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Original article

A Study on DEM-based Automatic Calculation of Earthwork Volume for BIM Application

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Abstract

Recently the importance of BIM (Building Information Modeling) that enables 3D location-based design and construction work is being highlighted around the world. In Korea, the road map has been established to settle the design based on BIM using drone survey results by 2025. As the first step, BIM would be applied to road construction projects worth more than 50 billion Korean Won from 2020. On the other hand, drone survey regulation has been enacted and the data for drone survey cost were also included on Standard of construction estimate in 2020. However, more careful improvement is required to reflect drone survey results in BIM design and construction. Currently, Engineering instructions and Standard of construction estimate specifies that earthwork volume must be calculated by cross section method only. So it is required to add the method of DEM (Digital Elevation Model) based volume calculation on these regulations to realize BIM application. In order for that, this study verified the method of DEM based earthwork volume calculation. To get an accurate DEM for accurate volume computation, drone survey was carried out according to the drone survey regulation and then could get an accurate DEM data which have errors less than 3cm in X, Y and 6.8cm in H. As each DEM cell has 3D coordinate component, the volume of each cell can be calculated by obtaining the height of area of the cell then total volume is calculated by multiplying total number of cells by volume of each cell for the construction area. Verification for the new calculation method compare with existing method was carried out. The difference between DEM based volume by drone survey and cross section based volume by traditional survey was less than 1.33% and it can be seen that new DEM method will be able to be applied to BIM design and construction instead of cross section method.

Keywords : Drone Survey, DEM, Automatic Earthwork Volume Calculation, BIM

1. Introduction

Recently the importance of smart construction, in which high-tech technologies such as BIM, IoT (Internet of Things), Big data, Drones, and Robots are fused to existing construction technology, is being highlighted. Among these technologies, especially BIM is the core technology of smart construction that enables 3D (Three-dimensional) location-based design and construction work that has been done in 2D (Two-dimensional) location-based. The Korean government established a road map to settle the design based on BIM using drone survey results by 2025 and settle the automated construction using IoT-based construction equipment. For more earlier settlement of BIM, Korean Government announced that BIM would be applied to road construction worth more than 50 billion Korean Won from 2020. And

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Public Survey Work Guidelines by drones was established in 2018 and also the labor cost item for drone surveying was added on Standard of construction estimate in 2020.

However, in order to reflect drone survey results in BIM design or construction, more careful improvement for legal regulations is required especially in standard of the earthwork volume calculation. According to the current regulations such as Engineering instructions and Standard of construction estimate, earthwork volume should be calculated by cross section method only. To be applied DEM based volume calculation method to BIM in the future, it is necessary to improve these regulations to be included the new method.

To apply drone surveying results to earthwork volume calculation, Choi and Kim (2014) and Lee and Jung (2015) calculated an earthwork volume by means of cross section method based on the DSM (Digital Surface Model) data created by drone survey. In addition to this, Han and Park (2018) compared two kinds of volume by drone and GNSS (Global Navigation Satellite System) survey and verified UAV (Unmanned Aerial Vehicle) based volume is accurate as much as GNSS based volume. However these researches were remained at the level of computing volumes by cross section method only based on DEM although it was created by drone survey.

