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UAV photogrammetry for volume calculations

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Abstract. This research assesses the suitability of UAV (Unmanned Aerial Vehicle) photogrammetry for calculating stockpile volumes and analyses the compliance of the accuracy of results to current laws. In addition two different UAV's and two different objects are compared and the necessity of using GCP's (Ground Control Points) is investigated. The time spent on each work stage is also evaluated. Data used in this study was collected in two sites, where the objects differed in shape, colour and texture. The investigated objects were a regularly shaped peat stockpile and an irregularly shaped gravel stockpile. Data was collected with a terrestrial laser scanner, a GNSS (Global Navigation Satellite System) device and two different UAVs. Volume of the models calculated from different data was compared to the volume of the models based on laser scanning data for accuracy assessment. Relative errors of all of the photogrammetric models compared to the laser scanning based model were under 4%. It was concluded that the advantages of UAV based photogrammetry become apparent as the complexity and size of the measured objects grow. Results of the study show that using UAV photogrammetry to determine stockpile volumes is sufficiently accurate with both of the tested UAVs. The results show that without using GCPs (Ground Control Points), sufficient accuracy was still achieved. Nevertheless accuracy was increased by using GCP's. It was concluded that using UAV's can significantly reduce the time spent on collecting data for volume calculations, especially when GCP's are not necessary.

Key words: stockpile, 3D modelling, GCP's.

INTRODUCTION

Thanks to the overall development of technology the use of UAV's is increasing. Using UAV photogrammetry for volume calculations and mapping large areas is in accordance with the principles of sustainable development. It is possible to measure large objects relatively quickly using an UAV. This saves time, human resources and also transportation costs, because it is possible to map a large object in one day using an UAV, whereas mapping the same object using traditional methods could take up to a week. Furthermore it is possible to map areas that are dangerous or difficult to access using an UAV, whereas it would be necessary to use some form of special equipment for mapping it otherwise. Using an UAV is also contactless, so it is possible to map sensitive areas, without driving or walking on the endangered area. In endangered areas, where getting a flight permit is difficult, terrestrial photogrammetry or laser scanning could be used as an alternative (Dlouhy et al., 2016; Burdziakowski, 2017). Thanks to the development of software and hardware it is possible to use smaller, low-priced UAV's and cameras, which makes work more efficient and less resource heavy, which is one of the main aspects of sustainable development.

UAV's are used for various different purposes from military, postal services and assessing forest health to different forms of entertainment. UAV's can be used as an alternative way to create DEM (Digital Elevation Model) for agricultural purposes (Moravec et al., 2017) and also in precision agriculture, for example to estimate hops canopy area (Starý et al., 2020). As the technology has advanced it is also possible to autonomously navigate UAV's even without GNSS signal (as in extremely low altitudes or indoors) (Dlouhy et al., 2016; Burdziakowski, 2017). Even data from a commercial remotely piloted aircraft can be successfully used in agriculture, when georeferenced with GCP's (Santos et al., 2019). In Estonia, some years ago UAV's were mainly used for inspecting power line corridors, calculating mining volumes and state control of agricultural sector (Liba & Berg-Jürgens, 2015). Photos collected with an UAV can be used both in mapping and creating 3D models (Kokamägi, 2018b; Burdziakowski et al., 2020). Surveying with UAV's is mostly used for large or hardly accessible areas but as the technology evolves, some surveys that were formerly done via total stations or RTK are also beginning to be replaced by UAV's. It is a technology that is rapidly expanding all over the world (Eisenbeiß, 2009). Because of the popularity of UAV's, the smaller models are in mass production and therefore available for a wider scope of users.

The study assesses the accuracy of stockpile volume calculations based on UAV photos and analyses the compliance of this accuracy to current laws. Besides that the impact of using different GCP's and different characteristics of the objects is also investigated. Also, the amount of time spent on each working stage was measured. Many similar studies were analysed to choose a suitable methodology.

Rhodes (2017) investigated using a low-priced UAV for creating 3D models. Different data collecting and processing methods were compared and the results were compared with known volumes and reference measurements. The investigated objects were hay bales and large water tanks (Rhodes, 2017).

In 2014 there was a study carried out in Canada, which researched using UAV's and terrestrial laser scanning (TLS) for collecting data to create digital elevation models (DEM). For accuracy assessment the results were compared to GNSS survey results. It was found that UAV's have great potential for collecting the needed data for this kind of purpose (Ouédraogo et al., 2014).

A research done in 2015 compared using an UAV and a total station for collecting data for stockpile volume calculations. The results were compared with the actual volume that was given by the engineers working on site. The relative errors compared to reference data were -0.67% for the UAV and 2.88% for the total station. The time spent on collecting data was also compared and it was found that surveying with a total station took about six times more time than surveying with an UAV (Arango & Morales, 2015).

