Comparing workflow and point cloud outputs of the Trimble SX10 TLS and senseFly eBee Plus drone

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Key words: terrestrial laser scanner, Trimble SX10, unmanned aerial vehicle, senseFly eBee Plus, gravel pit, volume calculation

SUMMARY

In order to compare two of today’s most cutting–edge surveying instruments, we surveyed a four–hectare gravel pit using Trimble's SX10 scanning total station and senseFly's eBee Plus RTK/PPK photogrammetry UAV.

A gravel pit is a typical survey site for which a digital point cloud is the most important output, being used for volume calculations, slope measurement, toe and crest detection, the generation of contour lines and more. The chosen gravel pit was appealing due to its deep floor (approx. 40 m) and the fact that it features horizontal, vertical and even overhanging sections.

Five individual point clouds were generated in total: four UAV point clouds (derived from two UAV flights, flown at different heights above ground level), and one merged laser scanner point cloud from five station set–ups.

On the question of whether a RTK/PPK–only flight could achieve the same absolute accuracy as a flight tied to GCPs, this was proven to be possible. For the point clouds where GCPs were used, the average offset of the flights was a few centimeters better than the flight flown with onboard RTK but without GCPs. Standard deviation was the same across all four UAV processings. This means that all types of processing give a constant accuracy all over the project. To be sure about the reliability of the output, especially vertically, we still highly recommend using at least one GCP.

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1. INTRODUCTION

In order to compare two of today's most cutting–edge surveying instruments, we surveyed a four–hectare gravel pit using Trimble's SX10 scanning total station and senseFly's eBee Plus RTK/PPK photogrammetry UAV.

We compared these instruments, both of which the company owns, in the following ways:

- In–office preparation time
- In–field data collection time
- Data processing time
- The quality of the point clouds they produced

In addition, the senseFly system was flown at two different flight heights to produce four different UAV point clouds, our secondary aim being to compare these clouds to define the optimum UAV workflow for such a survey.

Lastly, as part of this comparison, we also considered:

- What, if any, visual outputs were generated by each instrument
- What onsite risks using each instrument could pose to an operator
- The relative cost of these instruments

Of course, a direct comparison of these collection methodologies on a single standalone project cannot definitively answer the question of whether one of these technologies is best for every surveyor. As such, a choice depends upon: the needs of a particular surveying professional; the project in question; and is subject to the evolving nature of the technologies themselves. However, such a comparison can hopefully serve to highlight the relative strengths and weaknesses of these products and their point cloud outputs. It is with this general goal in mind that this project was conducted.

2. METHODOLOGY

2.1 Survey site and technologies

The location of the project was a four–hectare gravel pit in the Olten region of North–Western Switzerland (Figure 1). A gravel pit was chosen because this is a typical survey site for which a digital point cloud is the most important output, being used for volume calculations, slope measurement, toe and crest detection, the generation of contour lines and more. This specific gravel pit was appealing due to its deep floor (approx. 40 m) and the fact that it features horizontal, vertical and even overhanging sections.

Figure 1: The project site, a four–hectare gravel pit in Lostorf near Olten, Switzerland

The laser scanning technology used was Trimble’s SX10 robotic scanning total station (Figure 2), while the UAV (or drone/UAS) used was senseFly’s eBee Plus UAV. This UAV had its built–in RTK/PPK function enabled (Figure 2) and was equipped with a senseFly S.O.D.A RGB camera.

Figure 2: senseFly’s eBee Plus UAV (left) with Trimble’s SX10 hand controller (center) and SX10 scanning total station with carry case (right).

2.2 Point cloud overview

Five individual point clouds were generated in total: four UAV point clouds (derived from two UAV flights, flown at different heights above ground level), and one merged laser scanner point cloud from five station set–ups.

These point clouds were compared in terms of:

- In–field data collection workflow (time taken & relative complexity)
- In–office data processing time
- Positional accuracy, density and quality

2.3 Study area and control point set–up

The project's measurements were taken by four Lerch Weber AG employees, supported onsite by one senseFly engineer.

