

iPhone LiDAR-based Volume Estimation of Regular and Irregular Shaped Stockpiles

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Abstract

A stockpile typically refers to a large, accumulated bulk of loose materials, such as sand, soil, gravel, asphalt, salt, coal, and waste. These stockpiles are maintained by various industries, including construction, mining, quarrying, agriculture, energy, and waste management. Accurate volume estimation of stockpiles is crucial in these industries for effective inventory management, reliable cost estimation, efficient resource planning, enhanced profitability, and reduced waste. However, an accurate, cost-effective, and efficient method for estimating the volume of stockpiles is limited. Although iPhone-based Light Detection and Ranging (LiDAR) has been used in stockpile volume estimation, it has not been tested on both regular and irregularly shaped stockpiles. Accordingly, this study aims to assess the capability of iPhone LiDAR for accurately estimating the volume of both regular and irregularly shaped stockpiles. Six physical models were scanned using the LiDAR sensor available on the iPhone 12 Pro Max mobile phone. iPhone LiDAR point cloud was processed, and volumes were calculated using the free open-source CloudCompare software. For the ground truth, dimensions of all regular-shaped physical models were measured and averaged to calculate the volume manually. The volume of the irregular-shaped sand pile was estimated using a measuring cup. The Mean Absolute Percentage Error (MAPE) of volume estimation of regular-shaped stockpiles ranged from 0.56 % to 1.88%. However, the MAPE of volume estimation of the irregularly shaped sand stockpile was 4.45%. The results indicated that iPhone LiDAR is particularly effective for estimating the volume of both regular and irregularly shaped stockpiles, offering highly accurate measurements in such cases.

1. Introduction

Managing, handling, and storing bulk materials of many different types and their products is a fundamental process in a wide range of industries (Tucci et al., 2019). Normally, these materials or their products are stored in the form of heaps, which is called a stockpile (Ellinger et al., 2023). Especially, sand (Wang et al., 2024), asphalt (Ajayi & Ajulo, 2021), gravel (Wallner et al., 2024), soil (Muhammed & Abed, 2024), waste (Saepudin et al., 2024), and coal (Huang et al., 2023) are maintained as stockpiles in various industries. These stockpiles are specially managed in sectors, including construction (Chian et al., 2025), quarry (Yao, 2021), waste management (Filkin et al., 2022), and mining (Meng et al., 2023). Mainly, these stockpiles are maintained by the industries to use in the future, address unexpected shortages (Ajayi & Ajulo, 2021), avoid production delays (Alsayed & Nabawy, 2022), or transport materials outside the working zone (Muhammed & Abed, 2024). While maintaining the stockpiles, accurately estimating their volumes is essential in these industries for proper inventory management (Jafari & Dorafshan, 2025), effective resource planning (Hulanová et al., 2023), minimizing waste (Alsayed et al., 2021a), etc. Therefore, stockpile volumes are estimated using different methods in these industries.

Traditionally, stockpile volume is estimated with different methods, such as eyeballing, walking wheel, counting buckets, or truckloads (Alsayed et al., 2021b) and manually surveying with measuring tapes (Matsimbe et al., 2022). Although eyeballing is a quick method of estimating volume visually, the estimation accuracy is less (Alsayed et al., 2021b; Son et al., 2020). Walking wheel and tape surveying methods are difficult to apply for volume estimation of irregularly shaped stockpiles. In contrast, they can be used to estimate the volume of regularly shaped stockpiles, such as conical and trapezoidal, mathematically. Further, it is challenging to use the counting buckets method in a large-scale project (Son et al., 2020), and the truckload method is

also inaccurate (Perera et al., 2024) because trucks cannot be filled with the same amount. Consequently, there has been a shift toward the use of advanced surveying techniques, such as Total Station (TS), Global Navigation Satellite System (GNSS), Terrestrial Laser Scanning (TLS), and UAV methods in Stockpile Volume Estimation (SVE).