Raeva, et al. (2016) compared using a GNSS device and an UAV for volume surveys in their study in 2016. An open-pit quarry stockpile was measured via RTK GNSS and an UAV. The collected photos were processed in Pix4D software and volume calculations were done in Civil 3D software. It was pointed out that in many countries the relative error of the calculated volume compared to the actual volume is not allowed to exceed 3%. The error between the two surveys was 1.1%, which fits in the given limit. It was also pointed out that collecting photogrammetric data took a lot less time than collecting GNSS data. It was found that using UAV in open-pit quarries is justified, especially because the technology is continually developing (Raeva et al., 2016).

In Estonia the main focus of research has been on dermining vertical or horizontal accuracy (Berg-Jürgens, 2015; Huul, 2016; Köök, 2018). Based on the study of Natalja Liba et al. (2016), it became clear that an orthophotomosaic with sufficient accuracy in the national geodetic system can be created only by using reference points, and by automating other processes, the geometric accuracy remain within 0.1 meters.

As the determination of volumes by this method had not been studied in Estonia before, the accuracy of the determination of volumes on the basis of photographs taken from unmanned aircraft had to be studied, among other things, for updating legislation and making investment decisions for surveying companies. During the work, two different unmanned aircraft and two different objects were compared. The models generated by photogrammetric method were compared with the model based on measurements with RTK GNSS device and based on terrestrial laser scanning. In order to find out the efficiency of different methods of determining volumes, the time spent on different work steps of different methods is compared.

A master's thesis (Kokamägi, 2018a) was prepared and defended at the Estonian University of Life Sciences in the spring of 2018 based on the data presented in the article, which is reviewed in the article 'Accuracy of stockpile volume calculations based on UAV photogrammetry' Kokamägi, 2018b).

This study aims to assess the accuracy of stockpile volume calculations based on UAV photos and analyse the compliance of this accuracy to current laws and to investigate the impact of using different types of GCP's and UAV's to the accuracy.

MATERIALS AND METHODS

Two objects were selected for the research. The first object was a regular-shaped dark-coloured peat stockpile in a peat extraction area in Western Estonia, and the second was a light-coloured irregular-shaped gravel stockpile in the Karude quarry in Central Estonia (Fig. 2). Measuring volumes of peat stockpiles is a daily work of surveyors, and since they have to be measured several times during the season, it is useful to study the possibilities to make the work more efficient, therefore the time spent on different work stages was taken into account during the research.

During the preparation of the object, ground control points were installed and their locations were measured with a Trimble R4-3 GNSS device. After that, the contours of the object were measured using a GNSS device and then laser scanning was performed.

The area of the peat stockpile was 463 m^2 and the area of the gravel stockpile 394 m^2. Both the Laiküla peat extraction area and the Karude quarry are currently in use and are typical objects where it is necessary to determine the volumes of material on a regular basis.

The Trimble R4-3 GNSS instrument was used to measure the contours and control points of both objects, and both dumps were scanned with a Trimble SX10 scanning total station.

The process of the methodology that was used to achieve the set goal is shown in Fig. 1.

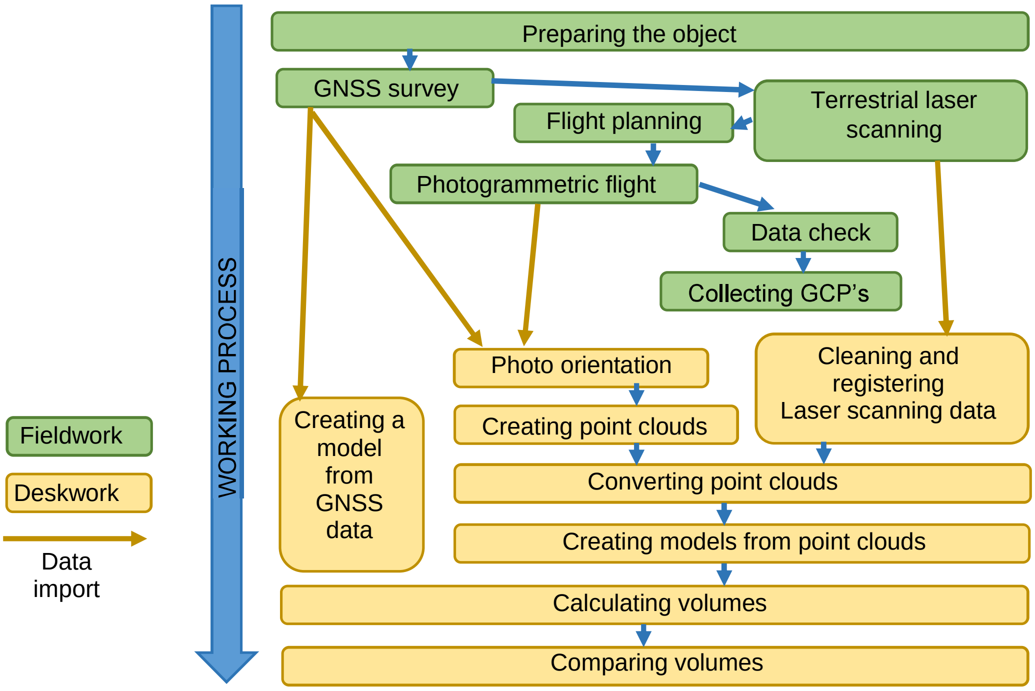

Figure 1. Working process (Kokamägi, 2018a).

