6	0.837	0.673	0.161	11.6	12.7	26.4	11	Pix4d
DT18	CSTN	969	8.0	3.3	4.0	4.0	2.0	0.034	0.052	0.015	16.0	16.7	37.8	11	UASM

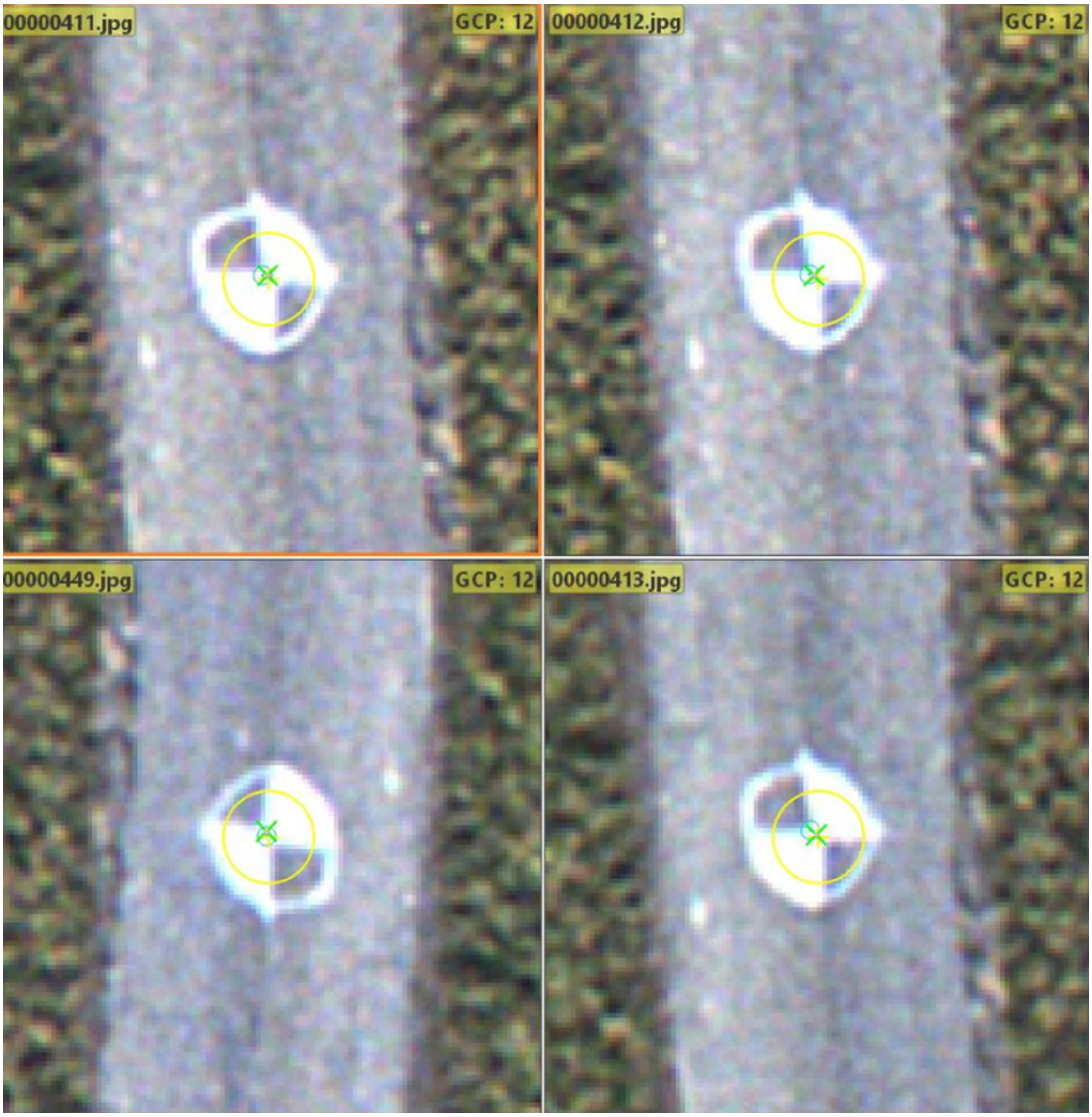
9.2 Cover zones

UAV	Base	Img	Area (km2)	GSD (cm)	ΔX (cm)	ΔY (cm)	ΔZ (cm)	ΔO (°)	ΔP (°)	ΔK (°)	ΔXG (cm)	ΔYG (cm)	ΔZG (cm)	N CP	Soft
DT26	R6	720	0.42	1.9	3.1	3.7	2.6	0.171	0.237	0.384	3.8	2.9	5.0	8	Pix4d
DT26	CSTN	191	0.27	1.7	2.6	2.7	3.3	0.214	0.145	0.567	5.2	4.7	5.6	6	Pix4d
DT18	R6	161	0.14	4.0	2.2	2.2	0.8	0.010	0.009	0.004	1.3	2.7	8.9	6	UASM
DT18	CSTN	2534	1.67	3.7	3.7	3.8	1.2	0.018	0.017	0.004	10.3	7.2	9.7	4	UASM
DT26	CSTN	3245	4.81	2.0	2.0	2.11	0.83	0.009	0.007	0.002	2.0	7.0	11.1	12	UASM
DT1	R6	161	0.14	4.0	0.6	0.6	1.0	0.285	0.444	0.871	1.4	1.8	11.4	6	Pix4d

10. Reprojection

Here is how the checkpoints look in Pix4D after reprojection of the results of the Aerial Triangulation (therefore only using the on-board data, no GCPs at all).

GCP12



GCPs:

Green cross: Projection of the 3D point computed from marks of the selected GCP.

Yellow cross: Position where the selected GCP has been marked.

Yellow circle: Its radius indicates the zoom level at which the selected GCP has been marked. It defines the area in which the point has to be reprojected when estimating the 3D position. When zooming back out from the image, the smaller the circle, the lower the zoom level of the marked point. The higher the zoom level, the more influence the mark has on the reconstruction.

Blue circle: The position corresponds to the projection of the input 3D coordinate of the selected GCP.

11. Conclusion

DT18PPK and DT26X PPK can be used to obtain a very precise solution without the need to measure ground control points.
The absolute accuracy for corridor mapping is between 15 cm and 30 cm in Z.
For cover zones, the accuracy is between 2-5 cm in X,Y, and between 5-10 cm in Z.