In comparison, Kim *et al*. (2016) computed earthwork volume by means of DSM based volume estimation method using Pix4D software and compared it with the GNSS surveying data. They verified there is only 1.2∼1.6% of volume difference between two methods. Sung *et al*. (2018) also compared two kinds of volume created by drone and GNSS survey. However they used PhotoScan software to calculate a volume based on a DEM created by drone survey and used ArcGIS software for volume calculation based on point clouds and TIN (Triangulated Irregular Network) data created by GNSS survey. Hugenholtz *et al*. (2015) and Raeva *et al*. (2016) also calculated earthwork volume automatically using DEM and TIN data obtained by UAV photogrammetry and GNSS survey. The volume differences between drone and GNSS surveying results were 2.5% and 1.1%. They also used PhotoScan and Pix4D for drone data processing and used AutoCAD Civil3D for GNSS data processing. On the other hand, Stalin and Gnanaprakasam (2017) and Ekpa *et al*. (2019) calculate earthwork volume based on the DEM and GNSS data using various software such as PhotScan, ArcGIS, AutoCAD Civil3D, Global Mapper and Suffer etc. As a result, they confirmed Suffer data are not acceptable to apply to volume calculation. Also ArcGIS and AutoCAD Civil3D are ideal to process vector data while PhotoScan is ideal to raster data processing. Wang (2018) calculated a volume using various type of data which were converted to cross section, grid and contour with DEM created by drone survey. She insisted that when the space of cross section and grid are created at less than 3m interval, their volume accuracy would be better than DEM based volume but the interval is more wider, DEM based volume accuracy would be better.

This paper aims to suggest that DEM based earthwork volume calculation method will be included officially in Engineering instructions and Standard of construction estimate as one of the methods for earthwork volume calculation. Therefore we summarized the principle for the method and verified its accuracy through an experiment by actual drone survey.

2. Basic Theory

2.1 Existing earthwork volume calculation based on 2D drawings

There are several ways to calculate earthwork volume such as cross section method, prism method, grid method and horizontal section method etc. However, all of them are based on 2D maps and drawings and among these, only cross section method has been mainly used for design and construction in Korea. It is caused that the regulations which are referenced for design and construction such as Engineering instructions and Standard of construction estimate specifies that earthwork volume must be calculated by cross section method only. When using cross section method, the volume between each pair of sections is computed by multiplying the distance between cross sections by the average of the end cross sectional area, as presented in Eq. (1). In order to calculate the volume, surveyor need to plot cross section of the existing and proposed ground level at

20m interval across the construction site, as shown in Fig. 1. To plot cross sections, surveyor need to carry out field survey using GNSS or Total station then lots of time and expenses are required to complete volume calculation by means of cross section method.

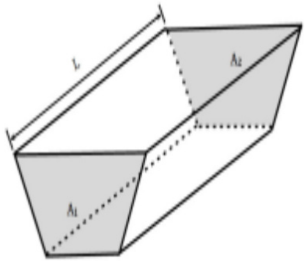


Fig. 1. Cross section

$$V=\left(\frac{A_1+A_2}{2}\right)\times L \tag{1}$$

where, The V is the earthwork volume between the cross sections 1 and 2, L is the distance between cross sections, A_1 and A_2 are areas of the cross sections 1 and 2. The accuracy of the cross section method largely relies on the distance between the sections, especially for the irregular-shaped sections.

For the other methods such as prism method, grid method and horizontal section method were omitted to summarize since they are used only for a few design and constructions.

2.2 DEM based earthwork volume calculation for BIM design and construction

It is available to calculate earthwork volume by means of several method based on DEM, TIN, Cross section, Grid and Contour etc. since all of them are processed with computer software. However DEM based method is widely used as an algorithm for most popular software such as PhotoScan and Pix4D because its principle is very simple and it allows most fast calculation compare with other methods. Therefore this study is focused to DEM based volume calculation method. DEM is generated by interpolation of the point clouds which was created as a drone survey result and is consisted of numerous cells which have 3D coordinates. Each cell has their own size which is determined by GSD (Ground Sample Distance), which is the distance between two consecutive pixel centers measured on the ground. So DEM can be expressed in 3D structures as shown in Fig. 2.

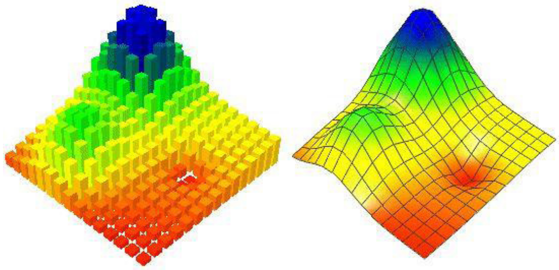


Fig. 2. 3D structures of DEM (Kidner *et al.*, 1999)

In 3D structures, each cell can be recognized in the form of a square column, as shown in Fig. 3 and it makes easy computation of the volume.