Point-based survey methods, such as TS and GNSS, are often costly and time-consuming for many stockpiles available in large areas, although they provide higher positional accuracy (Deliry & Avdan, 2023). In contrast, TLS is a slow approach when quantifying the volume of large stockpiles (Deliry & Avdan, 2023; Tamin et al., 2019) and difficult to use in a dangerous field (Tamin et al., 2019) due to relatively heavy equipment (Deliry & Avdan, 2023). Although UAV methods can accurately survey the real shape of the stockpile, according to the instrument cost and the requirement of Ground Control Points (GCPs), these methods are also difficult to apply in SVE. Therefore, there is a trend of using iPhone LiDAR technology for SVE.

iPhone LiDAR has the best solution to mitigate the limitations of these methods. The iPhone LiDAR scanner is available on iPhone 12 Pro and later models. These iPhones offer advanced 3D scanning capabilities. In the literature, some studies have been conducted using iPhone LiDAR for SVE. Gejdoš et al. (2024) compared different methods for determining wood chip pile volumes. They concluded that TLS provided the most accurate volume estimation, but at a greater cost and effort. iPhone LiDAR was the most cost-effective and time-efficient. However, iPhone LiDAR significantly underestimated volume. Nevertheless, according to the literature, the iPhone LiDAR-based studies conducted for volume estimation of both regular and irregular stockpiles are limited. Therefore, this study was conducted to assess the capability of iPhone LiDAR to estimate the volume of both regular and irregular stockpiles.

2. Methodology

2.1 Study Area

As shown in Figure 1, the study area is situated in Universiti Teknologi Malaysia - Johor Bahru (UTM-JB). A playground of the UTM-JB was selected for the survey. The selected area is relatively flat and bare ground, having an extent of 615 m². It is bound from top 172078.30, right 348959.39, bottom 172049.12, and left 348928.12 m Universal Transverse Mercator zone 48N coordinates. The six physical models, including five regular and one irregular model, were placed in the study area for the iPhone LiDAR survey.

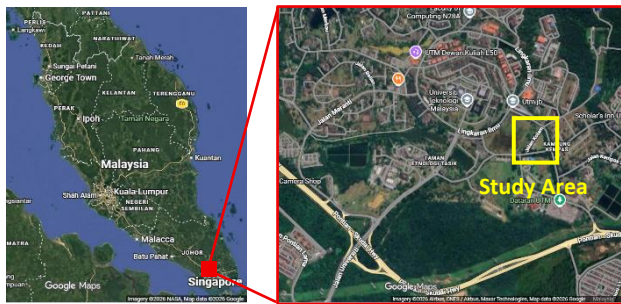


Figure 1. Study Area: UTM-JB (Malaysia)

Source: Google Maps (Map data ©2026 Google; Imagery ©2026 Airbus, CNES / Airbus, Maxar Technologies, NASA)

2.2 Physical Models to Represent Stockpiles

In this study, iPhone LiDAR-based surveys were conducted using six physical models to represent stockpiles. Accordingly, SVE was tested on five regular-shaped physical models and one irregularly shaped physical model. The five regular models: cube, pyramid, cone, cylinder, and triangular prism, were prepared using hardboards and aluminum sheets according to the dimensions depicted in Figure 3. In contrast, a heap of sand with a volume of 0.275 m³ was used to represent an irregularly shaped physical model. All physical models were placed in the study area for the iPhone LiDAR surveys, as shown in Figure 2.



Figure 2. Physical models placed in the study area

2.3 Data Collection

The iPhone 12 Pro, which has a 12MP camera and a LiDAR sensor with a 5 m range, was selected in this study based on the lowest price. LiDAR Data was collected using this iPhone with the 3D Scanner app at 2 m from stockpiles. All stockpiles were scanned five times to compare the results. After collecting iPhone LiDAR data, all regular-shaped physical models were measured using five survey tapes to obtain average dimensions and

calculate the volume manually to get validation data. The volume of the irregular-shaped sand pile was estimated using a measuring cup, shown in Figure 4. To assess the global positional accuracy of point clouds, checkpoints (CPs) were placed as Figure 5, and they were surveyed using Topcon HiPer HR GNSS receivers as shown in Figure 6.

