White Paper

Trimble UX5 HP – Increasing Your Productivity

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TECHNOLOGY THAT transforms

Trimble.

Accurate Mapping & Surveying

Building on the proven quality and durability of the UX5 platform, we announce the **Trimble UX5 HP (High Precision)**, featuring significant hardware additions and upgrades**.** These changes enable accurate and repeated mapping and surveying of large swaths of land without the burden of extensive ground control point (GCP) surveys.

In this paper, we highlight and discuss the key hardware and software benefits of the Trimble UX5 HP in addressing real-world challenges when working with unmanned aircraft systems (UAS). We also present elaborate and independent accuracy analyses in the different surveying scenarios enabled by the UX5 HP.

Reducing the Need for GCPs

Possibilities

The adoption of fixed wing unmanned aircraft systems has greatly increased in recent years with the advent of affordable yet high-end platforms such as the Trimble UX5 (Cosyn & Miller 2013). Some key aspects in this success story are:

- an advanced level of automation in flight management software such as Trimble Access Aerial Imaging and image processing software packages like Trimble Business Center (TBC) Aerial Photogrammetry Module (APM) and Trimble Inpho UASMaster

- as a non-survey or photogrammetry specialist, you take control and successfully complete both the image acquisition and the generation of deliverables required for a job

- geospatial professionals worldwide obtain on-demand orthorectified imagery and 3D models

Challenges

However, the process of measuring in UAS surveys is laborious:

- placing and measuring ground control point markers, and indicating the points of measurement in the imagery has traditionally been a time-consuming and expensive component of accurate UAS surveys

- in some cases, the ruggedness of the terrain or non-stop operations involving heavy machinery in the area of interest restrict the use of highly accurate UAS surveys in such environments

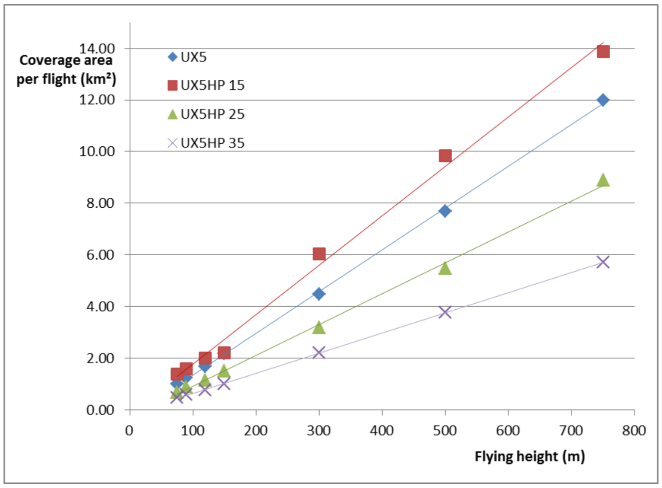
Therefore, the next logical step in automating UAS surveys involves the **reduction or elimination of the need for GCPs in generating highly accurate deliverables**. This can be achieved by the technological evolution in miniaturization and improvements of multiple frequency GNSS antennas and receivers.

Improving Hardware Aspects

Aerial Photography with the Sony a7R

Our Trimble UX5 HP comes with a 36 MP full frame (35.9 mm wide sensor), mirrorless interchangeable lens camera, the Sony a7R (figure 2, B). With more than twice the sensor surface area compared to popular APS-C sensor cameras, the system offers unrivalled resolution while upping the pixel size to 4.9 µm, further improving dynamic range and signal-to-noise ratio (SNR). Offered with three different lenses, users can now instantly make a trade-off decision between coverage area and ground sample distance (GSD) best suited for their given job requirements at any time (figure 1).

- For increased coverage area per flight and better modeling of vertical surfaces, choose the **Voigtländer 15 mm** lens. It offers a market leading combination of an **ultra-wide viewing angle** of 90° cross-track at a GSD of 2.4 cm from 75 m above ground level (AGL), compared to the 75° cross-track viewing angle and 2.0 cm GSD of the UX5 at the same flying height.



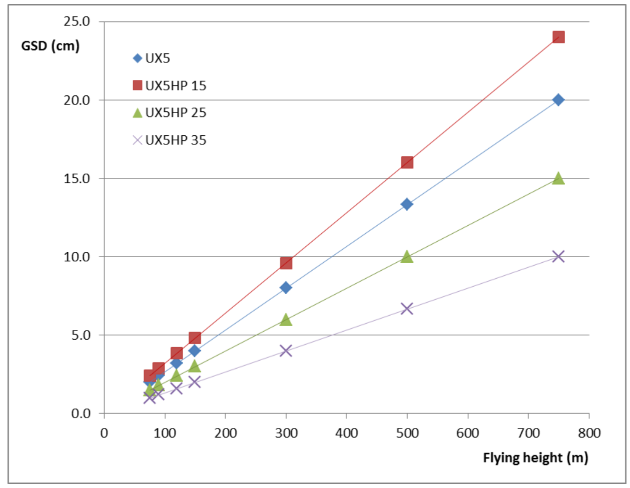


Figure 1. GSD and coverage area per flight as a function of flying height for all Trimble fixed wing UAS camera and lens combinations.

