TRIMBLE BUSINESS CENTER PHOTOGRAMMETRY MODULE

ABSTRACT

The newly released Trimble Business Center Photogrammetry Module is compatible with the Trimble Gatewing X100 and the new Trimble UX5 Aerial Imaging Solution, and allows users to process their aerial imagery accurately using traditionally collected ground survey data in a seamlessly integrated workflow. The deliverables include a dense point cloud, raster DSM and an orthomosaic that can be further used within TBC Photogrammetry Module for surface analyses such as contour generation, profiling and volume calculation. In this paper, we describe the processing software's capabilities, which are based on INPHO technology, a market leading technology in photogrammetric software. Test case examples with independent ground control points and volume measurements are presented to demonstrate TBC Photogrammetry Module's superior performance on Trimble Gatewing X100 imagery, even on difficult terrain types. This translates in accuracies that are on par with conventional terrestrial and airborne surveying techniques. Additionally, we show that market-leading site coverage, resolution and planimetric accuracy can be obtained with Trimble UX5 imagery processed in TBC Photogrammetry Module.

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INTRODUCTION

Digital imaging is a rapidly expanding and highly valuable technology for geospatial professionals. Images can be used to visualize job site conditions, review survey and mapping observations, measure points photogrammetrically, and create 2D and 3D deliverables such as an orthomosaic and a dense point cloud or raster DSM. The aerial perspective is optimal for mapping medium to large horizontal sites such as open-pit mines, farms, and construction sites. In recent years, the use of Unmanned Aerial System (UAS) has emerged as an efficient way to map relatively small areas where sub-decimeter Ground Sampling Distance (GSD) and accuracy are required or where imagery on a very frequent basis is required, even in weather conditions that are adverse for conventional aerial surveys. With the release of Trimble Business Center 3.0 and the Photogrammetry Module, users can now seamlessly integrate projects from Trimble UAS solutions with their ground-based GNSS,total station, and 3D laser scanner measurements to obtain highly accurate 2D en 3D deliverables in an automated way. This paper demonstrates the planimetric and vertical accuracy, as well as the overall quality of the deliverables that can be created in Trimble Business Center Photogrammetry Module. First, an overview of the features and processing algorithms is given. Next, two use cases with independent ground control data for accuracy analyses are presented.

IMAGE PROCESSING THEORY AND APPLICATION

Trimble Business Center is a desktop application that processes and adjusts combined surveying data sets of GNSS, optical, scanning and now aerial photogrammetric observations. With Trimble Business Center Photogrammetry Module, users can import and visualize images from Trimble total stations and aerial surveying rovers, adjust aerial images using cross tie points and control points, measure points, and automatically create 3D deliverables.

Images in Trimble Business Center Photogrammetry Module are visualized as terrestrial and aerial photo stations. Photo station locations are displayed in the planimetric and 3D views to indicate coverage, and photo stations can be opened and viewed as 3D perspective views. In a photo station view, users are able to visualize project data and easily "jump" to other photo stations. This gives the sense of a virtual tour, where it is simple to review survey data and detect blunders.
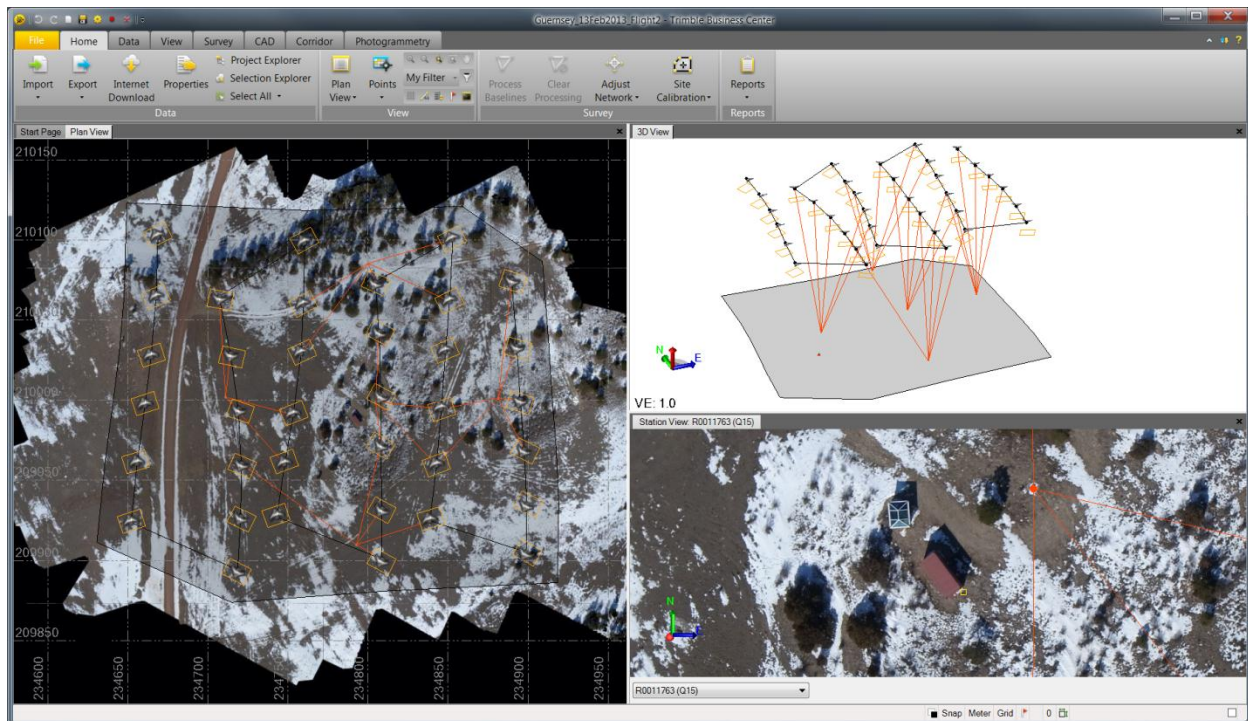
Images are displayed as aerial photo stations in Trimble Business Center Photogrammetry Module.