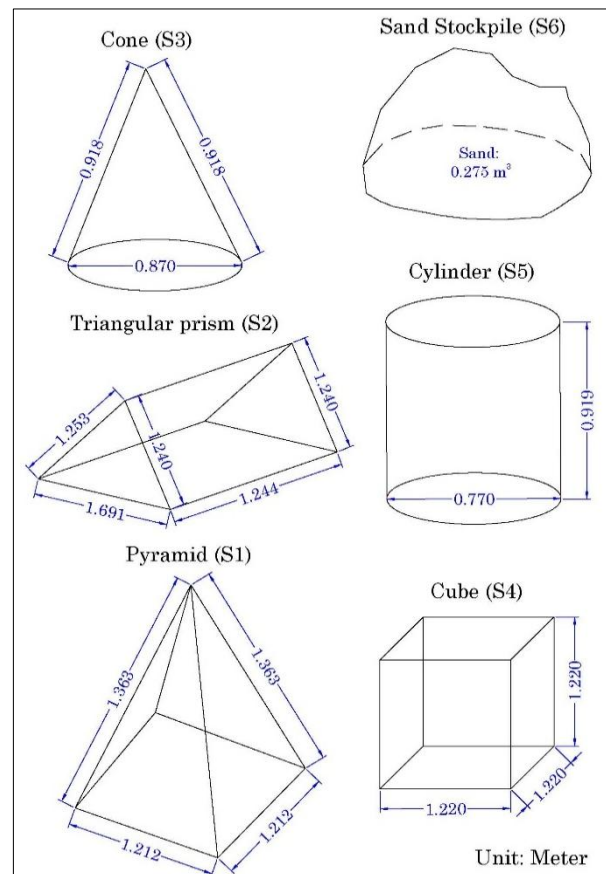


Figure 3. Dimensions of the physical models



Figure 4. Measuring cup used for sand volume

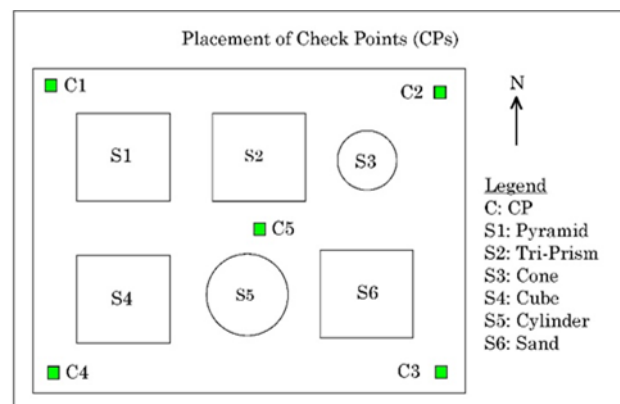


Figure 5. Placement of CPs



Figure 6. Surveying CPs using the GNSS receiver

2.4 Data Processing

After completing iPhone LiDAR data, the raw files were processed using the same mobile app (3D Scanner) and exported to LAS files. These LAS files were imported into the open-source CloudCompare software for further processing. The LAS files were processed in CloudCompare based on the workflow depicted in Figure 7 to estimate the volume of each stockpile.

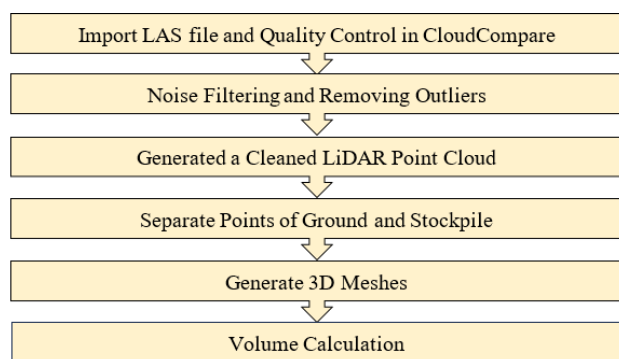


Figure 7. Processing workflow in CloudCompare

2.5 Accuracy Assessment

The accuracy of iPhone LiDAR-derived point clouds and the volume of each stockpile were assessed using statistical metrics, including Absolute Percentage Error (APE in %, Equation 1), Mean Absolute Error (MAE, Equation 2), and Root Mean Square Error (RMSE, Equation 3).