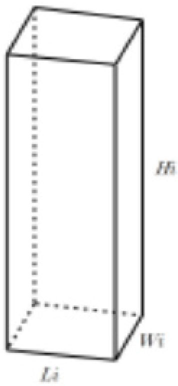


Fig. 3. Square column of the DEM cell

The volume of each cell is computed by multiplying the area by the height simply as presented in Eq. (2).

$$V_i = L_i \times W_i \times H_i \tag{2}$$

where,
L_i = GSD = the length of the cell
W_i = GSD = the width of the cell
H_i = the height at the center of the cell

However each cell has two kind of height, one is original ground level and designed ground level for construction and the earthwork height is determined by Eq. (3). where is the

$$H_i = Z_{Ti} - Z_{Bi} \tag{3}$$

where, Z_{Ti} is the original ground level of each cell at the center of the cell, Z_{Bi} is the designed ground level of each cell at the center of the cell.

Therefore earthwork volume of the certain cell i is computed by Eq. (4).

$$V_i = GSD \times GSD \times (Z_{Ti} - Z_{Bi}) \tag{4}$$

At this moment, when the original ground level is higher than the designed ground level, it is cut while the designed ground level is higher than the original ground level, it is fill. The quantity of cut and fill is calculated by Eq. (5) and Eq. (6).

$$\text{Cut, } VC = VC_1 + VC_2 \times VC_n \tag{5}$$

$$\text{Fill, } VF = VF_1 + VF_2 \times VF_n \tag{6}$$

where, $VC_1 \dots VC_n$ is cutting volume for the dells $i \dots N$ and $VF_1 \dots VF_n$ is filling volume for the cells $i \dots N$.

3. Application and Analysis

3.1 Drone survey and Automatic earthwork volume calculation

GCP (Ground Control Point) survey was carried out for 5 points before flight for aerial triangulation as shown in figure 4 as the first step of drone survey. Square shape of the marks are the GCP location. Triangular shape of the marks are the location of check points which will be used for accuracy verification for created DEM, but they were not used for DEM creation.

Fig. 4. The location of the GCPs and check points

X, Y coordinates for GCP and check points were acquired by network RTK survey and H coordinates were acquired by direct leveling as shown in Figs. 4 and 5. The edge points of traffic lane which are clearly visible in the image was selected as a GCP as Fig. 5(a) while aerial survey marks were installed as the GCP for the area where clearly invisible in the image as Fig. 5(b).

(a) Edge of the traffic lane (b) Mark for aerial survey

Fig. 5. GCP survey by network RTK survey method

For the height survey for the GCPs, direct leveling by automatic level was carried out as shown in Fig. 6.

Fig. 6. Direct leveling from Unified Control Point, U08

The results of GCP surveying are shown in Table 1.

Table 1. The results of GCP surveying

unit: m

Point	X	Y	H
GCP1	535181.091	174701.021	20.410
GCP2	535207.357	174668.265	15.108
GCP3	535255.211	174721.772	7.409
GCP4	535264.764	174638.659	6.297
GCP5	535107.561	174650.314	11.084

Flight by VTOL(Vertical Take-off and landing) fixed-wing and multi-rotor drones were carried out after GCP survey as shown in Fig. 7.