Aerial and terrestrial images are imported to Trimble Business Center Photogrammetry Module along with their locations, orientations, and camera calibrations. Images from Trimble VISION total stations import with very little geometric error as a result of the precise survey methods used in the field to position, plumb, and orient the integrated camera. However, geometric errors in the raw images from an Unmanned Aerial Vehicle (UAV) are significant as a result of the dynamic platform from which they are captured and the imprecision in the UAV's position and orientation sensors.

To correct for errors in the positions and orientations of the aerial images, the user must use photogrammetric methods to adjust the photo stations. This is done in Trimble Business Center Photogrammetry Module first as an adjustment with photo tie points - features that can be located in two or more adjacent images. Trimble Business Center Photogrammetry Module automatically finds tie points in all available stations based on state-of the-art computer vision algorithms, and then the software adjusts the stations simultaneously for a best fit. Automatically matched photo tie points are distributed densely over the complete project, even in challenging low-texture terrain.

Once the adjustment with tie points is complete, it is quick and easy for the user to locate and register Ground Control Points (GCPs). Ground Control Points are identifiable locations in the aerial images with known precise geodetic or Cartesian coordinates. Ground Control Points are typically comprised of easily

identifiable visual targets that are placed on the ground prior to the flight occurring. Once the targets are registered, the user runs a final adjustment in which additional processing steps such as full camera calibration, automatic quality assurance and blunder removal are performed by Trimble Business Center Photogrammetry Module. The user can verify the adjustment results quantitatively and independently based on any number of ground control points labeled as check points rather than being enabled in the adjustment with control points. After adjusting with control points, the stations display accurate perspective views, where surveyed data will align accurately in each image. Overall, image adjustment is executed completely automatically, requiring only 10 seconds per image to process (including the camera refinement) and achieving an average re-projection error of about 1 pixel.
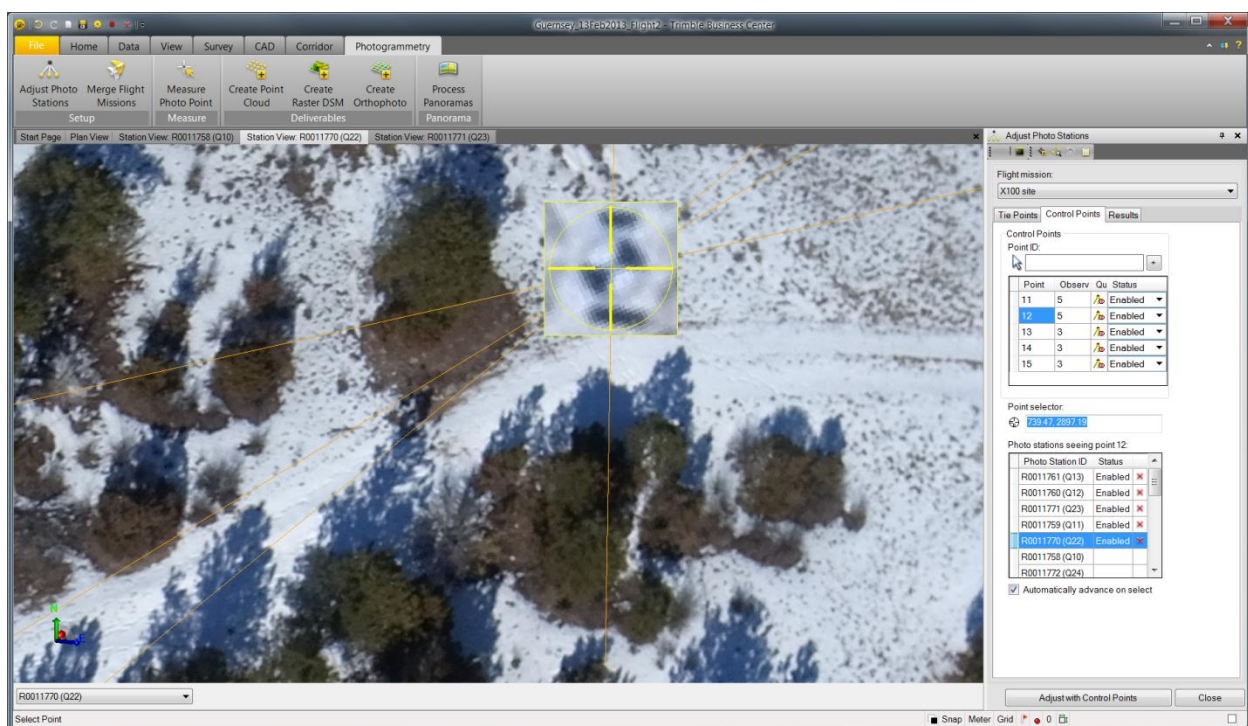