$$APE = \left| \frac{E_i - R_i}{R_i} \right| \times 100 \quad (1)$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |E_i - R_i| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (E_i - R_i)^2} \quad (3)$$

where APE = Absolute Percentage Error
MAE = Mean Absolute Error
RMSE = Root Mean Square Error
R = Reference value
E = Estimated (Obtained) value
n = Number of observations

3. Results

This study was conducted to assess the capability of iPhone LiDAR for estimating the volume of both regular and irregular stockpiles. Accordingly, the results obtained are presented in this section.

3.1 iPhone LiDAR Point Cloud of First Observation

The six physical models placed in the study area were scanned five times using an iPhone 12 Pro with the 3D Scanner app. After collecting the data, the raw data were processed using the same app, and LiDAR point clouds were exported as LAS files. The iPhone LiDAR point cloud obtained from the first observation is presented in Figure 8. This point cloud comprises 2,382,445 points, representing the study area. All point clouds were then imported into the CloudCompare software for further processing and volume calculation.

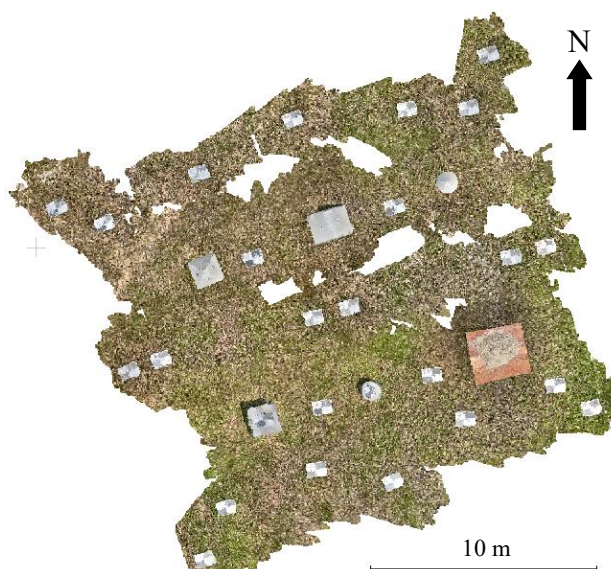


Figure 8. iPhone LiDAR point cloud of the first observation

3.2 Ground Truth Volume of Stockpiles

Dimensions of all regular-shaped physical models were measured using five survey tapes. Then the average dimensions were obtained, depicted in Figure 3. Based on these dimensions, the volume of each regular-shaped stockpile was calculated manually. The volume of the irregular-shaped sand pile was estimated using a measuring cup, shown in Figure 4. Ground truth volume of all stockpiles is presented in Table 1.

Table 1. Ground truth volume of stockpiles

Stockpile No.	Stockpile	Ground truth Volume (m ³)
Regular-shaped stockpiles		
S1	Pyramid	0.518957
S2	Triangular Prism	0.963451
S3	Cone	0.160188
S4	Cube	1.815848
S5	Cylinder	0.427944
Irregular-shaped stockpile		
S6	Sand	0.275157

3.3 Volume Estimation of Stockpiles

After processing the LiDAR point clouds, the volume of each stockpile was estimated using CloudCompare software. The results obtained are discussed as follows.

3.3.1 Pyramid Stockpiles: The 3D mesh of the pyramid stockpile generated using the first observation data is presented in Figure 9. The accuracy of the dimensions and volume of the pyramid at each observation is included in Table 2. APE for dimension and volume was calculated using Equation 1. According to the measurement of dimensions, the accuracy of the pyramid stockpile can be quantified as MAE 0.012 m and RMSE 0.014 m. Further, the accuracy of volume estimation can be quantified as MAE 0.009779 m³ and RMSE 0.009786 m³.