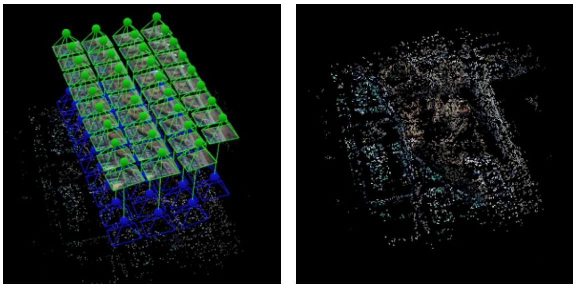
(a) VTOL Fixed-wing drone (b) Multi-rotor drone

Fig. 7. Flight of drones

Both of fixed-wing with 2.4Mb camera and multi-rotor drone with 2.0Mb camera were used for drone survey. At the 150m height, each of 75% and 80% overlap was applied for fixed-wing and multi-rotor drones and the images which have GSD 2.98cm by fixed-wing and GSD 4.11cm by multi-rotor were obtained.

The geo-tagged images are aligned automatically when the images which are recorded in the SD card of camera are transfered to PhotoScan software and then spares point cloud data are generated automatically by SfM (Structure from Motion) algorithm as shown in Fig. 8.

However the density of spares point clouds which are generated by SfM initially is too low to be used for mapping and it needs to be converted to dense point clouds by CMVS (Clustering view for Multi-View Stereo) / PMVS2 (Patch-based Multi-View Stereo2) algorithm. Dense point clouds are as shown in Fig. 9.



(a) Image alignment (b) Spares point clouds by SfM

Fig. 8. Point clouds generation by PhotoScan software

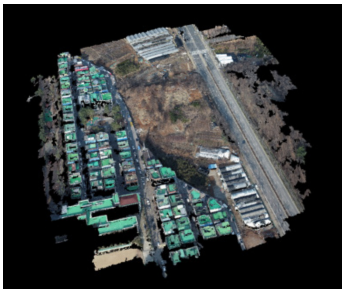


Fig. 9. Dense point clouds by CMVS/PMVS2

Check point survey by means of network RTK (Real Time Kinematic) method was carried out to verify the accuracy of point clouds for 5 of check points. Height data of the GCPs were acquired by reducing a geoid height from an ellipsoid height which is obtained by network RTK receiver. Geoid heights of the every check point were derived from the KNGeoid 18 model.

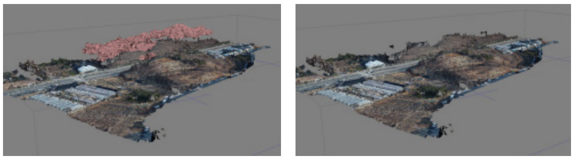
The results of check point surveying are shown in Table 2. As a result of check point survey on 5 points, errors are up to 3.0cm on X-axis, up to 2.3cm on Y-axis and up to 6.8cm on H and it can be seen that high accurate DEM was created by drone survey.

In order to take-off earthwork volume, vegetations should be removed from the point clouds, as shown in figure 10, by rotating the 3D point cloud data so that vegetations can be seen standing up for easy removal.

Table 2. Results of check point survey

unit: m

Point No.	Drone survey results			check point survey results			Differences		
	X	Y	H	X	Y	H	X	Y	H
CK1	535190.5237	174679.8254	17.7941	535190.547	174679.848	17.765	-0.023	-0.023	0.029
CK2	535275.4251	174684.2185	7.1542	535275.437	174684.220	7.128	-0.012	-0.001	0.026
CK3	535227.0836	174670.1954	13.8184	535227.078	174670.201	13.779	0.005	-0.006	0.040
CK4	535166.4421	174628.8833	9.7063	535166.472	174628.885	9.757	-0.030	-0.001	-0.050
CK5	535146.807	174657.9812	15.03	535146.791	174657.979	14.962	0.016	0.002	0.068
RMSE							-0.009	-0.006	0.022



(a) Rotated point clouds (b) Removed vegetations

Fig. 10. Removal vegetations from the point clouds

DEM is created based on the dense point clouds which was removed vegetations as shown in Fig. 11 and earthwork volume is automatically calculated as shown in Fig. 12.