To georeference the laser scanner and to assess the accuracy of the UAV's flights, nine ground control points (GCPs), acting effectively as checkpoints, were set across the site. These GCPs were measured using a Trimble R10 GNSS receiver and were evenly distributed over the entire study area (Figure 3). The GCPs were marked on the terrain with 50 cm–wide square yellow plastic boards. These were chosen due to their high visibility, ensuring that they could be properly identified later and marked in the UAV's digital imagery.

Figure 3: One of the project's nine ground control points (left) and a preliminary sketch showing possible scanning stations (right).

Setting the nine GCPs—used for both surveys—took approximately 1.5 hours. The GCP points and point cloud derived from the laser scanner were measured in the Swiss national coordinate system CH1903+/LV95 and the national levelling system LN02. The eBee Plus flight was carried out in the WGS84 coordinate system and afterwards transformed to the Swiss national coordinate system using Agisoft's PhotoScan photogrammetry software (used also to process the drone's imagery).

2.4 UAV flight preparation

The planning of the UAV's flights took place in the office beforehand using the eBee Plus supplied eMotion 3 software: a senseFly Satellite background map was loaded within eMotion, then a polygon was drawn around the site, leaving a few meters of additional coverage outside the pit's survey perimeter.

Once the trajectories of the flight had been decided, two key flight parameters were set: the required ground sampling distance (GSD), in cm per pixel, and the required image overlap (lateral and longitudinal). The UAV's flight height, calculated automatically, is then a direct result of the GSD specified in eMotion. We decided to fly the UAV twice, at two different heights, in order to assess the influence of ground resolution on the quality of the UAV’s point cloud outputs.

In terms of image overlap, the settings specified (Table 1) were chosen to produce well reconstructed and matched images in the photogrammetric process. To achieve the required overlap, the flight with the highest GSD – the lower of the two flights, flight no. 1 – was carried out using standard and perpendicular flight lines, while the shorter, lower resolution flight no. 2 employed a standard single set of flight lines.

	Flight no. 1	Flight no. 2
Flight height above terrain [m]	100	150
Ground resolution [cm]	2.5	3.6
Overlap (lateral/longitudinal)	60/50 and grid pattern	85/70
Number of images	180	173
Flight time [min]	14	13

Table 1: Comparison of the project’s two UAV flights.

To enhance the precision of its image geotags, the eBee Plus is capable of receiving RTK corrections. In our case, a VRS RTK correction stream from swisstopo was used. This required a swisstopo service subscription and a network connection in the field (enabled through the laptop PC running eMotion having an active internet connection).

To achieve RTK precision of all the UAV’s images, the radio link between the UAV and the ground station had to be maintained at all times. Had this radio link, or the laptop’s internet connection, been lost, there would, however, still have been the possibility of applying corrections to the flight via the drone’s PPK capability. In the end, this was not required.

After arriving onsite, a location for both take–offs and landings was chosen; a grass field next to the gravel pit (Figure 4).

Figure 4: eBee Plus at take–off.

The preparation of each UAV flight took approximately 15 minutes in the office and an additional five to ten minutes in the field: to connect the wings, insert the UAV's battery and camera, carry out pre–flight checks and wirelessly upload the flight plan to the drone via its USB radio modem (connected to the laptop PC running eMotion).

2.5 Laser scanner preparation

In the office, the preparation of the Trimble SX10 survey primarily involved site analysis, in order to estimate the optimal distribution of the project's GCPs and laser scanner stations. Each station needed to provide line–of–sight access to at least three GCPs, with these points as well dispersed as possible. Since our staff already had knowledge of the site's terrain, this process took not much time, maybe around fifteen minutes. In order to cover the entire site sufficiently, three scanning stations were chosen outside the gravel pit and two at the bottom of the pit.

After marking and measuring the project's nine GCPs, the SX10 was set–up at the first of its five stations (Figure 5). To orientate and set the exact position of the laser scanner, instrument levelling was required, after which a 'free station' methodology was used (a method of determining the 3D-location of one unknown point in relation to known points, in this case three pre–set GCPs).