- For an **all-round solution**, choose the **Voigtländer 25 mm** lens. It results in a better GSD than the UX5 (1.5 cm from 75 m AGL) for a comparable coverage area per flight.

- For maximum detail, choose the **Voigtländer 35 mm** lens. It delivers a **unique GSD of 1.0 cm** from 75 m AGL, leading to 1,000 points per m² in dense point cloud extraction and enabling photogrammetric measurements with unprecedented detail and accuracy.

For all lens types, we ensured stability of the interior orientation, optimal photogrammetric accuracy and quality of the deliverables through:

- locking screws for mechanical fixation of the focus distance and aperture rings, adjustable by the user
- a custom-designed screw mount preventing movement of the optical axis
- correction for lens effects such as vignetting and color shift in Aerial Imaging

GNSS Log with Accurate Event Marks for Post-Processing

The UX5 HP is equipped with a high performance multiple frequency antenna embedded in the wing, providing excellent SNR in all operating environments while allowing an undisrupted airflow over the wing. In the payload bay, the gBox containing the GNSS receiver board is tightly strapped into the surrounding protective foam (figure 2, A). The receiver is logging GNSS data at 20 Hz for post-processing of the trajectory, and marks feedback events from the camera in the GNSS log with better than millisecond-level accuracy.

In contrast with real-time kinematic (RTK) corrected systems, the UX5 HP uses **post-processed kinematic (PPK) correction of the trajectory and event marker positions**. This choice was made specifically with the high speed and long distance characteristics of the UX5 HP platform in mind, where not depending on a radio link to get accurate solutions throughout the flight makes the system **more reliable**. As an added benefit, PPK-calculated solutions can be **more accurate** than RTK by making use of more precise orbital data and more sophisticated smoothing, filtering and interpolation algorithms. Additionally, you can spend **less time in the field** as setting up a base station for logging only is less complex, and when using an internet source of base data, a base station is not even necessary. Time spent in the office is the same as for RTK-only systems, as post-processing is also often necessary to get a precise position of the base station for RTK-based UAS.

Figure 2. Layout of the Trimble UX5 HP payload bay. **A.** gBox with GNSS receiver board and status LEDs. **B.** Sony a7R 36MP full frame mirrorless camera with 3 lens choices; note the feedback cable at the top left of the camera, connected to the hot shoe. **C.** System battery. All payload bay components are securely fastened with the Velcro strap **(D)**.

Improving Software Workflows

Autonomous, 5+ GCPs

With the UX5 HP, you can still process the data in the same workflow as ordinary UX5 data, relying on autonomous positions only for the relative adjustment, and with the option of using at least five GCPs for an accurate camera calibration. In the case studies section, you can read our examination on how the resulting accuracy from this approach compares to results based on a typical UX5 HP approach using post-processed event marker positions for the calibration of the camera.

Post-processed trajectory, no GCPs

1. All rover data including images and GNSS log file are imported into TBC through a single JXL file exported from the Aerial Imaging software.

2. As a user, you can import a base data file from a local base station, or online from a nearby CORS or VRS service.

3. The trajectory of the UX5 HP is post-processed in TBC (Complete or Advanced) using all available satellites and frequencies.

4. Fixed event marker position solutions are calculated (using interpolation algorithms set in the UX5 HP template available in TBC) and will be used as observations in the camera calibration. Float solutions are discarded to ensure reliability of the process.

5. After the trajectory post-processing, you either have the option to export the flight mission as post-processed event marker positions to a CSV file for image processing in Trimble UASMaster or third-party software, or in TBC APM to proceed directly to the *Deliverables* tab of the *Advanced UAS* tool in the *Photogrammetry* toolbar. In the *Deliverables* tab, you can also uncheck any deliverables and just run the adjustment, which will automatically include the camera calibration (absolute adjustment) despite the absence of GCPs, after which photo points can be measured with very high accuracy.

While this approach ensures an end result characterized by a very high relative accuracy, the absolute errors can sometimes show a systematic offset (global shift) in the vertical component. This would most likely be the case when working at a low flight height with a narrow viewing angle lens, or in datasets with low overlap, and is due to a limited observability of the focal length.