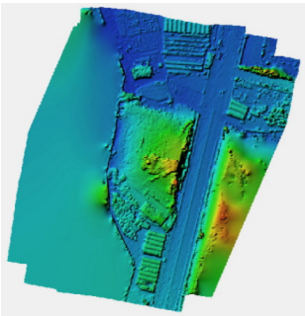


Fig. 11. Created DEM for pure ground data

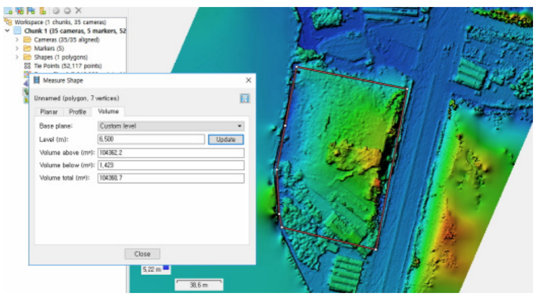


Fig. 12. DEM based earthwork volume calculation

3.2 Analysis of the earthwork volume

Earthwork volume was analyzed in three ways to verify the accuracy of the volume based on DEM which was generated by drone survey. Firstly, the volume calculated by the fixed-wing and the multi-rotor drone survey was compared. Secondly, the volume by actual drone survey and designed volume by cross-section method was compared. Lastly, volume differences according to the GSD of the images was compared.

3.2.1 The volume difference between fixed-wing and multi-rotor drone survey

The earthwork volume by the fixed-wing drone was 103,393㎥ and the volume by the multi-rotor drone was 103,758㎥, which shows that the volume by multi-rotor was about 0.35% larger than that of the fixed-wing. However, this difference can be attributed to the difference in resolution of the mounted camera rather than the difference depending on the drone type. GSD of the image by fixed wing was 2.98cm while the GSD of the multi-rotor drone was 4.11cm. In the case of the construction site where this study was conducted, the difference in earthwork volume did not occur largely because the site area is small and there is not much change in the topography but in case of the large scaled construction site and terrain with a lot of height changes, the difference in earthwork volume would be increased(Cho *et al*., 2016).

3.2.2 The volume change according to the size of GSD

In order to examine the increase and decrease of the volume according to the size of the GSD, we adjusted GSD size of multi-rotor image arbitrarily at 4.11cm to 5cm and 10cm.

As a result, the volume increased by 0.47% to 104,252㎥ in the GSD 5cm image, and the volume increased by 1.83% to 105,667㎥ in the GSD 10cm image, compared to 103,758㎥ of the volume calculated by the GSD 4.11cm image.

On the other hand, comparing the volume by the fixed-wing image of GSD 2.98cm, the volume was increased about 0.8% in the GSD 5cm and increased about 2.2% in the GSD 10cm as shown in Table 3. The larger the size of, the higher the amount of volume increased, and when the GSD is less than 5cm, a significant difference did not occur in comparison with the volume according to the GSD below, but the difference was found to be greater than 10cm GSD.

Table 3. Changes in earthwork volume according to the Size of GSD

GSD	2.98cm	4.11cm	5cm	10cm
Volume	103.393㎥	103.758㎥	134.252㎥	105.667㎥
Variation	0%	(+)0.35%	(+)0.8%	(+)2.2%

3.2.3 Comparison with design volume and DEM based volume

Since the study site is a part of the whole construction area, the partial earthwork volume for this study site is not shown in the quantity statement. Therefore, we created 8 numbers of cross-sections for the site by CAD using 3D data obtained from the design drawing as shown in Fig. 13 and 14.