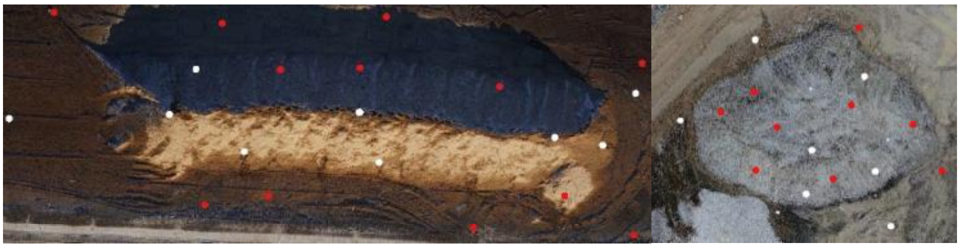

Figure 2. On the left an orthophotomosaic of the peat stockpile in Laiküla and on the right an orthophotomosaic of the selected object in Karude quarry. On the left special photogrammetric GCP's are marked with white and spray painted GCP's are marked with red dots. On the right the selected seven GCP's are marked with white and selected nine GCP's are marked with red dots.

The first object (Laiküla peat stockpile) was surveyed on October 24, 2017.

Measuring a peat stockpile is generally difficult and dangerous, as it is a soft material and it is generally necessary to use special instruments or heavy machinery to measure its ridge using conventional methods.

21 ground control points were installed on the first object: 12 points made with spray paint and 9 special photogrammetric markers. It took about 20 minutes to install them.

A total of 20 points were collected during the GNSS survey. Measurements yielded data from 13 to 19 satellites and PDOP (Position of Dilution of Precision) ranged from

1.3 to 2.0. According to the GNSS device report, the horizontal accuracy of the points was within three cm horizontally and 5 cm vertically. This step took about 40 minutes.

The stockpile was scanned from four points of view and it took about an hour to scan.

Two different UAVs were used for imaging (Table 1). Unmanned aircraft DJI Phantom 4 pro v2.0, (Fig. 3), a relatively inexpensive and widely used unmanned aerial vehicle, and the Aibotix Aibot X6, built specifically for photogrammetric use (Fig. 3). The first has a 20 MP (megapixel) integrated camera and the second had a 32.4 MP Sony ILCE-7RM2 camera on board.

Table 1. DJI Phantom 4 pro v2.0 and Aibotix Aibot X6 specifications (Phantom 4 Pro 2020, Aibot X6 2018, Sony ILCE-7RM2 Full 2020)

	DJI Phantom 4 Pro v2.0	Aibotix Aibot X6
Size	Diagonal 35 cm	105×105×45 cm
Weight	1,375 kg (including camera)	3.4 kg
Payload	-	2 kg
Max flight time	30 minutes	20 minutes
Max speed	20 km s^{-1}, positioning mode 13–89 m s^{-1}	11.11 m s^{-1}
Max ascent speed	6 m s^{-1}, positioning mode, 5m s^{-1}	8 m s^{-1}
Rotors	4	6
Camera	Integrated 1’’ CMOS 20 MP	Sony ILCE-7RM2
Effective pixels	5,472×3,648 (20 MP)	7,952×5,304 (42.4 MP)
Focal length	8.8 mm	35 mm
Sensor size	Diagonal 1 inch	1.4×0.9 inches
Image format	JPEG, DNG (RAW)	JPEG, RAW

The flight planning of the DJI Phantom 4 pro v2.0 was done with DroneDeploy software and lasted about five minutes. 415 photos were collected during the flight. To create the model, 76 of them, which were photographed at the correct height and had the object or a control point visible, were used. The flight height was 33 meters (AGL – above ground level) and the GSD (ground sampling distance) was 8 millimeters. The flight lasted about five minutes.

Figure 3. Aibotix Aibot X6 on the left and DJI Phantom 4 Pro v2.0 on the right (Leica-Geosystems, 2020; DJI, 2020).

The Aibot X6 flight was planned using AiProFlight software. Flight planning and aircraft assembly took about 15 minutes, which is significantly more than with the DJI Phantom. The flight lasted about 5 minutes. 95 photos were collected, of which 48 were used. The flight height was 47 (AGL) meters and the GSD was 6 mm.