The set–up of the SX10 at each of its five stations took 15 minutes. This involved the scanner operator deciding upon which GCPs to target, and a second operator standing at each of these known points in turn, holding a target. The laser scanning was carried out using the SX10's default point density setting of Medium. The scanning time required at each of the five stations depended upon the width of the area being scanned (selected directly on the SX10's screen). Figure 5: Orientating the Trimble SX10 scanning total station at the bottom of the gravel pit.

On average, setting up the Trimble SX10 and performing laser scanning with this instrument took 45 minutes at each station. This added up to a total 3 h, 45 min spent scanning, plus a few minutes more for the operators to move between scanning stations.

3. PROCESSING

Back in the office, the processing involved the following:

- Retrieving and processing the images (.jpg) from the UAV flights to create four digital point clouds (Table 2).
- Copying the laser scanner's point cloud file (.las) onto a PC (the five stations' points having been saved into one point cloud directly on the SX10).

The processing of the UAV's imagery was carried out using Agisoft PhotoScan photogrammetry software. In addition to this software generating the point cloud of each flight, it also generates an orthomosaic, a high–resolution orthorectified aerial image of the site.

Since the points gathered at the different scanning stations were already merged into one point cloud, the only possible work from a laser scanning perspective might have been to colorize the points with RGB images taken with the Trimble SX10. However, since this project's comparison was being made without colour being considered, we did not consider this procedure necessary. Therefore, the post–scanning work required, connecting the TLS to the PC and copying the .las file, took just five minutes.

3.1 UAV point clouds

With two UAV flights carried out at different heights, and GCPs set across the survey site, this project presented a unique opportunity to produce and compare several different UAV point clouds. This would allow the following three questions to be addressed:

- **Can an RTK flight alone achieve GCP levels of accuracy?** By comparing the point cloud of an RTK–enabled flight with the point cloud of a flight that had, instead, been tied to the project's GCPs, it would be possible to analyze whether GCP levels of geospatial accuracy are truly achievable when flying in RTK–mode only (i.e. without using GCPs).
- **What is the impact of flight height/GSD on point cloud quality?** Comparing the point clouds of two UAV flights carried out at different heights, i.e. with different GSDs, would enable the impact of resolution on point cloud quality to be assessed.
- **What effect does the number of photos have on point cloud density?** By merging the point clouds of the project's 100 m and 150 m flights, it would be possible to analyze whether or not the number of photos used in processing has a direct impact on point cloud density.

	Point cloud 1	Point cloud 2	Point cloud 3	Point cloud 4
Flight no.	1 [100 m flight height]	2 [150 m flight height]	1 & 2 [100 & 150 m flight heights]	1 [100 m flight height]
Ground resolution of images [cm/pixel]	2.5	3.6	2.5 & 3.6	2.5
Number of images	180	173	353	180
Number of GCPs used	9	9	0	0
Processing time [m]*	129	166	302	56

* Processing PC specifications: Xeon 3.00 GHz / 4 core processor, Windows 7 Pro / 64 Bit, 64 GB of RAM.

Table 2: Details of the four UAV point clouds generated following the project’s two eBee Plus flights.

3.2 Point cloud analysis

With reference to the accuracy of terrestrial scanning and UAV approaches, this topic is best divided into relative and absolute accuracy. Absolute accuracy can be achieved with a UAV via the use of ground control points (GCPs) or via RTK/PPK correction of the drone’s flight. Meanwhile, the relative accuracy of the results generated from the drone’s imagery depend on the resolution of its images, which is linked directly to the aircraft’s flight height—the lower the height, the higher the point cloud densification.

The absolute accuracy of a terrestrial laser scanner (TLS) depends on the method used to position the instrument; in the case of this project this was from the free station, meaning directly from the accuracy of the (three) GCPs measured to determine the position of each TLS station. The relative accuracy of the points measured with the TLS is directly correlated to the angular accuracy and the accuracy of the Electronic Distance Measurement (EDM).

Since the relative and absolute accuracy of the drone are a known error of a few centimeters, and the TLS can achieve accuracy of a few millimeters, we can assume that the a priori accuracy of the point cloud derived from a TLS is higher. For this reason, and because TLS collection achieves a higher density of points than UAV collection (at the TLS’s Medium density setting), it was decided to treat the SX10–derived point cloud as the reference, against which to compare the different UAV point clouds.