Fig. 13. Cross sections of the design drawing

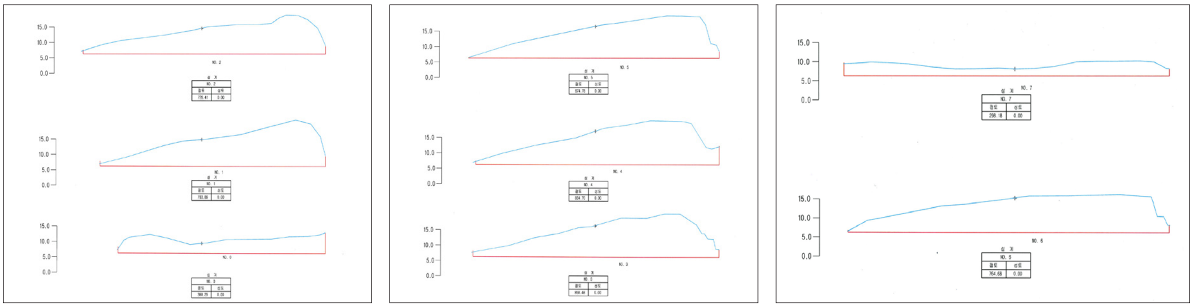


Fig. 14. Created cross sections by CAD

The earthwork volume was calculated by cross section method and as shown in Table 4.

The designed earthwork volume was about 104,763m^3, which was 1,370m^3 larger than the volume 103,393m^3 which was calculated by DEM created by GSD 2.98cm of fixed wing drone image. The volume difference was only 1.33% and it was not significantly different between two methods.

3.2.4 Comparison with design volume and volume by cross section method

Cross section was created from the DEM generated by the drone survey to compare volume differences between design and drone survey.

As a result of comparing the volume, it can be seen that the volume by designed cross section is 104,763m^3 and the volume by drone cross section is 105,929m^3, which is about 1.1% difference as shown in Table 5.

3.2.5 Summary of the volume analysis

Summarized results of the data analysis performed in the above four ways are as follows.

First, it can be seen that the earthwork volume is calculated in proportion to the GSD value of the image.

Second, as a result of quantitative analysis of the change in the earthwork volume according to the size of GSD, it is increased 0.47% in GSD 5cm and 1.83% in GSD 10cm compared to the volume by GSD 4.11cm. On the other hand, comparing the volume by the fixed wing image of GSD

Table 4. Design volume using cross sections created by CAD

No.	Interval (m)	Fill			Cut		
					Area(㎡)	Volume(㎥)	Total(㎥)
No.0	0				388.29	0	0
No.1	20				783.89	11,721.80	11,721.80
No.2	20				728.41	15,123.00	26,844.80
No.3	20				858.48	15,868.90	42,713.70
No.4	20				884.70	17,431.80	60,145.50
No.5	20				874.78	17,594.80	77,740.30
No.6	20				764.68	16,394.60	94,134.90
No.7	20				298.18	10,628.60	104,763.50
Total	140						104,763.50

Table 5. Volume comparison by cross-section method between design and actual drone survey

No.	Dist. (m)	Designed cross section			Cross scetion by drone survey			Differences		
		Cut			Cut			Cut		
		Area(㎡)	Volume(㎥)	Total(㎥)	Area(㎡)	Volume(㎥)	Total(㎥)	Area(㎡)	Volume(㎥)	Total(㎥)
No.0	0	388.29	0	0	400.67	0.00	0.00	12.38	0.00	0.00
No.1	20	783.89	11721.8	11721.8	770.89	11715.60	11715.60	-13.00	-6.20	-6.20
No.2	20	728.41	15123	26844.8	798.27	15691.60	27407.20	69.86	568.60	562.40
No.3	20	858.48	15868.9	42713.7	849.06	16473.30	43880.50	-9.42	604.40	1166.80
No.4	20	884.7	17431.8	60145.5	886.34	17354.00	61234.50	1.64	-77.80	1089.00
No.5	20	874.78	17594.8	77740.3	876.95	17632.90	78867.40	2.17	38.10	1127.10
No.6	20	764.68	16394.6	94134.9	762.52	16394.70	95262.10	-2.16	0.10	1127.20
No.7	20	298.18	10628.6	104763.5	304.18	10667.00	105929.10	6.00	38.40	1165.60
Total	140			104763.5			105929.10	0.00	0.00	1165.60

2.98cm, it is creased about 0.8% in GSD 5cm, 2.2% in GSD 10cm. As a result, when the GSD is less than 5cm, there is a slight difference of less than 1% compare to the volume of an image having a GSD value of less than that. Based on this, it would be necessary to consider that the GSD standard for drone images, which is applied to the future earthwork volume calculation, is 5cm or less.