The second object (Karude Gravel Quarry) is more accessible and manually measurable, but gravel quarries are also one potential place to make work more efficient with an UAV. The survey took place on April 10, 2018.

18 special photogrammetric markers were installed on the second object, which took about 20 minutes.

A total of 100 points were measured using the RTK GNSS method. Because the dump was quite complex in shape and had many bumps, it was measured quite densely. Measurements yielded data from 14 to 17 satellites and PDOP ranged from 1.2 to 1.8. According to the GNSS device report, the horizontal accuracy of the points was within 8 mm horizontally and 12 mm vertically. This step took about 55 minutes.

Scanning was performed with a Trimble SX10 scanning total station, the stockpile was scanned from eight positions and the point cloud was assembled automatically during field work. It took about two hours to scan.

Only the DJI Phantom 4 Pro UAV was used for imaging. The flight was planned using DroneDeploy software. The flight lasted less than 5 minutes, during which 139 photographs were collected, of which 55 were used. The flight height was 28 meters (AGL) and the GSD was 6 mm.

Data processing

Then the data was processed, during which 3D models of objects were created from the data collected with different devices and their volumes were calculated. After that, the volumes of the different 3D models were compared and absolute and relative errors compared to the scanning model were found.

The photos were oriented and point clouds created using Agisoft Photoscan Professional 1.4.0 software. Trimble Business Center and Autodesk Recap 2019 software were used to process the point clouds. Autodesk Civil 2019 drawing software was used to create models from point clouds and calculate volumes. The results were analysed using Microsoft Excel.

The research used the coordinates of points collected with a GNSS receiver, point clouds obtained with a laser scanner, and JPEG images collected with an unmanned aircraft with data about the location of the images. Data was collected on two objects.

Based on the coordinates of the points representing the surface of the objects measured by the GNSS method, the contours were drawn, and then the bottom of the dump and its surface were created as separate surfaces. The heights of these surfaces were then compared and the volume between the two surfaces was calculated.

In the Civil 3D software, the lower contour of the stockpile measured by the GNSS device was fixed to the height according to one of the selected control points. The surface of the base was then formed from the contour. After that, the surface of the scanned point cloud was created. For this, only the points inside the base contour were used, the cloud was thinned to a point spacing of 5 cm and the kriging method was used to create the grid. The heights of these surfaces were then compared and the volume of the model was calculated.

Agisoft PhotoScan Professional was used to find volumes by the photogrammetric method, the images were oriented and then the surveyed control points were attached to the GCP’s on the images. It was a time consuming process and lasted about one hour. After marking the GCP’s, the images were reoriented using the Medium accuracy class.

Then a point cloud was created, Medium was also chosen as the quality. For Aibot X6 data, camera orientation data collected on-board using an IMU device was also used.

After creating the point clouds, they were processed in the same way as the laser scanning point cloud described above. The control points used to position the base contour were not used in the photo orientation process.

Using the photogrammetric method, 8 different models were created for the first object (peat stockpile) and 4 different models for the second object (gravel stockpile) (Table 2). The volumes derived from laser scanning and GNSS survey were 722.52 m^3 and 680.55 m^3 for the first object and 674.04 m^3 and 651.94 m^3 respectively.

Table 2. Different models created by the photogrammetric method (Kokamägi, 2018a)

Object	UAV	GCP's used	Volume (m^3)
First object: Laiküla peat extraction area	Aibotix Aibot X6	no GCP's	704.92
		spray paint GCP's	715.02
		photogrammetric GCP's	730.27
		all GCP's	717.49
	DJI Phantom 4 Pro	no GCP's	708.21
		spray paint GCP's	699.50
		photogrammetric GCP's	742.23
		all GCP's	730.48
Second object: Karude gravel quarry	DJI Phantom 4 Pro	no GCP's	698.97
		7 photogrammetric GCP's	652.30
		9 photogrammetric GCP's	653.60
		16 photogrammetric GCP's	658.41

Assessment of the accuracy of volumes

After finding all the volumes from laser scanning, GNSS and photogrammetric data by different methods (Table 2), they were compared. As laser scanning is considered to be more accurate than other methods used in creating the models, the volume of the model obtained by laser scanning was considered correct for the sake of research. Both the absolute and the relative volume error were found and it was monitored whether the relative error was within the permissible limits.

Similar to the research conducted by Richard Kramer Rhodes (Rhodes, 2017), in addition to the relative error. the root mean square errors (*RMSE*) of different models created by photogrammetric method were also found in both objects. The Gaussian *RMSE* formula was used to calculate the *RMSE* (Randjärv, 1997).

$$m = \pm\sqrt{\frac{[\Delta^2]}{n}} \quad (1)$$

where Δ^2 – the sum of the squares of the errors of the volume of the model obtained by the photogrammetric method compared to the model obtained from laser scanning data; n – the number of different models.