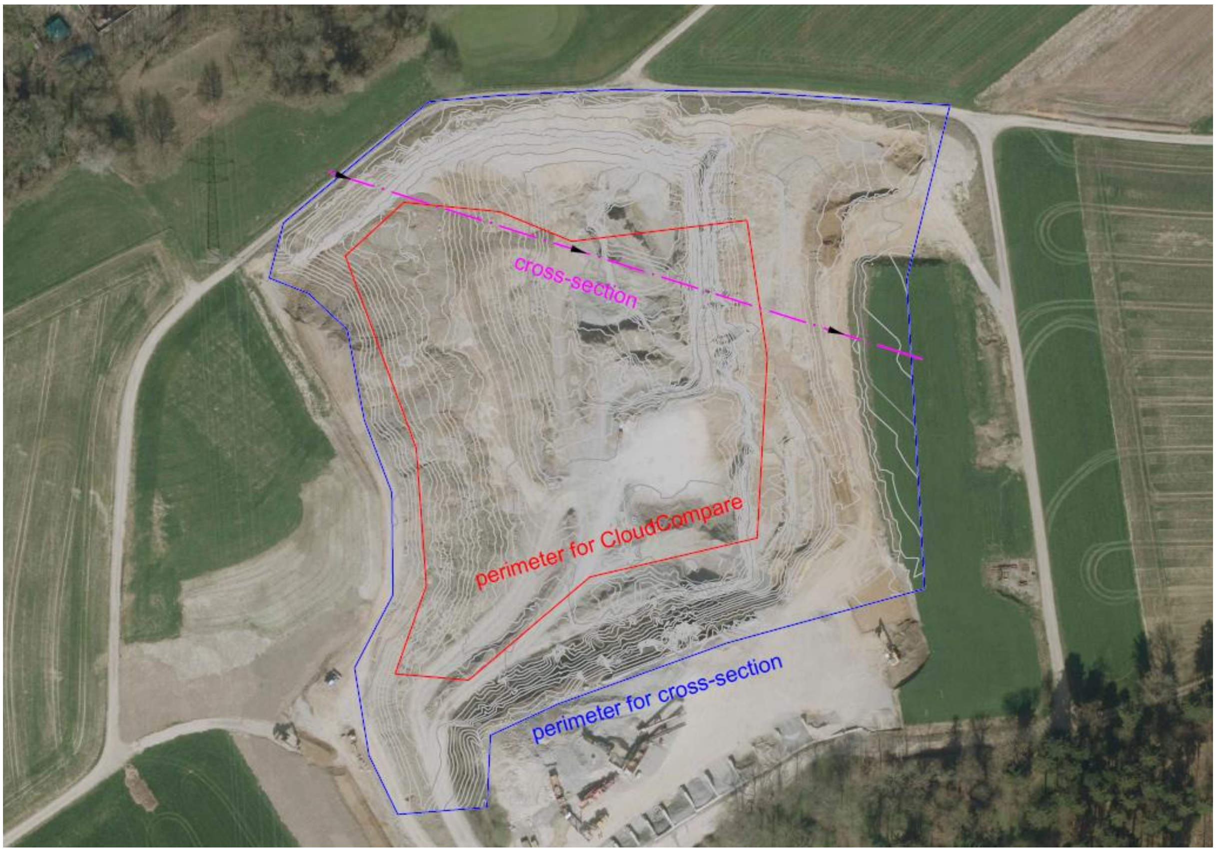


Figure 6: The map of the area used for comparison

The georeferenced SX10 point cloud and the four UAV point clouds were analyzed in CloudCompare and Autodesk AutoCAD Civil 3D 2015 (Figure 6).

In CloudCompare a function called M3C2 was used for analysis. This plugin is an advanced process to compute signed (and robust) deltas directly between two point clouds. The comparison of the 3D differences was then presented with mean and standard deviation (Table 3).

Meanwhile, a volume comparison was made in AutoCAD using the same base surface for all the point clouds (Table 3). Cut and fill volumes were then compared with regards to this surface.