The possibility of vertical shifts exists in data from all similar class UAS, and although it is much less known by UAS operators unexperienced in photogrammetry, it is well documented in photogrammetric literature when treating GNSS-only based camera calibration (see for example Casella & Franzini 2005, Grenzdörffer 2009, or see the whitepaper of Micro Aerial Projects 2015 for an account specifically involving UAS).

To increase the observability of the focal length and reduce the risk of a systematic vertical offset without the use of GCPs, the photogrammetric block can be strengthened by adding a few flight lines at a 20% higher flight level, diagonally crossing the area of interest, in the same flight. Our Trimble Access Aerial Imaging easily allows for this block configuration. The two flight blocks (the main block and the additional flight lines) can be merged for the adjustment to improve calibration of the focal length. After adjustment, the additional flight lines can be removed again to avoid artefacts in the dense point cloud extraction and the creation of orthomosaics due to differences in GSD or ambient light conditions between the two blocks.

Post-processed trajectory, one or few GCPs

In TBC APM and Inpho UASMaster, you also have the option to measure only one or few GCPs in the imagery before starting the adjustment. The available GCPs have no influence on the camera calibration itself, but are used afterwards to identify and automatically correct for any remaining global shifts in the photogrammetric solution relative to the control point(s) on the terrain. It is important that the GCPs are located within the flight plan boundary to ensure observability of the point in sufficient images.

When measuring the GCP(s) in the images, it is important to do so both in images that have the GCP marker in the center as well as in images that have the GCP towards the edge or corner of an image, in order to increase the observation angles and obtain better vertical accuracy (this is best practice whenever working with GCPs or when measuring check points on adjusted images).

Whenever you have the option to provide one or few ground control points to correct for potential global shifts, we recommend this approach over the use of additional flight lines to correct for any potential shifts. This is a more effective solution both in terms of accuracy (for example, it also corrects for datum transformation errors and is not dependent on GNSS quality of only a couple of flight lines) and economy (no coverage area is lost to flight lines covering the same area twice).

Regardless of the choice for processing with or without some GCPs, we want to stress that the possibility to reduce or eliminate the need for GCPs to get an accurate adjustment does not imply that valid surveys can be done without independently measured check points for quality assurance.

Results and Discussion

Reliability analysis of 25 test flights

- Over a period of 2.5 months, we captured 25 UX5 HP datasets comprising all lens types and a range of GSD values over our Belgian Trimble UAS test site (flat farmland), a UAS test site in New Zealand (undulating farmland) and an open pit mine in Australia, in varying weather conditions.

- We planned all flights with 80% forward and lateral overlap to ensure optimal photogrammetric accuracy, and flight line orientation was perpendicular to the wind direction to ensure stable flight behavior.

- For all projects, we used a local base station or a CORS operating at 1 Hz at a maximum of 5 km from the take-off site, and we had a set of accurately surveyed GCP markers available.

- We processed the imagery in TBC APM 3.61 following baseline processing of the trajectory, either without any GCPs in the adjustment or with only one GCP to correct for global shifts. In some cases, we used three additional flight lines diagonally crossing the flight area at a higher level instead of any GCPs to aid in calibration of the focal length and to ensure absolute accuracy.

- We measured all GCP markers covered by the flight that were not used in the adjustment as independent check points (CP).

Table 1 provides an overview of the characteristics and results of these 25 datasets. The radial horizontal ($\sqrt{(RMSE_x^2+RMSE_y^2)}$, ASPRS 2015) and vertical root-mean-square error (RMSE) values reported are those of the adjustment by measuring independent check points as photo points directly on the adjusted images (as opposed to measuring on the deliverables; ASPRS 2015). Figures 3a and 3b show these values as a function of the GSD, expressed in meters and times the GSD, respectively.

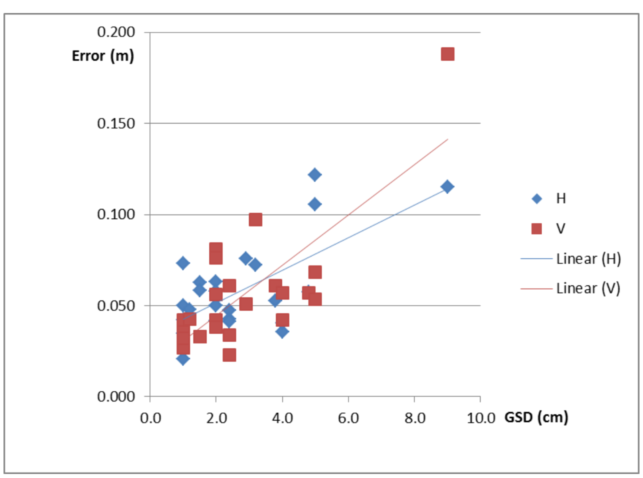
Table 1. Characteristics and results of a set of 25 UX5 HP test flights, ordered by GSD.