Photo stations are adjusted with a combination of tie points and control points

Once the aerial images are adjusted, the user can use the Measure Photo Point feature in Trimble Business Center Photogrammetry Module to determine the Cartesian coordinate of a location in the image by simply selecting pixels in aerial and terrestrial images. This creates photogrammetry observations, and Trimble Business Center Photogrammetry Module will automatically calculate the intersection of two or more observations to create a point.
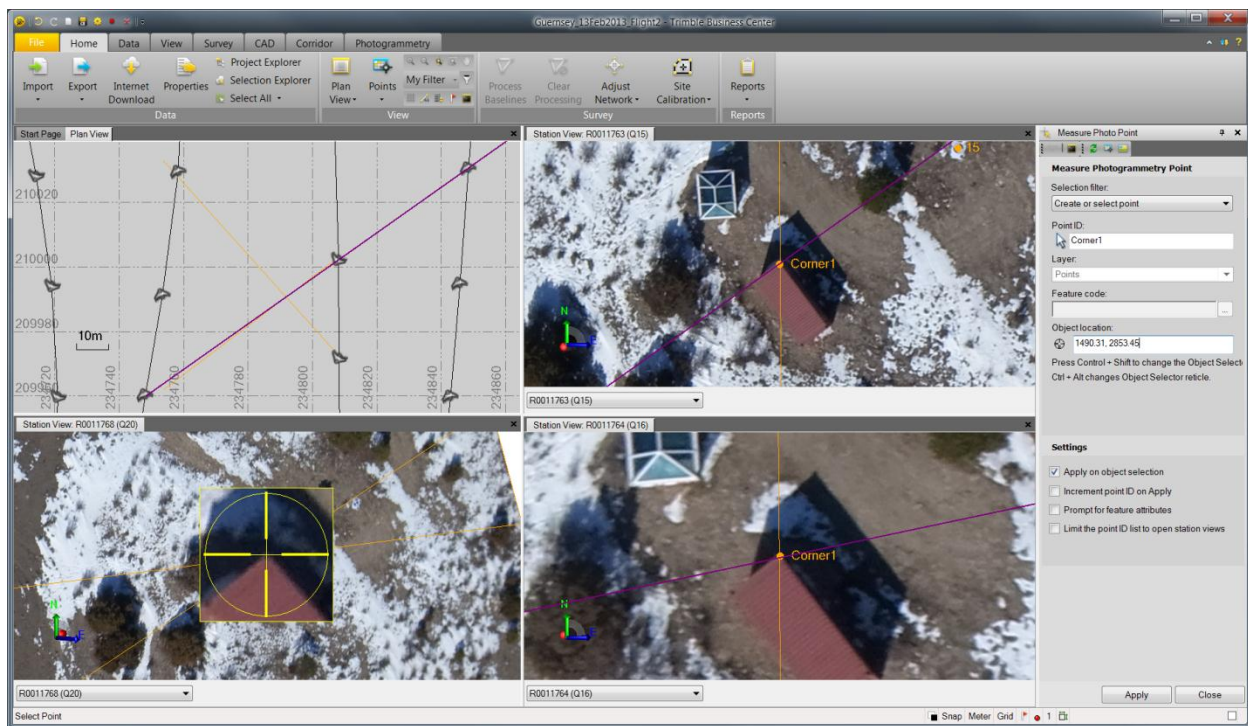
Discrete points are measured remotely with centimeter precision

Aerial images are typically used to create 3D deliverables including orthophotos, digital surface models, and point clouds. In a final step, the user specifies parameters such as desired output products, resolutions and densities, and the software automatically creates 3D point clouds from adjusted photo stations. Trimble Business Center Photogrammetry Modules' point cloud generation algorithms are based on more than 30 years of technology evolution by harnessing INPHO dense matching and Digital Terrain Model (DTM) generation algorithms. The fully automatic process adapts parameters to guarantee precision, providing extremely detailed and accurate results at a speed of about 3 seconds per image with about 1-2 pixels vertical accuracy.

A raster DSM created from the generated point cloud is refined using sophisticated interpolation routines, noise filtering, edge modeling and outlier detection to achieve rich detail within surface models.

Rigid "True-Ortho" rectification combined with outstanding geometric feature-based seamline-finding and radiometric balancing result in perfect looking seamless ortho-mosaics. Seams are adaptively blended according to image texture analysis. Radiometric single image corrections as well image group corrections are applied for perfect homogeneous colors and intensity, ready for GIS use. The automatic process only takes about 4 seconds per image.