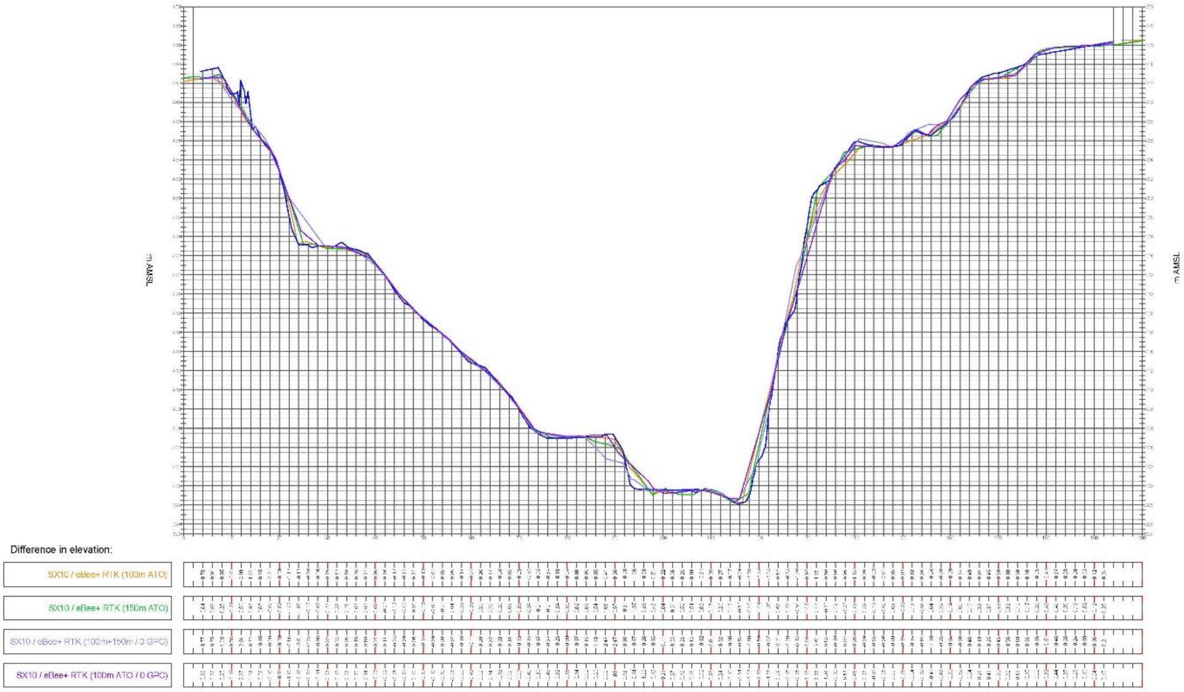


Figure 7: A third and final comparison was carried out in AutoCAD Civil 3D, using a cross–section of the deepest part of the gravel pit.

4. RESULTS

4.1 Numerical results

Numerical results from CloudCompare and AutoCAD are presented in Table 3. Each of the values compare a specific UAV–derived point cloud to the laser scanner's point cloud.

	Point cloud 1	Point cloud 2	Point cloud 3	Point cloud 4
Flight no.	1 [100 m flight height]	2 [150 m flight height]	1 & 2 [100 & 150 m flight height]	1 [100 m flight height]
CloudCompare – mean [cm]	5.5	6.4	9.4	9.5
CloudCompare – std.dev [cm]	5.2	5.9	5.9	5.8

AutoCAD – Volume difference [m^3]	–4198	–2041	619	–1078
Volume difference / Surface [cm]	–0.12	–0.06	0.02	–0.03

Table 3: Table of results comparing the point cloud derived from Trimble SX10 collection (our reference point cloud) to four different point clouds gathered with the eBee Plus UAV.