To evaluate the accuracy of the *RMSE* m. the *RMSE* of the result was calculated by the formula (Randjärv, 1997)

$$m_m = \pm\frac{m}{\sqrt{2n-1}} \quad (2)$$

where m – the *RMSE*; n – the number of different models.

In addition, the time spent on the different steps of the volume determination methods were analysed and compared.

RESULTS AND DISCUSSION

For the first object (Laiküla peat stockpile) a total of 10 models were created and their volumes and errors compared to the model created using the laser scanning data were calculated.

Table 3. Errors of the volumes of models created on the basis of surveys of Laiküla peat stockpile compared to the model created from laser scanning data with mean squared errors (Kokamägi, 2018a)

Instrument	GCP's	Volume (m^3)	Error (m^3)	Relative Error (%)	*RMSE* (m^3)
Scanning total station Trimble SX10		722.52	0	0	
GNSS Device Trimble R4-3		680.55	-41.97	-5.81	
UAVAibot X6	no GCP's	704.92	-17.60	-2.44	10.62 14.31
	Spray paint GCP's	715.02	-7.50	-1.04	6.87
	photogrammetric GCP's	730.27	7.75	1.07	
	all GCP's	717.49	-5.03	-0.70	
UAV DJI Phantom 4 Pro	no GCP's	708.21	-14.31	-1.98	17.23
	spray paint GCP's	699.50	-23.02	-3.19	18.09
	photogrammetric GCP's	742.23	19.71	2.73	
	all GCP's	730.48	7.96	1.10	

The errors in the volumes of the models created on the basis of the surveys made in Laiküla peat extraction area compared to the scanning model with the mean square errors are shown in Table 3. The relative differences of the volumes are shown in Fig. 4.

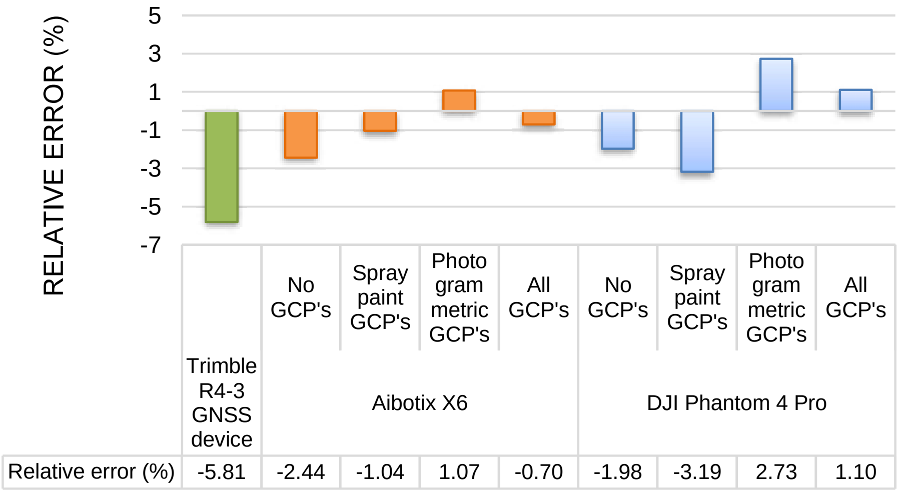

Figure 4. Relative errors of the volumes of the models of Laiküla peat stockpile (Kokamägi, 2018a).

The errors of the volumes of the models created by the photogrammetric method in different methods at the Laiküla peat stockpile show that the errors in the models created with the data collected by the special surveying UAV Aibot X6 with a better camera were more accurate than the models created using cheaper Phantom 4 Pro data. The mean square errors of the different models were 10.62 m^3 and 17.23 m^3, respectively. It is likely that the superiority of the more expensive instrument will come out even more when measuring objects in the global coordinate system, as the Aibot X6 positioning devices are more accurate. As the Phantom 4 Pro flew lower, the pixel sizes were about the same size for both aircrafts - 8 mm for the Phantom 4 Pro and 6 mm for the Aibot X6. For a larger object, of course, this means a longer flight for the Phantom 4 Pro, but since photogrammetric surveying is a lot faster than other surveys, it shouldn't be a big problem.

Also, no significant effect on the accuracy of the volumes was observed when using different types of GCP's. For the Phantom 4 Pro, the relative volume error was -3.19% using spray paint GCP's and 2.73% for special photogrammetric GCP's. For the Aibot X6, the relative errors were -1.04% and 1.07%, respectively. At the same time, the use of all GCP's at the Laiküla site improved the accuracy of the models created from the data collected by both aircraft. The relative error using all GCP's was only -0.7% for Aibot X6 and 1.1% for Phantom 4 Pro.

For the second object (Karude gravel stockpile) a total of 6 models were created and their volumes and errors of compared to the model created from the laser scanning data were calculated.