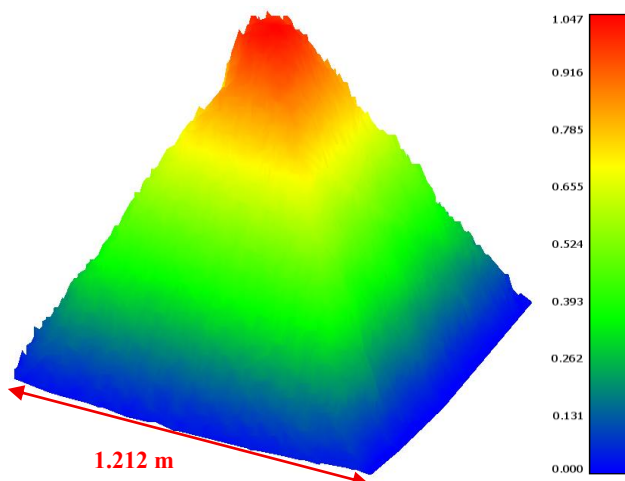


Figure 9. The 3D mesh of the pyramid

Table 2. Accuracy of dimensions and volume of the pyramid

Obs.	Length		Volume	
	m	APE (%)	m ³	APE (%)
1	1.229	1.40	0.509198	1.88
2	1.212	0.00	0.509385	1.84
3	1.197	1.24	0.509352	1.85
4	1.194	1.49	0.508479	2.02
5	1.202	0.83	0.509474	1.83

3.3.2 Triangulation Prism Stockpile: The 3D mesh of the triangulation prism stockpile generated using the first observation data is presented in Figure 10. The accuracy of the dimensions and volume of the triangulation prism at each observation is included in Table 3. According to the measurement of dimensions, the accuracy of the triangulation prism stockpile can be quantified as MAE 0.014 m and RMSE 0.016 m. Further, the accuracy of volume estimation can be quantified as MAE 0.005651 m³ and RMSE 0.005894 m³.

Table 3. Accuracy of dimensions and volume of the tri-prism

Obs.	Length		Volume	
	m	APE (%)	m ³	APE (%)
1	1.242	0.16	0.956499	0.72
2	1.259	1.21	0.958512	0.51
3	1.267	1.85	0.960082	0.35

4	1.264	1.61	0.958557	0.51
5	1.256	0.96	0.955349	0.84

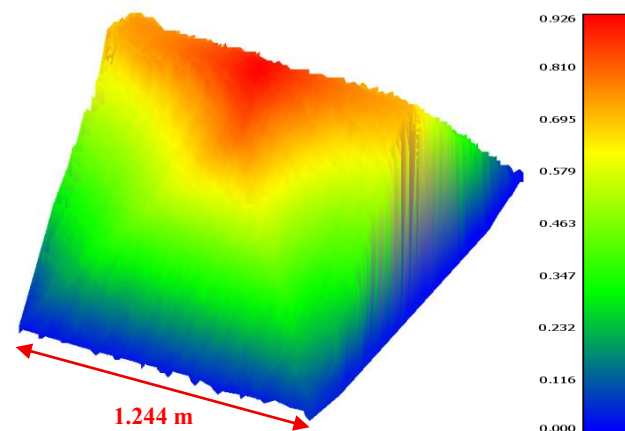


Figure 10. The 3D mesh of the triangular prism

3.3.3 Cone Stockpile: The 3D mesh of the cone stockpile generated using the first observation data is presented in Figure 11. The accuracy of the dimensions and volume of the cone at each observation is included in Table 4. According to the measurement of dimensions, the accuracy of the cone stockpile can be quantified as MAE 0.006 m and RMSE 0.007 m. Further, the accuracy of volume estimation can be quantified as MAE 0.000895 m³ and RMSE 0.000990 m³.