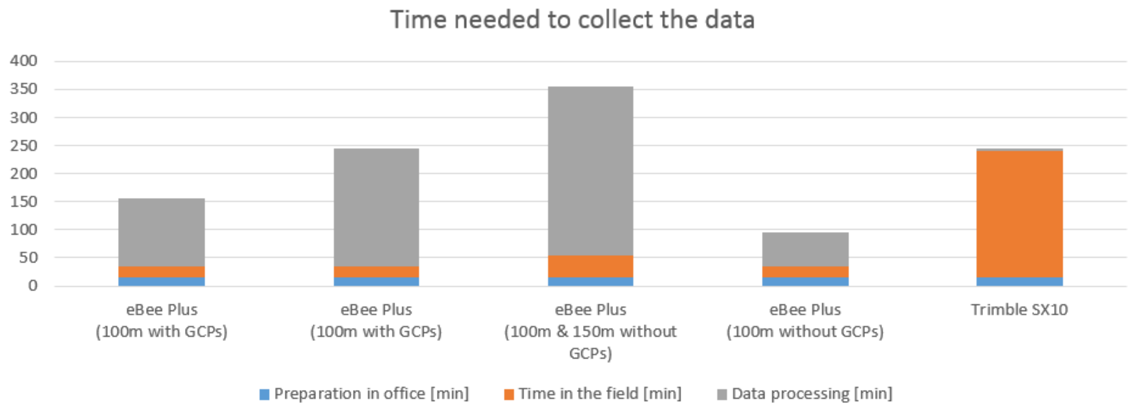
Another form of numerical comparison is to compare the number of points in each point cloud (Table 4).

	Number of points	Points per m^2
Laser scanner	24,416,594	741
UAV flight at 100 m	1,246,951	37
UAV flight at 150 m	645,695	19

Table 4: Number of points in different point clouds

The point cloud derived from merging the 100 m– and 150 m–height UAV flights contained a similar number of points to the 100 m flight's point cloud. This is due to the images of the two flights being merged and processed using the 100 m flight's exact same image processing settings.

4.2 Time needed to collect the data



Graph 1: Total time required for data collection.