Flight ID	Images	Lens f (mm)	GSD (cm)	H error (m)	V error (m)	H error (px)	V error (px)	QA	Nr of CP	Meteo	Wind (Bft)	Country
Flight002	486	35	1.0	0.035	0.027	3.5	2.7		20	Overcast	1	BE
Flight009	114	35	1.0	0.021	0.037	2.1	3.7	1	6	Broken	2	BE
Flight014	557	35	1.0	0.050	0.042	5.0	4.2		16	Broken	3	BE
Flight015	620	35	1.0	0.042	0.032	4.2	3.2	2	17	Sun	1	BE
Flight022	621	35	1.0	0.073	0.032	7.3	3.2		18	Overcast	4	BE
Flight013	550	35	1.2	0.048	0.043	4.8	4.3		5	Overcast	0	NZ
Flight016	517	25	1.5	0.063	0.033	4.2	2.2		17	Overcast	3	BE
Flight021	699	25	1.5	0.059	0.033	3.9	2.2	1	16	Sun	5	BE
Flight003	300	35	2.0	0.050	0.042	2.5	2.1		16	Overcast	4	BE
Flight004	303	25	2.0	0.042	0.056	2.1	2.8		17	Overcast	4	BE
Flight005	300	25	2.0	0.041	0.038	2.1	1.9		17	Broken	1	BE
Flight006	295	35	2.0	0.063	0.081	3.2	4.1	1	16	Broken	1	BE
Flight024	291	35	2.0	0.058	0.076	2.9	3.8	1	17	Sun	5	BE
Flight001	399	15	2.4	0.047	0.023	2.0	1.0		20	Overcast	1	BE
Flight017	330	15	2.4	0.042	0.061	1.8	2.5		18	Sun	3	BE
Flight020	388	15	2.4	0.041	0.034	1.7	1.4		18	Sun	5	BE
Flight019	1324	15	2.9	0.076	0.051	2.6	1.7	1	8	Sun	3	AUS
Flight018	691	15	3.2	0.072	0.097	2.3	3.0		6	Sun	0	AUS
Flight007	195	15	3.8	0.052	0.061	1.4	1.6		21	Broken	2	BE
Flight023	117	15	4.0	0.035	0.057	0.9	1.4	2	11	Sun	5	BE
Flight025	52	15	4.0	0.040	0.042	1.0	1.1	2	8	Overcast	2	BE
Flight008	140	15	4.8	0.057	0.057	1.2	1.2	1	17	Broken	2	BE
Flight010	179	15	5.0	0.122	0.068	2.4	1.4		12	Sun	1	NZ
Flight011	56	15	5.0	0.105	0.053	2.1	1.1		12	Sun	0	NZ
Flight012	108	15	9.0	0.115	0.188	1.3	2.1		12	Broken	0	NZ
					Min	**0.9**	**1.0**					
					Max	**7.3**	**4.3**					
					Average	**2.7**	**2.4**					
					Median	**2.3**	**2.2**					
					St Dev	**1.5**	**1.1**					

Quality Assurance (QA) actions taken during flight planning or processing to ensure absolute accuracy (avoid global shifts)

1: use of 1 GCP (not included as checkpoint)

2: use of a few additional flight lines diagonally crossing the main block at a higher flight level



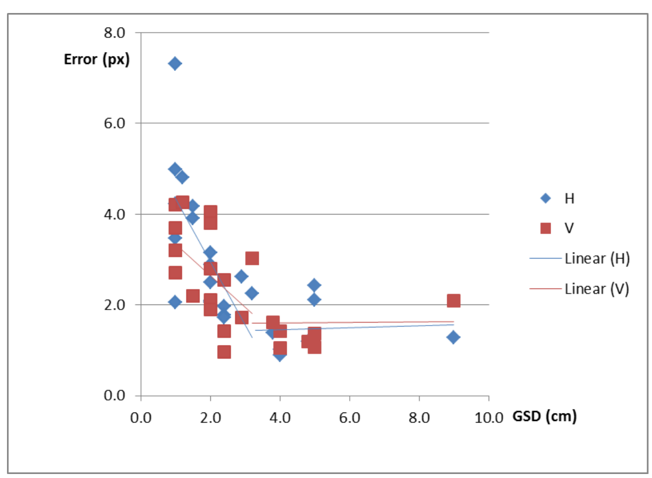


Figure 3a (left). Horizontal and vertical RMSE in meter (vertical axis) for different GSDs in cm (horizontal axis).
Figure 3b (right). Idem but with horizontal and vertical RMSE in pixels (or times the GSD).

Given optimal flight planning (80% planned overlap and flight lines perpendicular to the wind), we did not see a relation between accuracy and weather conditions.