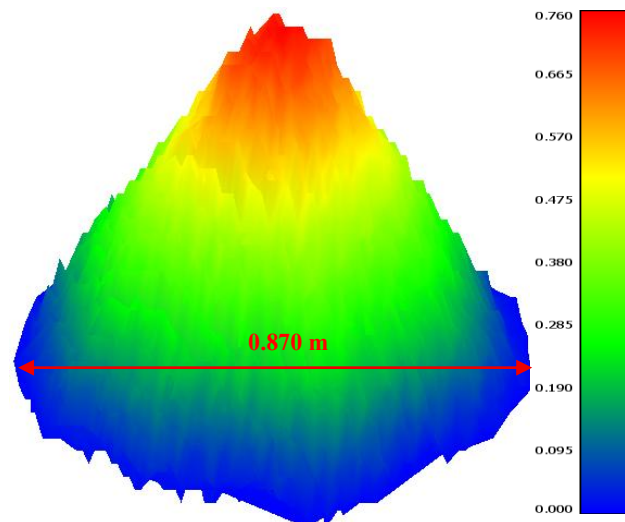


Figure 11. The 3D mesh of the cone

Table 4. Accuracy of dimensions and volume of the cone

Obs.	Length		Volume	
	m	APE (%)	m ³	APE (%)
1	0.884	1.61	0.159880	0.19
2	0.869	0.11	0.160907	0.45
3	0.864	0.69	0.161779	0.99
4	0.874	0.46	0.161245	0.66
5	0.875	0.57	0.159387	0.50

3.3.4 Cube Stockpile: The 3D mesh of the cube stockpile generated using the first observation data is presented in Figure 12. The accuracy of the dimensions and volume of the cube at each observation is included in Table 5. According to the measurement of dimensions, the accuracy of the cube stockpile can be quantified as MAE 0.008 m and RMSE 0.008 m. Further, the accuracy of volume estimation can be quantified as MAE 0.017759 m³ and RMSE 0.018026 m³.

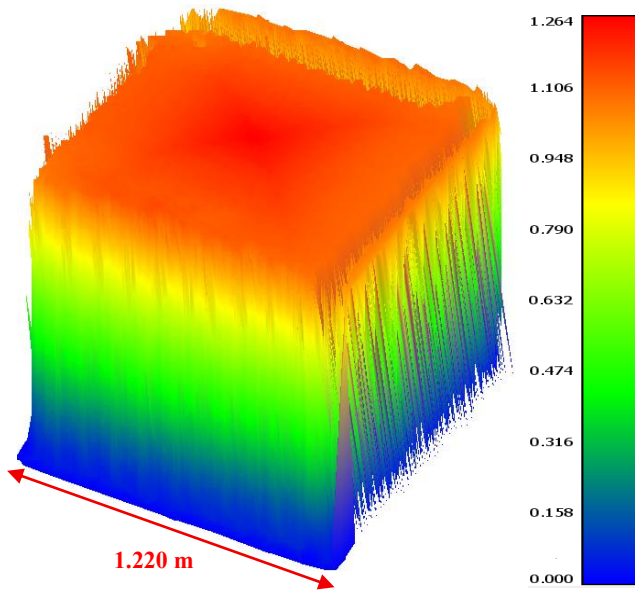


Figure 12. The 3D mesh of the cube

Table 5. Accuracy of dimensions and volume of the cube

Obs.	Length		Volume	
	m	APE (%)	m ³	APE (%)
1	1.228	0.66	1.801251	0.80
2	1.226	0.49	1.801065	0.81
3	1.230	0.82	1.793286	1.24
4	1.228	0.66	1.799019	0.93
5	1.229	0.74	1.795826	1.10

3.3.5 Cylinder Stockpile: The 3D mesh of the cylinder stockpile generated using the first observation data is presented in Figure 13. The accuracy of the dimensions and volume of the cylinder at each observation is included in Table 6. According to the measurement of dimensions, the accuracy of the cylinder can be quantified as MAE 0.008 m and RMSE 0.008 m. Further, the accuracy of volume estimation can be quantified as MAE 0.003624 m³ and RMSE 0.003928 m³.