4.3 Screenshots of the point clouds

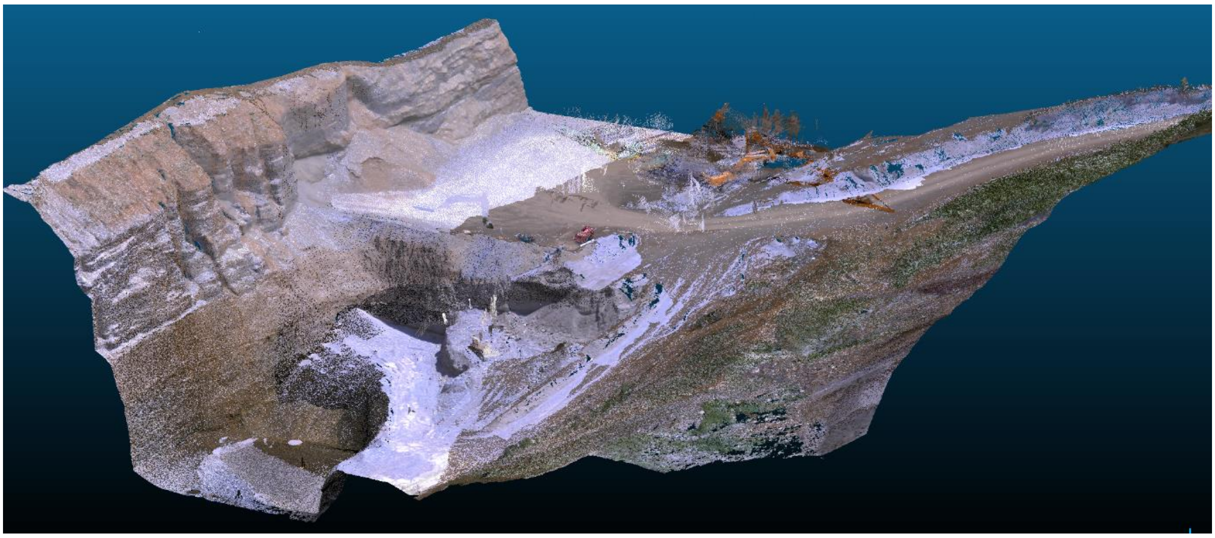


Figure 8: Screenshots of the TLS’ point cloud

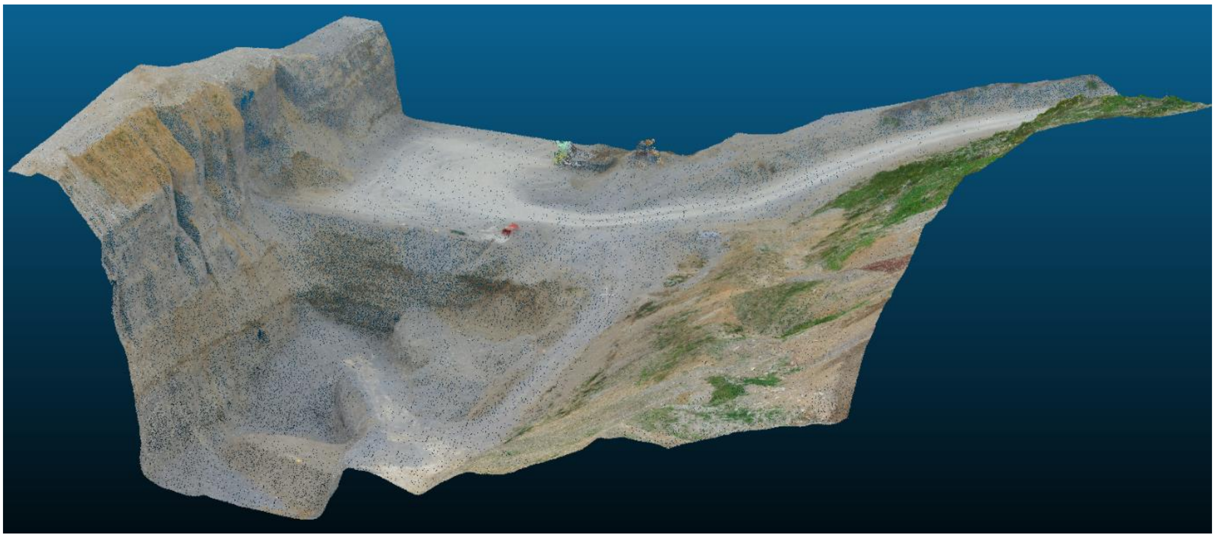


Figure 9: Screenshots of the 100 m / no GCP UAV point cloud

4.4 Discussion

While the influence of GSD on cloud density was confirmed as expected—namely, that there are more points in point clouds with higher GSDs—merging the two flights flown at different height (with double the number of images to be processed), did not bring any discernible benefit. The average GSD was not more precise, the point cloud did not contain more points (due to the images being merged and processed using the same settings as the single 100 m flight), and the overall processing time was longer.

On the question of whether an RTK–only flight could achieve the same absolute accuracy as a flight tied to GCPs, this was proven to be possible. For the point clouds where GCPs were used, the average offset of the flights was a few centimeters better than the flight flown with onboard RTK but without GCPs. Standard deviation was the same across all four UAV processings. This means that all types of processing give a constant accuracy all over the project.

Regarding the number of points captured—point density—in particular the average number of points per square meter, the UAV flights produced a high enough level of detail with which to survey sites such as quarries. The TLS meanwhile provides a greater level of detail (at its default density setting), which can be appropriate for smaller, more demanding projects such as digital conservation mappings. Also, important however, is that the density of points was homogeneous in each case (UAV and TLS), meaning a minimal difference between the lowest and highest point densities per square meter, which is more relevant to the final level of detail than the average number of points alone.

While the preparation time for TLS and UAV (Graph 1) is similar, the time spent in the field with the UAV was significantly shorter (approximately ten times shorter for a single flight over the gravel pit). In terms of post–processing, the UAV image processing time is a factor to be considered, however this time is notably longer when using GCPs—approximately 50% longer than RTK–only flights.

With respect to the total data production time (collection & processing) required for each technology (Graph 1), in the case of a single RTK flight, without GCPs, this requires one–third of the time of the TLS. In the case of a single 100 m UAV flight with GCPs, this time saving is reduced to approximately 40%.

5. CONCLUSION

The aim of this remote sensing project was to compare the point clouds generated from TLS and UAV imagery; in particular by assessing the efficiency of each point cloud's data collection and assessing each point cloud's final quality.