In cases where quality assurance steps were taken to ensure absolute accuracy (see Table 1, QA), the applied shift correction was in Z only and was 14.9 cm on average, with a minimum of 3.7 cm and a maximum of 51.8 cm.

Overall, an average RMSE of 2.7 pixels horizontal and 2.4 pixels vertical was obtained.

As expected, there is a strong linear relation with GSD for both horizontal and vertical accuracy when expressed in meters (figure 3a). However, the relation of RMSE expressed as pixels with GSD (figure 3b) is not uniformly flat: a linearly decreasing error can be seen between 1 cm and 3.5 cm GSD before flattening off. Although the absolute accuracy achievable with a smaller GSD is still better than for a higher GSD, three factors play an important role at a smaller GSD (< 4 cm):

1. *The accuracy of onboard GNSS:*
   The accuracy of the post-processed image event marker positions is around 3 cm, which is three times the smallest achievable GSD (using the 35 mm lens at 75 m flying height). Thanks to the availability of typically more than 100 of these “airborne control points”, averaging of errors and a robust blunder detection leads to an RMSE that is sometimes less than 3 cm, but there is a limit to the accuracy that can be realized in the adjustment, imposed by the accuracy of GNSS data used for camera calibration.

2. *The accuracy of the ground control and check point measurements in the field and in images:*
   Contrary to UX5 projects where the accuracy of RTK surveys of GCP markers in the field is normally better than the smallest possible GSD, these measurements can now be at the level of 1–2 times the GSD for the 1–2 cm range of GSDs. This has an impact on either the absolute accuracy of the adjustment, or the perceived absolute accuracy when using RTK-measured check points.

3. *Lens focal length:*
   While we offer the 25 mm and 35 mm lenses to achieve a GSD that is out of reach for the UX5 for more detailed inspection, **we generally recommend to use the shortest possible focal length to obtain a required GSD**. In longer focal length lenses, less oblique viewing information is available and the base:height ratio decreases, leading to less accurate photogrammetric observations. For instance, table 1 shows that at 2 cm GSD, results from the 25 mm lens are generally more accurate in an absolute and relative sense than from the 35 mm lens.

Ultimately, for a smaller GSD, it is the accuracy of the GNSS control and check point measurements in the field as discussed under 1 and 2 above that will determine the ASPRS accuracy class of the results, because those will supersede the accuracies of the photogrammetric processing (ASPRS 2015, Whitehead & Hugenholtz 2015).

Case studies

From the set of 25 flights listed above, you can find detailed analyses on one 1 cm GSD flight and one 2.4 cm GSD flight, executed on our Trimble UAS test site in Belgium.

Test terrain

Our test terrain consists of farmland with some buildings, concrete roads and courtyards, bare soil and short grass or crops. We installed 24 permanent GCPs made of artificial markers on flat, open terrain (both paved and short grass) covering a 0.4 km² flight area.

Ground control

We measured GCPs by RTK using a Trimble R10 in the FLEPOS VRS network with an occupation time of 60 seconds, resulting in an average horizontal accuracy of 1.3 cm and vertical accuracy of 1.7 cm.

Table 2. Accuracy analysis of Flight020.

Flight020	With trajectory, no GCPs (18 CP)	No trajectory, 9 GCPs (9 CP)
$RMSE_X$ on CP (average error)	**0.033** (0.001)	**0.026** (-0.01)
Min, max error(X)	-0.073, 0.062	-0.051, 0.024
$RMSE_Y$ on CP (average error)	**0.025** (-0.015)	**0.013** (0.000)
Min, max error(Y)	-0.043, 0.053	-0.024, 0.017
$RMSE_Z$ on CP (average error)	**0.034** (0.014)	**0.058** (0.051)
Min, max error(Z)	-0.045, 0.065	-0.009, 0.096
$RMSE_Z$ on scan (average error)	**0.068** (-0.033)	NA
Min, max error(Z)	-0.496, 0.496	