The errors in the volumes of the models created from the surveys done in the Karude gravel quarry compared to the model created from the laser scanning data with the mean square errors are shown in Table 4. The relative errors in the volumes of the models of Karude gravel stockpile are shown in Fig. 5.

Table 4. Error of the volume of models created on the basis of surveys of Karude gravel stockpile compared to the model created from laser scanning data with mean squared errors (Kokamägi, 2018a)

Instrument	GCP's	Volume (m^3)	Error (m^3)	Relative error (%)	*RMSE* (m^3)
Scanning total station Trimble SX10		674.04	0	0	
GNSS Device Trimble R4-3		651.94	-22.1	-3.28	
UAV DJI Phantom 4 Pro	no GCP's	698.97	24.93	3.70	20.95
	spray paint GCP's	652.3	-21.74	-3.23	19.45
	photogrammetric GCP's	653.6	-20.44	-3.03	
	all GCP's	658.41	-15.63	-2.32	

The error of the model created on the basis of GNSS measurements at the Karude gravel quarry remained in the same order of magnitude as the models obtained by photogrammetric method.

In Karude gravel quarry, where only Phantom 4 Pro data and special photogrammetric GCP's were used, the results obtained using different amounts of

GCP’s were quite as expected - the more markers used, the more accurate the model. The relative errors were 3.70% without GCP’s. -3.23% with 7 GCP’s. -3.03% with 9 GCP’s, and -2.32% using all 16 GCP’s.

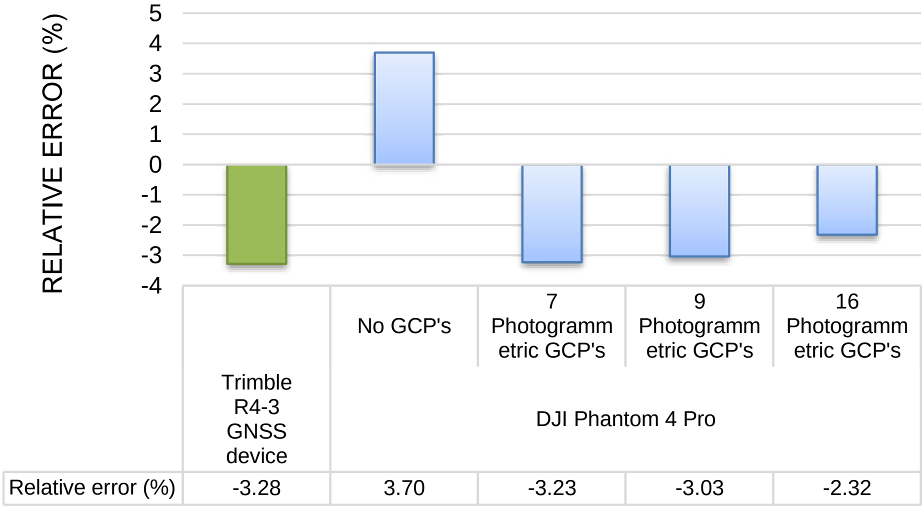

Figure 5. Relative errors of the volumes of the models of Karude gravel stockpile (Kokamägi, 2018a).

A comparison of the relative volume errors of models created from GNSS data and the DJI Phantom 4 Pro data generated for the two objects is shown in Fig. 6.

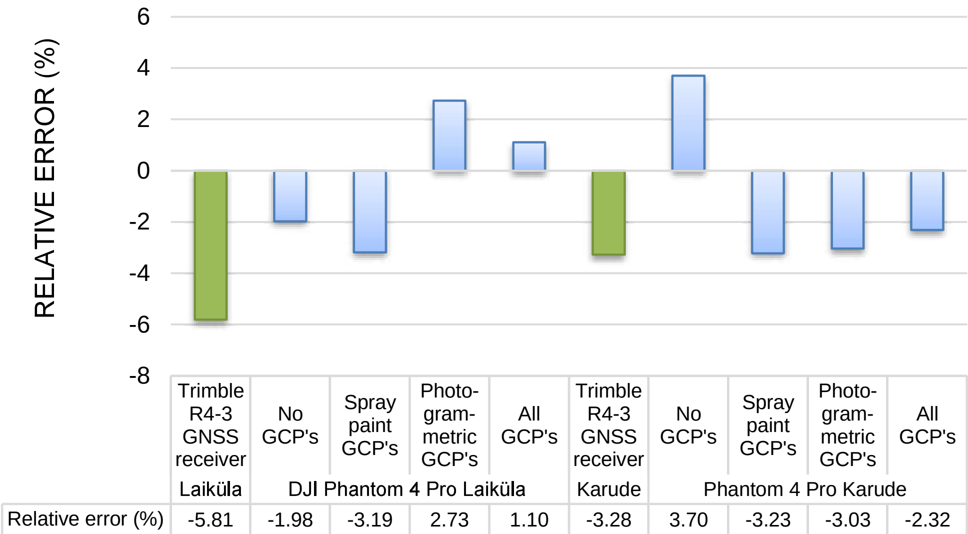

Figure 6. Relative errors in the volumes of the models created from the GNSS and DJI Phantom 4 Pro data of Laikúla and Karude objects compared to the results obtained from the laser scanning data (Kokamägi, 2018a).