The dense point cloud and orthomosaic produced by Trimble Business Center Photogrammetry Module can be further used for surface analyses and editing within the same software module, without the need to convert between different export/import formats. Besides the possibility to drape the orthomosaic on the 3D view, these analyses tools include point cloud and breakline editing, profiling, generating contours and calculating volumes in a typical survey workflow. These unique abilities set Trimble Business Center Photogrammetry Module apart from existing 3rd party UAV image processing software packages.

USE CASE EXAMPLES AND RESULTS

A benchmark of 22 projects was used to assess the robustness of the adjustment algorithms and completeness of the orthophotos in comparison with state-of-the-art 3rd party processing software packages. The benchmark included small and large projects, with and without ground control points, and covered project types such as open pit mines and dump sites, dense forests and plantations, areas with enclosed lakes and surrounding water, urban and suburban areas, desert and crop land and construction areas. Two of the 22 benchmark projects failed to adjust in other software, while Trimble Business Center Photogrammetry Module was able to adjust the entire benchmark successfully. These projects that were only successfully adjusted with Trimble Business Center Photogrammetry Module featured notoriously repetitive textures such as a palm plantation and very smooth, reflective surfaces such as a cylindrically constructed roof. The superior ability to adjust photo stations containing highly reflective artificial surfaces also results in reduced distortions around these features in other urban projects as well.

Orthophoto crop of a palm plantation adjusted by Trimble Business Center Photogrammetry Module but not by other processing software


Orthophoto of a built up area adjusted by Trimble Business Center Photogrammetry Module but not by other processing software

The accuracy of Trimble Business Center Photogrammetry Module is demonstrated based on several projects for which independent test data are available. Here, we show 3 projects acquired by the Trimble Gatewing X100 and Trimble UX5 UAS: an agricultural test field featuring a grid of ground control points

and known volumes measured with a Trimble S3 Total Station, and a railway classification yard for which a Trimble TX5 Laser Scanner dataset is available.

Agriculture Field Example

The 0.25 km² agriculture field is characterized by plowed crop fields, grass meadows, ditches, tree lines and houses. The Trimble Gatewing X100 was flown 100 m above ground level and used a 70% image overlap, as well as 150 m flying height with both 70% and 80% overlap, to check processing accuracies across a range of flight parameters. An additional flight at 75m and 80% forward and sideward overlap with the Trimble UX5 allowed demonstrating the increase in horizontal accuracy resulting from a smaller GSD. For the Trimble Gatewing X100 flights, the area was covered by a grid of control points, each 100 meters apart horizontally, 33 in total at the terrain level, measured with a Trimble R8 GNSS Receiver using Real-Time Kinematic (RTK) measurements. Of these control points, 5 or 9 were enabled in the control point adjustment and the remaining 28 or 24 were used as check points. The enabled control points were spread out towards the corners of the field and included one in the center of the project area in the case of 5 control points, and contained an extra point in the middle of each side in the case of 9 control points. Check points north and south of the northernmost and southernmost control points allowed investigating extrapolation outside of the project area enclosed by control points. The project area covered by the Trimble UX5 contained 10 ground control points irregularly distributed at the terrain level, of which 6 were enabled and 4 were used as check points in the adjustment. In order to test effects of errors on elevated structures, volumes were calculated of two artificial constructions at the site: a temporary container building and a permanent farm building. Volumes calculated based on a surface created from the point cloud obtained from Trimble Gatewing X100 and Trimble UX5 imagery processed in Trimble Business Center Photogrammetry Module were compared to measurements by total station (Trimble S3).
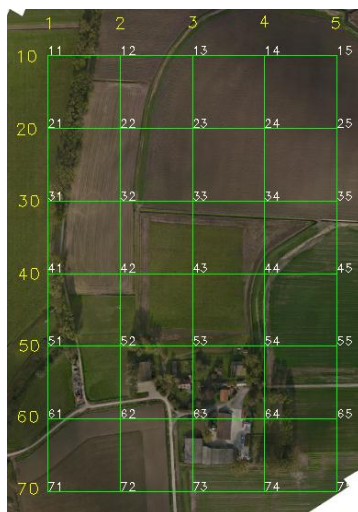