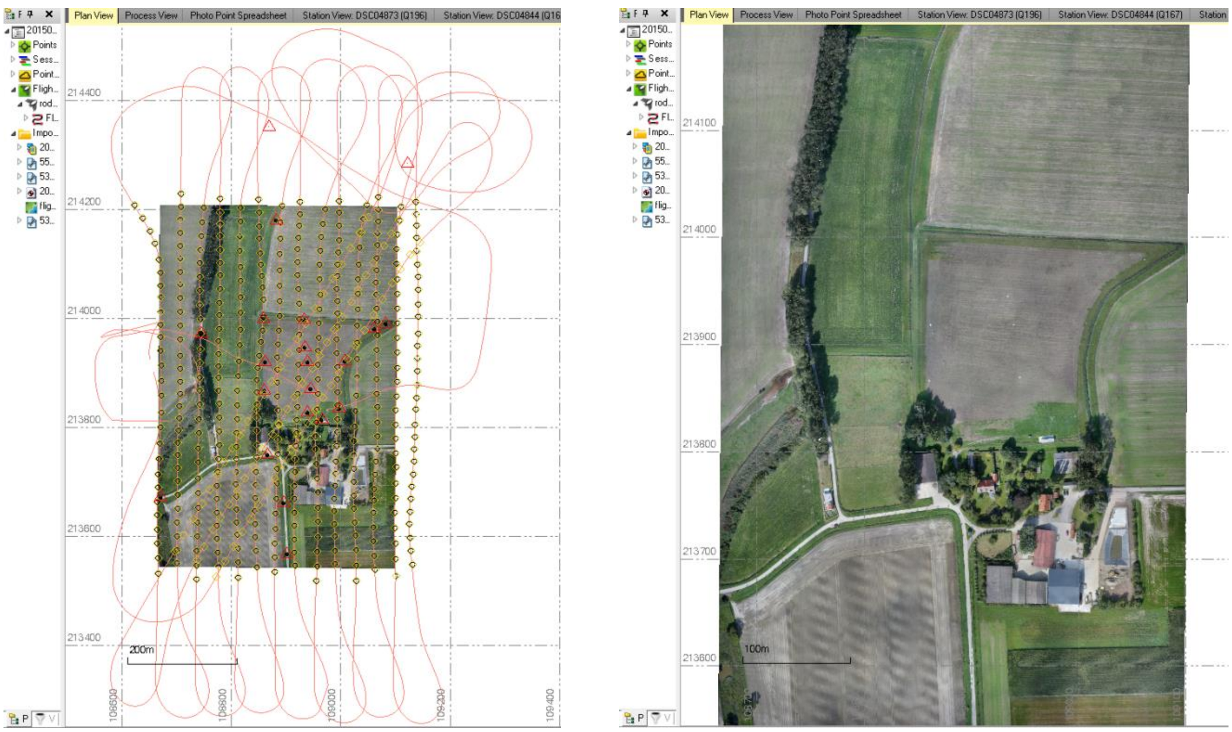


Figure 4. Flight trajectory, GCP distribution and orthomosaic of Flight 020.

Terrestrial scan

In addition, we used a Trimble TX8 to scan all hard surfaces and relatively unvarying soft surface types from 15 overlapping scan positions. After conversion to an elevation grid, we used a subset of around 10,000 points at 50 cm spacing on hard surfaces, both at the terrain level and on oblique and elevated features (such as roofs) to evaluate the vertical errors on the resulting digital surface model (DSM) deliverable. This procedure accounts for noise and other effects introduced by the deliverable generation process not visible in the adjusted images only (ASPRS 2015).

Flight020 – 2.4 cm GSD

Figure 4 shows the orthomosaic overlaid with the flight trajectory and ground control point distribution. Table 2 summarizes the horizontal and vertical errors for the different processing strategies used.

The $RMSE_Z$ of the DSM resulting from the standard UX5 HP workflow (using a post-processed trajectory and no GCPs) on the roughly 10,000 scan points is twice the $RMSE_Z$ of the adjustment as measured by photo points. This is in agreement with the expectations expressed by ASPRS (2015) and shows the effect of noise and potential artefacts, for example around buildings in the DSM extraction. Regardless, the **$RMSE_Z$ of the DSM processed without GCPs on the scan points is still better than the widely accepted three-pixel threshold**, and **meets the vertical accuracy requirement** for mapping non-vegetated areas as defined by the **10 cm $RMSE_Z$ class** (ASPRS 2015).

The horizontal RMSE of the adjustment in this case would **meet the accuracy requirements for the 5 cm RMSE class**. This means that for the final map product, the expected horizontal accuracy class would also be 10 cm according to ASPRS (2015). However, we have found horizontal RMSE on final map products to reflect the results from the adjustment much more closely than the stipulated factor 2, since horizontal noise in the production of true orthomosaics is much less of an issue than vertical noise in the DSM.

While the processing strategy without trajectory, but with nine GCPs (equivalent to processing normal UX5 data) resulted in a better horizontal accuracy, the strategy without GCPs **using a post-processed trajectory outperformed the conventional result for absolute vertical accuracy.** Regardless, the RMSE values resulting from both strategies would place the outcomes in the same ASPRS accuracy class both horizontally and vertically, meaning in practice the results from both strategies are equally accurate.