	TLS	UAV [100 m flight height]	UAV [150 m flight height]
No. of points	24,416,594 [741 points/m^2]	1,246,951 [37 points/m^2]	645,695 [19 points/m^2]
CloudCompare – std.dev [cm]	n/a (reference)	5.2	5.9

Total collection time (in–field & processing) [min]	225	20	20
Approximate cost (CHF)	80,000 CHF	30,000 CHF	

Table 5: Summary of key comparison findings.

5.1 Efficiency

The process of collecting point data in the field with the RTK–enabled eBee Plus UAV, without the need for GPCs, was more than twice as efficient as using the TLS (Graph 1). In the case of non–RTK flights, both flights (100 m and 150 m) were still notably (40%) quicker than a TLS approach.

Regarding data processing, the TLS requires zero processing, just the copying of one file from instrument to computer. By contrast, the UAV imagery must be copied and processed, which takes between one and three and a half hours depending on the flight height (Table 2). However, it must be noted that photogrammetric processing time is computer time only—once started, this processing runs autonomously. Therefore, staff can still be doing other things, such as planning or carrying out more UAV flights.

When combining these in–field and processing timings, comparing each technology's total data collection time (Table 5) shows that that the overall efficiency of the RTK–enabled eBee Plus is higher than that of the TLS for a gravel pit survey such as this. For such sites, UAVs therefore represent a valuable method with which surveying teams can reduce their data collection workloads. UAVs could therefore allow such organizations to reduce their staffing costs, offer more competitive pricing and/or complete more projects within a set time.

5.2 Absolute positional accuracy

We can conclude that the use of GCPs is not required to ensure high absolute accuracy is achieved with a UAV (Table 3), since the senseFly drone and the Swiss VRS systems enabled the images to be geotagged with high absolute accuracy. This was proven when comparing the point clouds processed with GCPs and RTK–only to the TLS point cloud; the offset was minimal, and all comparisons showed the same standard deviation, meaning the noise was constant across the project, no matter whether GCPs were employed or not.

5.3 Point cloud quality

The quality of the various point clouds can be assessed by observing point density and noise. Point density is very high in the case of the TLS point cloud, however the comparisons above show that the UAV's less dense point clouds achieve similar results. We can conclude therefore that, while the UAV point clouds provide less detail than a TLS point cloud (set to medium density), there is still enough detail provided for most typical survey applications.

While the noise of each individual point cloud was not assessed, on comparing the various UAV point clouds with the TLS point cloud (via overlaying these in turn), the same standard deviation and minimal offset were recorded. Therefore, we can conclude that the noise from all these sources is minimal and not relevant—all point clouds were perfectly exploitable and their derived products, such as DTMs, volumes, etc., were not affected.

5.4 Summary

For surveying projects where the very highest level of detail is essential, such as digital preservation projects on small sites for example, a laser scanning methodology is undoubtedly optimal.

For larger surveying projects, such as this project's gravel pit or a quarry or construction site of a similar size, RTK–enabled UAV technology provides more than acceptable levels of point cloud detail and accuracy, alongside greater efficiently. Plus, a UAV approach can potentially improve worker safety, since survey staff do not need to traverse the terrain within a site.

For this project's particular gravel pit site, the optimal data collection approach, in terms of efficiency and quality, can be concluded to be a RTK UAV flight (without GCPs), flown at low altitude (100 m). This approach achieves the shortest image processing time, high absolute accuracy and acceptable point density, while minimizing onsite risk.

Another noteworthy difference between UAV and TLS data collection is the ability to save, and in future re–load, a UAV's automated flight plan. This can ensure the consistency of future data when monitoring a site over time, for example for the calculation of volume differences from one week, or month, to the next. In contrast, the TLS approach requires control points, the setting of which can be time consuming if these are not already fixed in place.

The additional free visual data that the UAV provides, in the form of the aerial 2D orthomosaic (orthophoto) created after processing its imagery is valuable. This client–pleasing output that can serve as a great compliment to a point cloud or digital surface model.

Lastly, also worth noting is that, from a cost perspective, the UAV's retail price (Table 5) is currently, in January 2018, approximately one third that of the TLS here in Switzerland.

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