GCP layout at the agricultural test field. Points 21, 25, 43, 61 and 65 were used as control points in the adjustment with 5 GCPs, and points 13, 41, 45 and 63 were additionally used in the adjustment with 9 GPCs. Points 12 and 31 were not in use, while the remaining were used as check points.
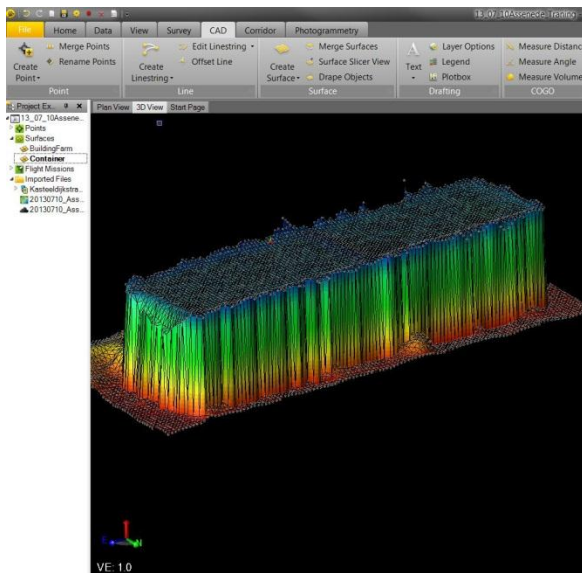
Buildings used to compare volumes measured by total station and based on the X100 DSM calculated by TRIMBLE BUSINESS CENTER Photogrammetry module.
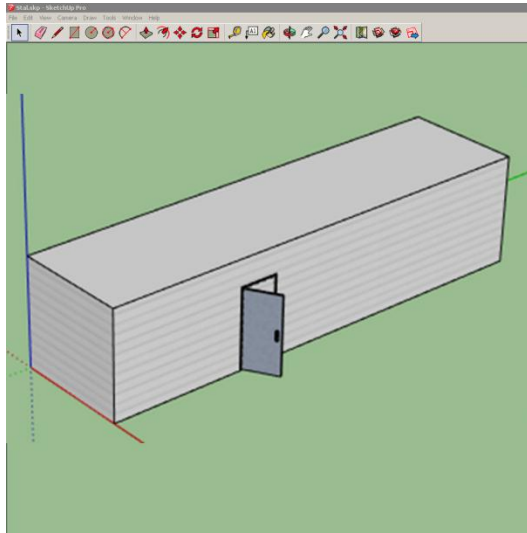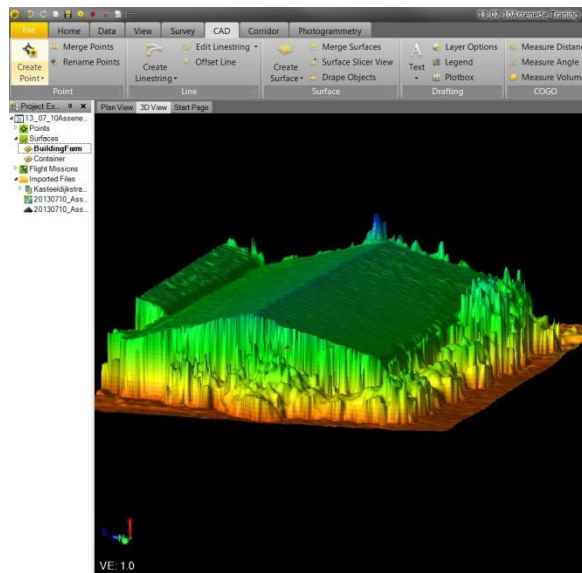

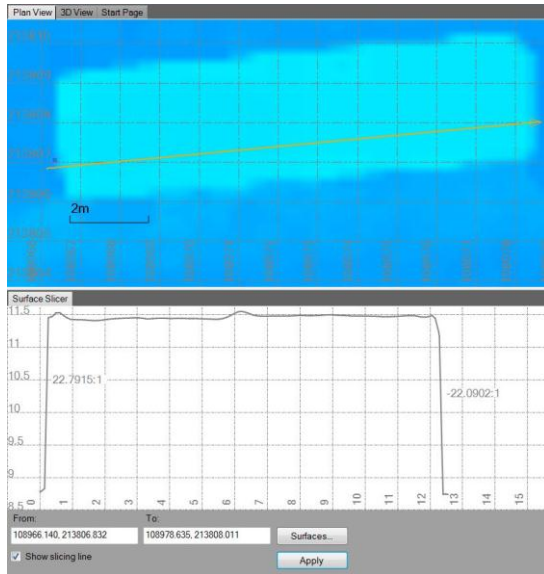*Temporary container building drawn in Trimble Sketchup Pro 2013*
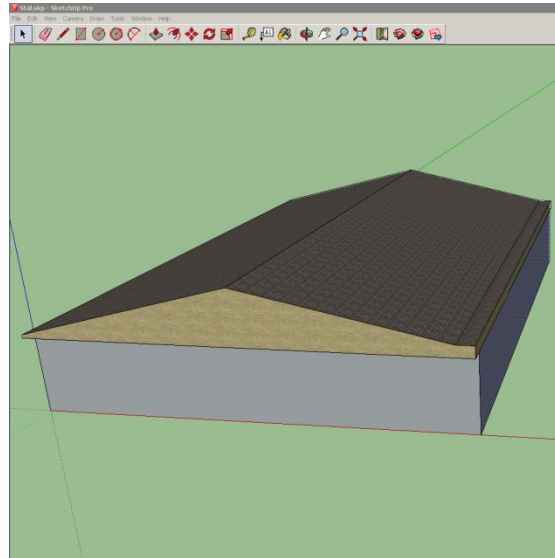
*Permanent farm building drawn in Trimble Sketchup Pro 2013*

Shaded point cloud surface showing the temporary container building in Trimble Business Center Photogrammetry Module

Shaded point cloud surface showing the permanent farm building in Trimble Business Center Photogrammetry Module