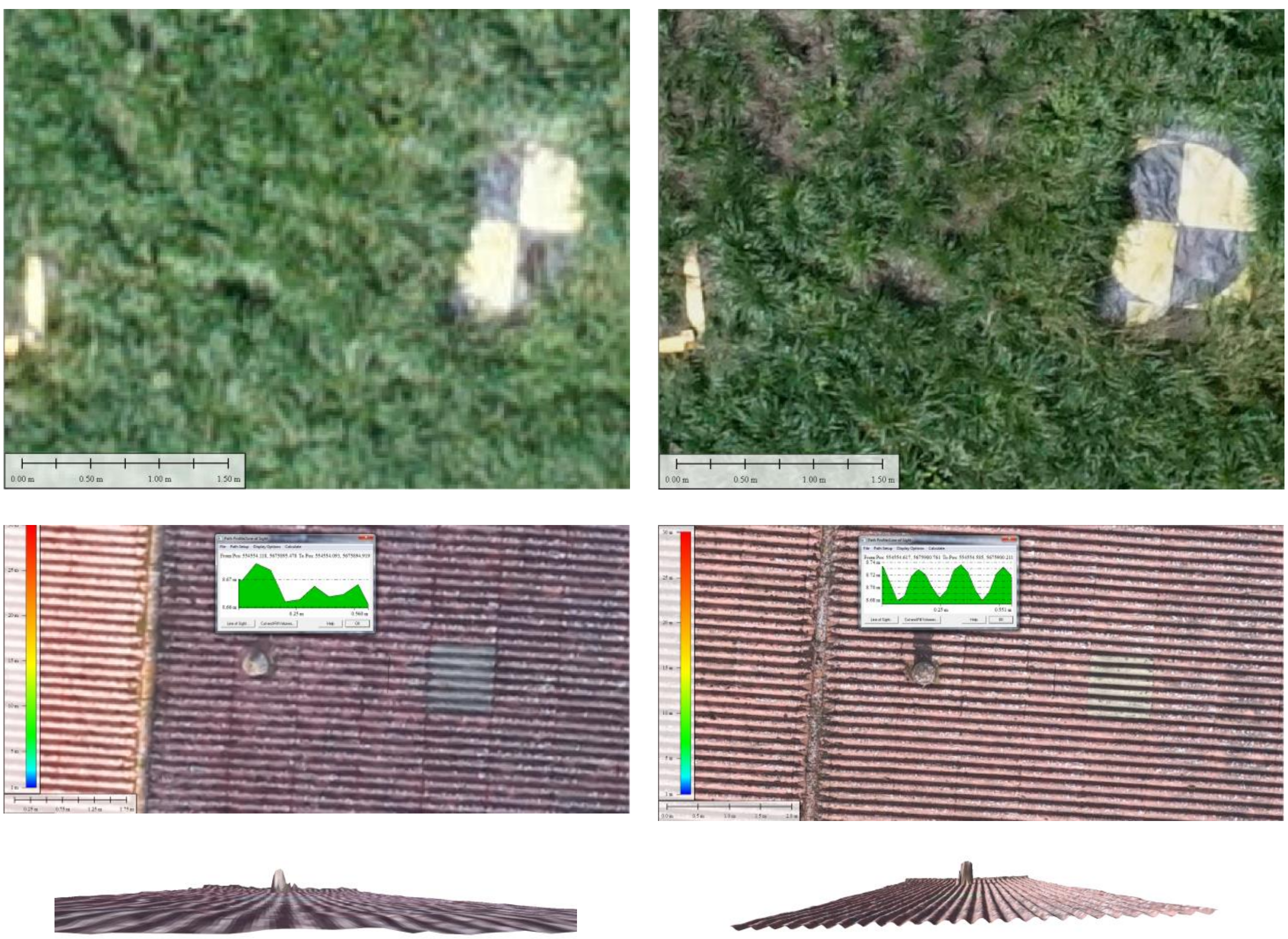


Figure 5. Example of different levels of detail from a 2.4 cm GSD (left) vs 1 cm GSD datasets (right), both in orthomosaic and DSM.

Table 3. Accuracy analysis of Flight015.

Flight015	No GCPs (17 CP), 3 additional lines	No GCPs (17 CP), main block	1 GCP (16 CP), main block	9 GCPs (6 CP), main block
$RMSE_X$ on CP (average)	**0.025** (0.012)	**0.052** (0.010)	**0.055** (0.005)	**0.062** (0.022)
Min, max error(x)	-0.017, 0.084	-0.058, 0.156	-0.066, 0.153	-0.077, 0.134
$RMSE_Y$ on CP (average)	**0.034** (0.018)	**0.063** (0.043)	**0.047** (-0.001)	**0.024** (0.013)
Min, max error(y)	-0.022, 0.085	-0.072, 0.108	-0.116, 0.061	-0.010, 0.053
$RMSE_Z$ on CP (average)	**0.032** (-0.013)	**0.075** (-0.071)	**0.026 (0.005)**	**0.064** (0.031)
Min, max error(Z)	-0.054, 0.048	-0.118, 0.021	-0.046, 0.052	-0.041, 0.141
$RMSE_Z$ on scan (average)	NA	NA	**0.042** (-0.001)	NA
Min, max error(Z)			-0.322, 0.500	