Looking at the relative errors of the two objects, we see that, when using all the GCP's in the Laiküla object (peat stockpile), the relative difference was 1.10% compared to the volume of the model formed from the laser scanning data and 2.32% in the case of the Karude object (gravel stockpile). GNSS survey of Laiküla peat stockpile had the largest error, this could have been caused by measuring too few points and oversimplifying the shape of the stockpile and also by the soft material.

Differences of photogrammetrical models could have been caused by the different distribution of GCP's in the area (Fig. 2). For the first object (Laiküla peat stockpile), shadows and the amount and distribution of GCP's in the shadow could also affect the result.

Time spent on different methods

In the course of the work, the time taken to determine the volumes in different ways was also assessed. Table 5 shows the stages of determining the volume of the Laiküla peat stockpile with different methods and the time spent on each. Fig. 7 compares the total time taken to determine the volume with different methods.

Table 5. Stages of determining the volume of Laiküla peat stockpile with different methods and the time spent on (Kokamägi, 2018a)

	GNSS device Trimble R4-3	Scanning total station Trimble SX10	UAV DJI Phantom 4 Pro using GCP's	UAV DJI Phantom 4 Pro no GCP's	UAV Aibotix Aibot X6 using GCP's	UAV Aibotix Aibot X6 no GCP's
Object preparation (min)			20		20	
RTK GNSS survey (min)	15		25		25	
Laserscanning (min)		60				
Flight planning (min)			5	5	15	15
Photogrammetric flight (min)			5	5	5	5
Collecting GCP's (min)			10		10	
Data processing (min)	15	30	90	30	90	30
Total (min)	30	90	155	40	165	50

The fastest way to determine the volume of the Laiküla peat stockpile was to use GNSS measurements, but this is misleading because it was only one small object with a regular shape. The larger the area and the more irregular the objects, the more the advantage of laser scanning and especially unmanned aircraft becomes apparent. In addition, it took more time than usual to prepare the object and measure the GCP's, as different types of GCP's were used. Using GCP's in this case took so long to process, as the locations of the tags were determined manually in the photographs and this is a time consuming process.

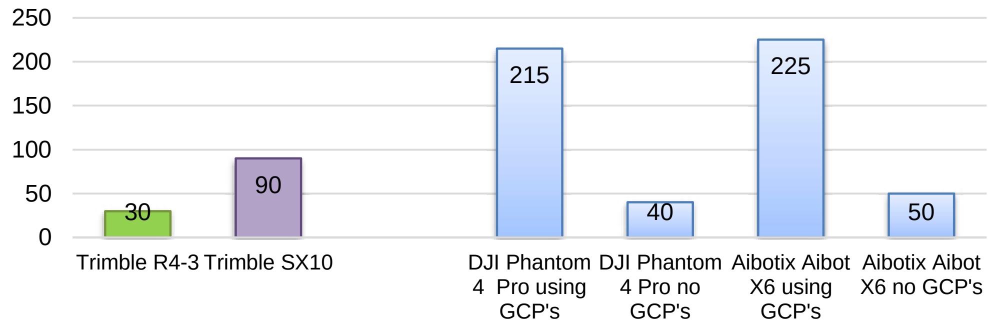

Figure 7. Total time spent to determine the volume of Laiküla peat stockpile using different methods (minutes). (Kokamägi, 2018a)

Table 6 shows the stages of determining the volume of the Karude gravel stockpile with different methods and the time spent on each. Fig. 8 compares the total time taken to determine the volume with different methods.

Table 6. Stages of determining the volume of Karude gravel stockpile with different methods and the time spent on each (Kokamägi, 2018a)

	GNSS device Trimble R4-3	Scanning total station Trimble SX10	UAV DJI Phantom 4 Pro using GCP's	UAV DJI Phantom 4 Pro no GCP's
Object preparation (min)			20	
RTK GNSS survey (min)	30		25	
Laserscanning (min)		120		
Flight planning (min)			5	5
Photogrammetric flight (min)			5	5
Collecting GCP's (min)			10	
Data processing (min)	20	30	90	30
Total (min)	50	150	155	40