Profile of the temporary container building derived from the point cloud surface in TBC
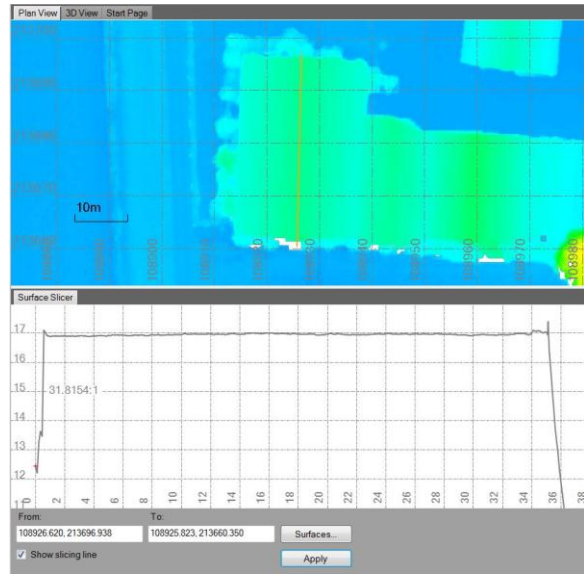
Profile of the permanent farm buildingalong the center ridge, derived from the point cloud surface in TBC

The following table summarizes the residual errors (indicated by RMS) on the 28 or 24 independent check points for the different Trimble Gatewing X100 flights, and the 4 independent check points for the Trimble UX5 flights, obtained by Trimble Business Center Photogrammetry Module. The residual errors in the horizontal plane (indicated as xy) as well as in elevation (indicated as z) are all in the 0.5 to 1.1 pixel range for the flights at 100m and 150m height. This is the smallest achievable error, since it coincides with the expected error when measuring ground control points on discretely sampled imagery (pixel data). The results show that survey-grade vertical accuracy can be achieved using 5 GCPs optimally distributed across the project area. Using a grid of 9 GCPs significantly increases the planimetric accuracy in this project, but hardly reduces vertical errors. The biggest gain in vertical accuracy can however be obtained by increasing the (forward and sideward) overlap to 80%. It is worth noting that unpublished tests suggest that further increasing the overlap to 90% makes only a marginal difference, since usually this high forward overlap cannot be reached at these relatively low flying heights, and only sideward overlap can be effectively increased, limiting its influence on accuracy. It is also clear that decreasing the GSD by flying below 100m with the Trimble UX5 has a clear effect in increasing the planimetric accuracy, with again an error in the range of 0.5 to 1 pixels, but the effect is not dramatic in vertical accuracy. While the vertical accuracy of the deliverables from the 75m flight falls outside the expected error range at 1.6 pixels, it is still the highest vertical accuracy achieved for all the projects in this case study.

Flight & Image Overlap	Ground Sample Distance (cm)	Number of GCPs used in adjustment	Number of GCPs used as check	RMS XY (m)	RMS Z (m)
150m 70%	5	5	28	0.038	0.048
150m 70%	5	9	24	0.029	0.046
150m 80%	5	5	28	0.03	0.033
100m 70%	3.3	5	28	0.034	0.036
75m 80%	2.4	6	4	0.019	0.030

As a reference, the following figures illustrate the difference in GSD between a 150m flight and 75m flight with the Trimble UX5. It is clear that the finer level of detail in the 75m imagery increases the certainty with which one can indicate the exact point of measurement on the GCP marker, increasing the accuracy in XY. However, the more significant parallax and reduced achievable forward overlap limit the gain in vertical accuracy that could be expected, from 1 to 3 pixel sizes in Z

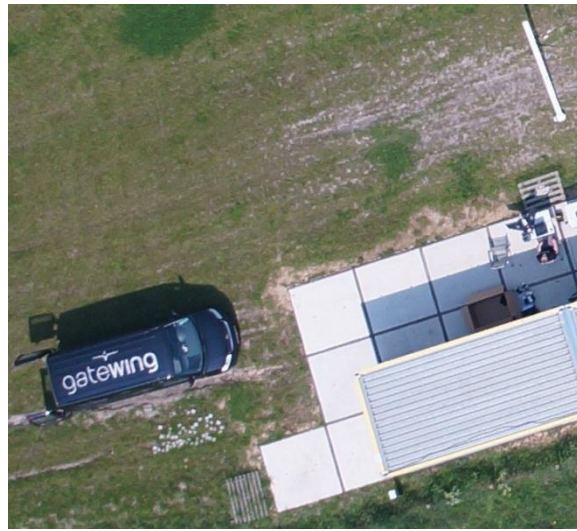*Image crop from the Trimble UX5 at 150m flying height, 4.8cm GSD*

Image crop from the Trimble UX5 at 75m flying height, 2.4cm GSD

The following table compares volume measurements of the buildings using a total station versus a DSM from the Trimble Gatewing X100 data processed with Trimble Business Center Photogrammetry Module. The Trimble Gatewing X100 dataset used for volume measurements was flown at 150m flying height and 80% overlap. While arguably UAS-based volume measurements would primarily be suited for the calculation of irregular volumes such as dump sites and open pits, artificial structures with well-defined

contours and corners were chosen in this study to provide a comparison between the two technologies using objects with very clear limits and therefore exactly known volume.