Table 6. Accuracy of dimensions and volume of the cylinder

Obs.	Length		Volume	
	m	APE (%)	m ³	APE (%)
1	0.782	1.56	0.424327	0.85
2	0.766	0.52	0.422842	1.19
3	0.760	1.30	0.428744	0.19
4	0.764	0.78	0.424097	0.90
5	0.778	1.04	0.423191	1.11

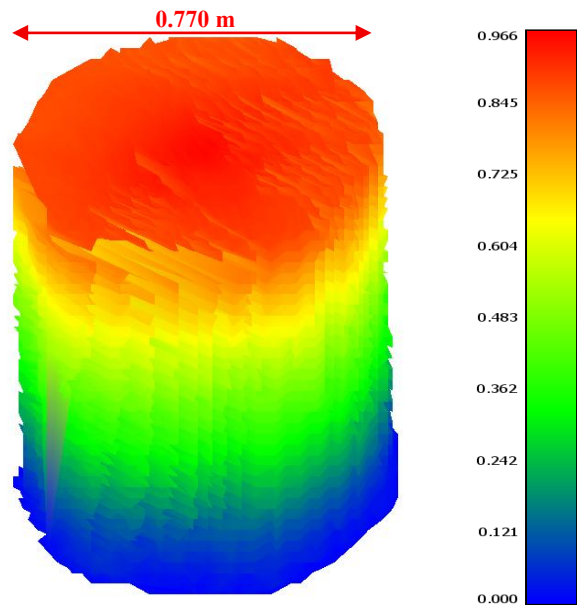


Figure 13. The 3D mesh of the cylinder

3.3.6 Sand Stockpile: The 3D mesh of the sand stockpile generated using the first observation data is presented in Figure 14. The accuracy of the dimensions and volume of the sand stockpile at each observation is included in Table 7. APE for dimension and volume was calculated using Equation 1. According to the measurement of dimensions, the accuracy of the sand stockpile can be quantified as MAE 0.004 m and RMSE 0.199 m. Further, the accuracy of volume estimation can be quantified as MAE 0.012255 m³ and RMSE 0.012294 m³.

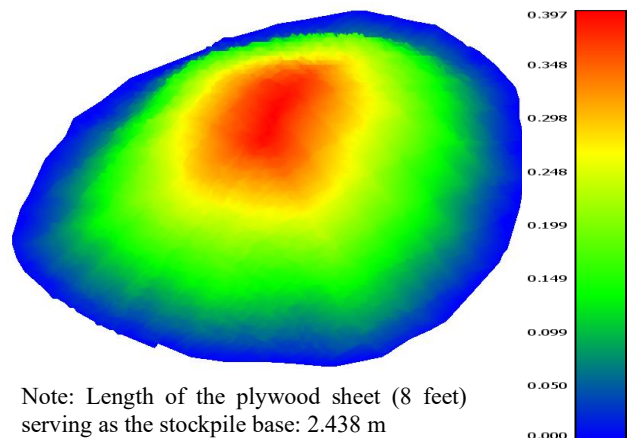


Figure 14. The 3D mesh of the sand stockpile

Table 7. Accuracy of dimensions and volume of sand stockpile

Obs.	Length		Volume	
	m	APE (%)	m ³	APE (%)
1	2.440	0.08	0.262547	4.58
2	2.437	0.04	0.262863	4.47
3	2.441	0.12	0.262123	4.74
4	2.448	0.41	0.264781	3.77
5	2.436	0.08	0.262196	4.71

3.4 Applicability of Global Positional Accuracy for SVE

The five CPs placed in the study area were surveyed using Topcon HiPer HR GNSS receivers with local base RTK mode. The GNSS coordinates of CPs are presented in Table 8. Then, the coordinates for CPs were derived from the point cloud obtained during the first iPhone LiDAR observation and are presented in Table 9. Finally, the coordinate differences of the CPs between GNSS and the iPhone LiDAR point cloud are presented in Table 10.

Table 8. GNSS coordinates of CPs

CP No	WGS 1984 UTM Zone 48N		
	X (m)	Y (m)	Z (m)
1	348933.799	172068.713	25.722
2	348950.347	172072.392	26.372
3	348953.373	172060.231	26.311
4	348938.859	172055.450	25.791
5	348942.889	172063.692	26.024

Table 9. Coordinates of CPs derived from LiDAR point cloud

CP No	WGS 1984 UTM Zone 48N		
	X (m)	Y (m)	Z (m)
1	348934.500	172069.422	17.060
2	348950.563	172074.547	17.659
3	348954.375	172062.188	17.684
4	348939.875	172056.844	17.261
5	348943.625	172065.266	17.395