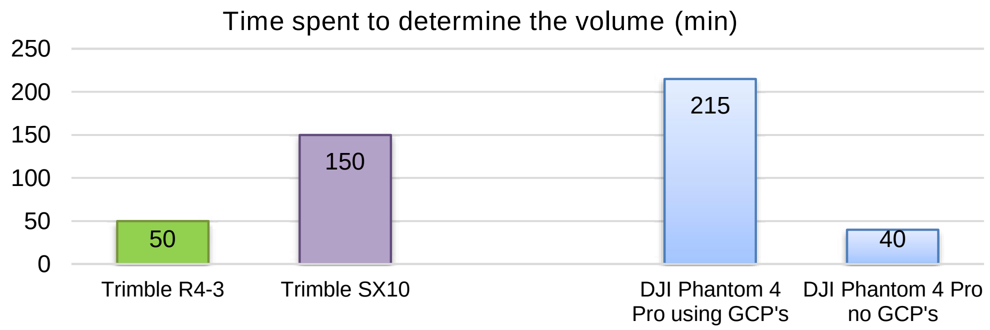

Figure 8. Total time spent to determine the volume of Karude gravel stockpile using different methods (Kokamägi, 2018a).

In the case of the Karude gravel quarry, the fastest determination of volume was made by photogrammetric method without markings. The time taken for GNSS measurements is again misleading for the reasons mentioned above. The Karude object also took more time than usual to prepare the object and survey the GCP's, as more GCP's were used than usual. It was also more time-consuming to create a model using GCP's during data processing for the reasons mentioned earlier. During laser scanning, the Karude object was surveyed from eight points of view, but normally three or four points of view would be sufficient to measure such an object, so the time taken for scanning could be considerably shorter.

DISCUSSION

As expected, more accurate results were obtained from regularly shaped peat stockpile located in the Laiküla peat extraction area. The exception here is GNSS measurements, where the error compared to the volume of the laser scanning model was -5.81%. This may have been due to errors caused by the soft ground in the field measurements, as well as excessive simplifications and measuring too few points. Surprisingly. the photogrammetric models made without using GCP's gave errors in the same order of magnitude and in some cases even more accurate results than the models made using GCP's. However, the use of all GCP's in both objects helped to improve the accuracy of the results. However, if it is necessary to georeference the coordinates of objects, the GCP's should of course be used.

Comparing the two objects, it became clear that the differences in the volumes calculated on the basis of GNSS data were -5.81% for the Laiküla object and -3.28% for the Karude object. In the case of the regularly shaped Laiküla peat stockpile, the relative error of the model created from the DJI Phantom 4 Pro data created without GCP's was -1.98% and 1.10% using all symbols. In the case of the irregularly shaped Karude gravel stockpile, the relative error of the model created from the DJI Phantom 4 Pro data created without GCP's was 3.70% and -2.32% using all the GCP's.

For comparison, the research of Richard Kramer Rhodes using unmanned aerial vehicles resulted in volume errors of less than 5% from the reference data for 13 sites, more than 15% for four sites and between 5% and 15% for three sites. In this research the measured objects were more regularly shaped hay bales and water tanks. A commercial UAV and camera were used for the research (Rhodes, 2017).

In the study of Arango & Morales (2015), the error of the model created from the total station data compared to the reference data was 2.88% and for the model based on unmanned aircraft data -0.67%. In this research the surveyed object was a soil stockpile and a commercial UAV was used for photogrammetric purposes.

In the work carried out by Raeva et al. (2016), the relative error of the model created on the basis of unmanned aircraft data was also quite good at 1.1%. An eBee UAV was used in this study and the surveyed object was the stockpile of an open quarry.

The results of current research regarding volume errors are similar to the results of previous studies. However in addition to that, using different amounts and different types of GCP's and using two different UAV's was also investigated in this study. It was found that using different types of GCP's does not affect the accuracy of results significantly. It was also found that sufficient accuracy was achieved even without any GCP's with both UAV's. However using GCP's did increase the accuracy.

Comparing the times spent on different methods to determine volumes, it turned out that GNSS is useful for measuring objects as small as those selected for research in the present work, but the larger and more complex the object, the more useful the photogrammetric method becomes. For a larger object, the photogrammetric data collection time would not be greatly extended, but GNSS measurements would take much longer.

CONCLUSIONS

The research revealed that the use of photographs collected from unmanned aircraft to determine volumes would significantly reduce the time spent on fieldwork. The volumes of all models created by the photogrammetric method in this work were within the limits of 12% of the permitted error established in Estonia with a fairly large margin (Markšeideritöö kord, 2012). It also turned out that simple spray paint GCP's could be used, which also increases the speed of field work. It turned out that sufficient accuracy of calculating volumes can also be achieved by using an inexpensive UAV and camera kit. It would be particularly useful to use unmanned aircraft to determine the volumes of larger and hard-to-reach objects.

Similar measurements could be investigated for larger objects in the future. The effect of using different photogrammetric software on the result of the volume calculation should also be tested. In addition, the effect of automatic GCP detection on the volume calculation results in photogrammetry software should be investigated, as in the present study, manual tagging of images was the most time-consuming part of data processing.

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