Building Type	Calculated Volume (m³) from Trimble S3	Calculated Volume (m³) from Trimble Gatewing X100	% difference
Temporary Container	105.38	106.22	0.80%
Permanent Building	5256.01	5212.21	0.83%

Additionally, filtering algorithms in Trimble Business Center Photogrammetry Module are much less severely applied than in existing 3rd party software, eliminating noise in the DSM while leaving small vertical features still pronounced. The same effect can be noted on isolated tall vertical structures such as tree tops, which tend to be eliminated from the DSM or modeled lower than their true height in other software.
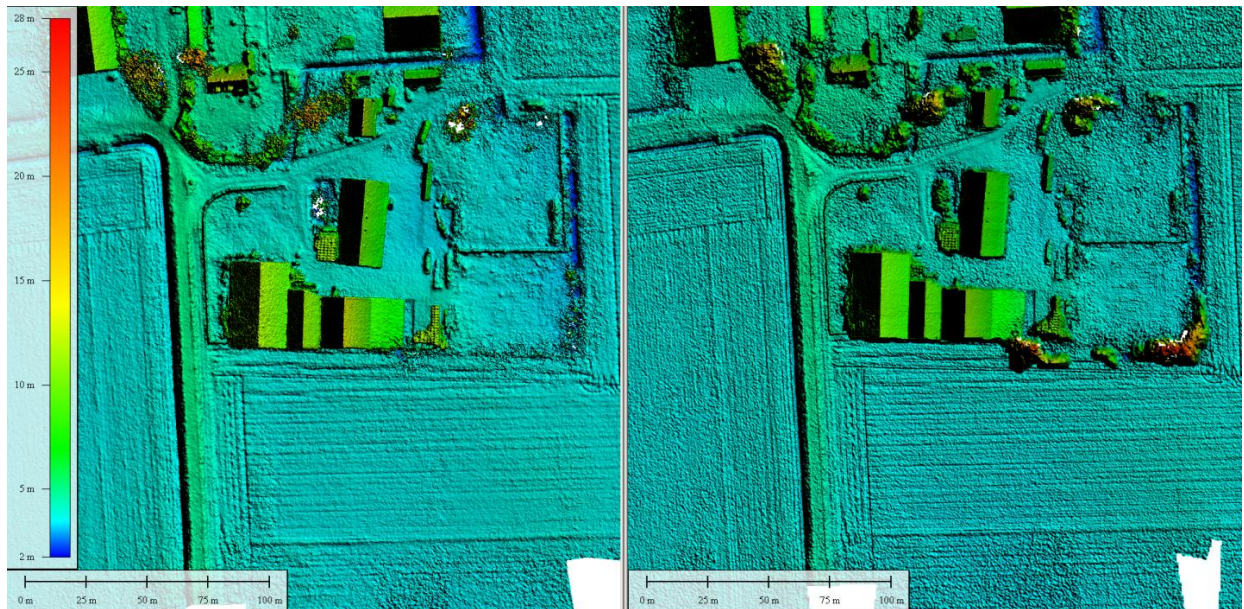
Excessive filtering on plow furrows and trees but more noise on roofs in a DSM resulting from existing 3rd party software. Example flown at 100m, 70% overlap.

Pronounced plow furrows and tree tops and less noise on roofs in a DSM resulting from TBC Photogrammetry module. Example flown at 100m, 70% overlap.

Railway Yard Example

This railway yard features tracks, railcars, buildings as well as a variety of terrains including tarmac, forest, short and tall grass meadows. The area was flown with the Trimble Gatewing X100 at a height of 100 m above the ground, resulting in 475 images, and including 26 available ground control points. On the same date, the project area was also measured using the Trimble TX5 laser scanner. The Trimble Gatewing X100 data was processed using 3rd party software and Trimble Business Center Photogrammetry Module. Although visually the buildings and artificial objects in the project area seemed very sharp and well modeled in existing 3rd party software and although ground elevations tied in very well with the point cloud produced by Trimble RealWorks from the TX5, the comparison showed that elevations of the artificial objects were consistently underestimated by 3rd party software by about 0.5-1.0 m. This difference is believed to be due to excessive filtering applied by default in 3rd party software. In contrast, the Trimble Business Center Photogrammetry Module point cloud was in agreement with Trimble TX5 data within 5-10cm both at the terrain level and on elevated objects, as illustrated below. To ensure the validity of the point clouds obtained by the Trimble TX5 and the Trimble Gatewing X100 data processed in Trimble Business Center Photogrammetry Module, isolated photo-identifiable points were re-measured with total station. This confirmed that point elevations obtained with3rd party software were too low for elevated structures, while estimated elevations from Trimble Business Center Photogrammetry Module and the Trimble TX5 were reflecting the correct situation
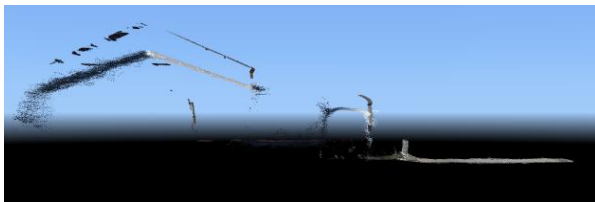
Differences in point cloud elevations based on X100 data and Trimble TX5 survey. Comparisons between existing 3rd party software point clouds and TX5 data are always shown on the left, while comparisons between Trimble Business Center Photogrammetry Module point clouds and TX5 data are always shown on the right.