Flight015 – 1 cm GSD

Figure 5 illustrates the increase in detail that can be seen in 1 cm GSD deliverables as compared to 2.4 cm GSD deliverables, both in the orthomosaic and the DSM. Due to the smaller features visible in the 1 cm imagery, points can be measured more precisely and accurately compared to 2.4 cm imagery (for example in figure 5 top row, the survey nail in the center of the marker on the right and the measuring hole in the *FENO* block on the left are directly visible in the 1 cm GSD image, as opposed to the 2.4 cm GSD image). The differences in the DSM can be even more pronounced for small features (such as the 5 cm tall corrugated iron roof waves in the bottom rows of figure 5) since the DSM extraction is typically done at the level of 2–3 pixels rather than at the pixel level to save on computing requirements.

Table 3 summarizes the horizontal and vertical errors for the different processing strategies used. When processing the main block of Flight015 using a post-processed trajectory and one GCP, a global shift of 7 cm is removed compared to processing the same block without GCPs. In this case, **the $RMSE_Z$ of the DSM on the 10,000 scan points is 0.042 m, compliant with the ASPRS vertical accuracy requirements for the 5 cm $RMSE_Z$ class.** We obtained similar results by adding three additional higher flight lines in the same flight. However, in these cases, the vertical accuracy of the RTK check point measurements in the field and the ASPRS requirement of check point accuracy not to exceed one third of the RMSE class, would determine the deliverables to fall under the 10 cm $RMSE_Z$ class (see also Whitehead & Hugenholtz 2015).

Figure 6 shows a profile overlay of the Flight015 DSM obtained from processing with one GCP compared to the terrestrial scan in one of the areas used for accuracy calculation, demonstrating very good agreement both at the terrain level and on elevated or oblique surfaces, except for some noise in the DSM around the vertical wall of the building.

Even though the vertical accuracy of Flight015 relative to its GSD (2.6 pixels in the best strategy) is worse than that of Flight020 (1.4 pixels), induced by the lower base:height ratio and the less oblique viewing angles in Flight015, the absolute accuracy is still slightly better for Flight015 owing to the small GSD, especially in the strategies where steps were taken to eliminate any global shifts.

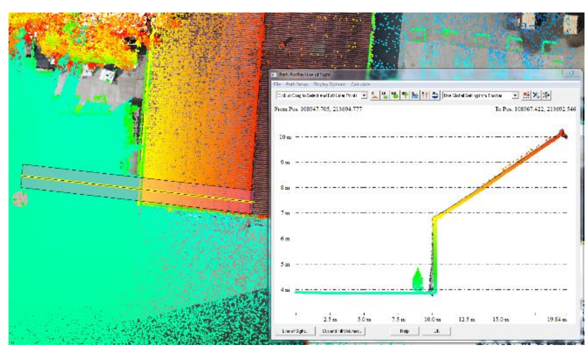


Figure 6. Overlay of the TX8 point cloud (sampled to a minimum of 2 cm) on the UX5 HP dense point cloud of Flight015. The TX8 point cloud is colored by elevation while the UX5 HP point cloud is colored according to image RGB values. The circular hole in the TX8 point cloud at the beginning of the profile line is a scan position.

Figure 7. Overlay of a UX5 HP 1 cm GSD orthomosaic (north-eastern part) on a UX5 HP 2.4 cm GSD orthomosaic, both resulting from processing using a post-processed trajectory without ground control points. This overlay shows the tight horizontal fit on a rooftop 9 m above ground level.

The horizontal accuracies achieved from processing flights 020 and 015 without any ground control points are very comparable and fall under the same ASPRS accuracy class, and are likely determined more by the onboard GNSS accuracy than the GSD. **The good horizontal agreement between these two flights is illustrated in figure 7, demonstrating the effectiveness of the UX5 HP in repeated mapping without ground control points.**

Conclusion

The Trimble UX5 HP offers significant upgrades to the UX5, acting together to increase your UAS surveying productivity.

- The 36 MP full frame camera with three different lens options enables **mapping larger areas**, or **surveying with an unprecedented level of detail**
- The availability of a multiple frequency GNSS logger allows doing so with a **highly reduced or eliminated need for laborious ground control point measurements**
- Our analysis of 25 test flights in varying conditions demonstrates the **reliability of the system**
- Our case studies show that the vertical accuracy obtained through image processing **using a precise trajectory equals or betters the vertical accuracy reached with a traditional approach using ground control points without trajectory**.

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