Third, the difference between designed volume and DEM based volume was only 1.33%.

Fourth, the volume difference which was applied cross section method for both of design drawing and DEM by drone was only 1.1%. Therefore it can be seen that DEM based earthwork volume calculation method using drones can be used instead of the existing cross section method.

4. Status and Improvement of Current Legal System for the Earthwork Volume Calculation

Current legal regulations such as various Engineering instructions and Standard of construction estimate which are referenced in design and construction represent that earthwork volume must be calculated by cross section method only. This is the main reason that DEM based earthwork volume calculation method can not be applied to BIM design as well as current design and construction. So it is necessary to improve the regulations that the DEM method can be used for earthwork volume calculation in addition to cross section method. Also this study suggest some of specific standards for DEM based earthwork volume calculation based on the results of the experiment in this study as follows.

First, since the accuracy of earthwork volume depends on the accuracy and size of DEM, the accuracy of the DEM should be less than 10cm in X, Y and 15cm in H and the size of DEM which is same as the size of GSD should be less than 5cm.

Second, since widely used drone surveying software such as Pix4D and Metashape (former PhotoScan) as well as the other conventional software already have the function for DEM based automatic earthwork volume calculation, inspectors and project owners can check the results of volume calculation simply in a very short time when they have DEM data only which is submitted by contractor or surveyor. Only one issue is to accept to use proven software recommended by project owners.

5. Conclusion

This study summarized basic theories for the method of DEM based automatic earthwork volume calculation and derived the results through experiments by drone survey in the actual construction site so that the method can be applied to BIM in future construction. The following conclusions were drawn.

First, the accuracy of DEM based earthwork volume depends on the accuracy of drone survey results and it was conducted according to the drone survey regulation to get an accurate. To check the accuracy of DEM check point survey for 5 points was carried out. The errors of check points were less than 3.0cm on X-axis, 2.3cm on Y-axis and 6.8cm on height and we could see that accurate DEM was generated. Both of fixed-wing and multi-rotor drone were used to compare their volume.

Second, DEM based earthwork volume calculation was conducted using two DEM created by two types of drones. As a result, the volume by fixed-wing drone was calculated to be about 0.35% less than the volume by multi-rotor drone, However the difference is caused by the GSD according to the resolution of the mounted camera, not a type of the drone.

Third, since DEM based volume depends on the size of DEM cell which has the same size as GSD, volume calculation was carried out by varying the size of GSD of the image, As a result of comparing the volume based on the GSD 2.98cm image, it was increased 0.35% for GSD 4.11cm image, 0.8% for GSD 5cm and 2.2% for GSD 10cm image. In conclusion, when the GSD is 5cm, it shows a slight difference within only 1% compared to the volume of images with GSD value below that. Based on this, it is necessary to consider that the GSD size standard for drone images which will be applied to the earthwork volume calculation in the future is 5cm or less.

Fourth, to verify the accuracy of DEM based automatic volume calculation method, it was compared with more various methods. There was a slight difference of about 1.33% between design and DEM based volume. Also the volume difference which was applied cross section method for both of design drawing and DEM was only 1.1% and it can be seen that DEM based earthwork volume calculation method can be replaced the existing cross section method.

Fifth, Currently earthwork volume must be calculated by cross section method only according to the regulations such as the Engineering instructions and Standard of construction estimate etc. Therefore, in order to use the method of DEM based earthwork volume calculation in BIM design and construction, it is considered to improve the legal regulations to accept it.

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