Railway cars shown by the true color point cloud obtained from the Trimble TX5 overlaid with the point cloud obtained from 3rd party software. It is apparent that the roof of the cars are modeled too low in the 3rd party software point cloud.

Railway car shown by the true color point cloud obtained from the Trimble TX5 overlaid with the white point cloud obtained from Trimble Business Center Photogrammetry module. In the profile view, it is clear that the roof of the car as modeled by Trimble Business Center Photogrammetry module ties in well with the side of the car. Note that due to occlusion, only the right half of the car was modeled with the Trimble TX5.
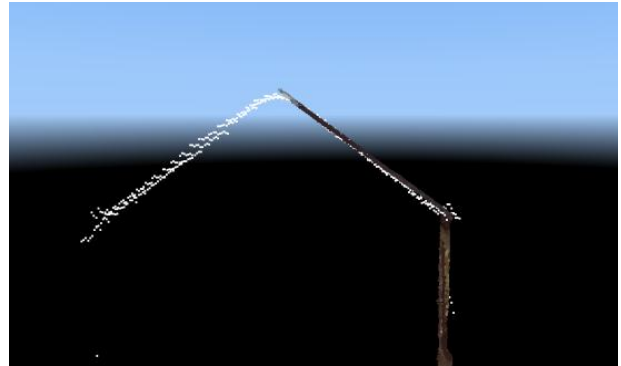

House shown by the Trimble TX5 true color point cloud overlaid with the point cloud of 3rd party software. The latter shows lower elevations for the top of the building.
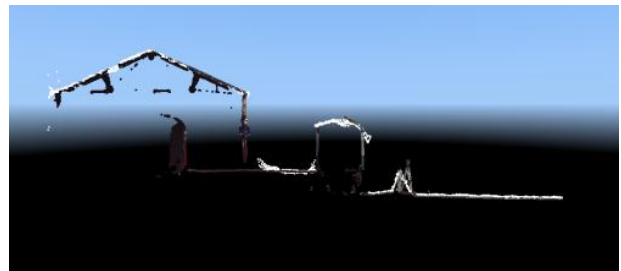
House shown by the Trimble TX5 true color point cloud overlaid with the white point cloud obtained from Trimble Business Center Photogrammetry Module, in profile view. Note that due to occlusion, only the right half of the building was modeled with the Trimble TX5. The white points match the elevations of the true color points well at all places

House shown by the Trimble TX5 true color point cloud overlaid with the point cloud of 3rd party software. The

House shown by the Trimble TX5 true color point cloud overlaid with the white point cloud obtained from Trimble

latter shows lower elevations for the top of the building, while the terrain elevations corresponds between both datasets.

Business Center Photogrammetry Module, in profile view. The elevations between both point clouds correspond well at all places, both elevated and at the terrain level

In this project, cut-and-fill volumes were calculated from the point cloud created from the X100 data and compared to point cloud created from the TX5 data with a 3 cm sampling rate (distance between points) for each of the terrain types present in the project area, to ensure consisting performance across different terrain types. The below table shows the measurements based on point cloud surfaces obtained from Trimble Business Center Photogrammetry Module. Errors are calculated as volume differences with TX5-based measurements per surface area unit. Errors for the same measurements are also given for existing 3rd party software, showing a consistently better result for Trimble Business Center Photogrammetry Module, even on photogrammetrically challenging terrain such as long grass.

	Trimble UX5	Trimble Business Center Photogrammetry Module				3rd party
Terrain	**Area (m²)**	**Cut (m³)**	**Fill (m³)**	**Cut-Fill (m³)**	**Error (m)**	**Error (m)**
Built-up	2625	116.1	13.2	102.9	0.039	0.066
Tarmac	1937	149.7	2.2	147.5	0.076	0.076
Short grass	13336	686.9	223.4	463.5	0.035	0.052
Long grass	2428	315.1	6.5	308.6	0.127	0.173

CONCLUSION

The independent test results from the use cases presented in this paper clearly show that the accuracy of the deliverables from Trimble Gatewing X100 and Trimble UX5 Aerial Imaging Solutions processed with Trimble Business Center Photogrammetry Module are of survey grade and exceed the accuracy offered by existing 3rd party software. In some cases, the superior performance of Trimble Business Center Photogrammetry Module is also illustrated by the ability to adjust projects and extract dense point clouds on difficult terrain types where other software fails to complete the processing. Combined with the unique ability for integration of conventionally surveyed control data and the seamless workflow to perform point cloud edits and surface analyses based on the deliverables, this makes Trimble Business Center Photogrammetry Module the leading software for surveyors wanting to process their imagery from Trimble UAS.