Table 10. Coordinate difference of CPs

CP No	dX (m)	dY (m)	dZ (m)
1	-0.701	-0.709	8.662
2	-0.216	-2.155	8.713
3	-1.002	-1.957	8.627
4	-1.016	-1.394	8.530
5	-0.736	-1.574	8.629

4. Discussion

In this study, the capability of iPhone LiDAR for estimating the volume of both regular and irregular stockpiles was assessed. Accordingly, iPhone LiDAR data were collected to estimate the volume of five regular stockpiles and one irregularly shaped stockpile. In Figure 15, iPhone LiDAR-based SVE is compared with the ground truth volume. The fitted line appeared blue, nearly overlapping with the 1:1 line, which appeared in red. According to this figure, the results clearly show a strong correlation between iPhone LiDAR-based SVE and ground truth.

APE of each stockpile is compared in Figure 16, while MAPE, MAE, and RMSE of iPhone LiDAR-based SVE are presented in Table 11. Based on this figure and table, it can be concluded that MAPE for all regular-shaped stockpiles is less than 2%, whereas the MAPE for irregular-shaped stockpiles is around 4.5%. These results show that iPhone LiDAR can be used to quantify the volume of regular and irregular stockpiles with acceptable

accuracy. However, analysis of checkpoint coordinates clearly shows that the positional accuracy of the obtained LiDAR point clouds using the iPhone is lower. Despite the lower positional accuracy of the iPhone LiDAR data, the results demonstrate that volume estimation derived from these data remains accurate. Therefore, it can be concluded that positional accuracy is not significant for stockpile volume calculation.

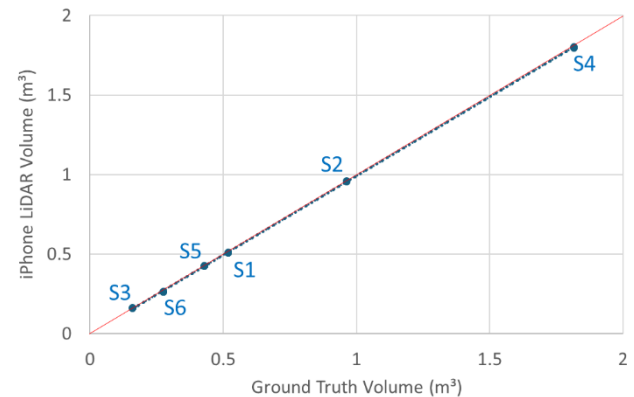


Figure 15. Volume comparison: iPhone LiDAR vs. ground truth

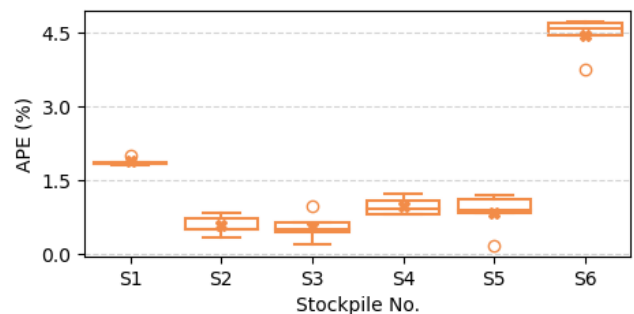


Figure 16. Comparison of the APE of each stockpile

Table 11. MAPE, MAE, and RMSE of each stockpile

No.	Stockpile	MAPE	MAE (m³)	RMSE (m³)
Regular-shaped stockpile				
S1	Pyramid	1.88 %	0.009779	0.009786
S2	Tri-Prism	0.59 %	0.005651	0.005894
S3	Cone	0.56 %	0.000895	0.000990
S4	Cube	0.98 %	0.017759	0.018026
S5	Cylinder	0.85 %	0.003624	0.003928
Irregular-shaped stockpile				
S6	Sand	4.45 %	0.012255	0.012294

5. Conclusion

Accurate SVE is essential in various fields, including construction, mining, quarrying, agriculture, energy, and waste management. Although conventional methods are applied in these industries for SVE, those methods are often tedious, labor-intensive, and time-consuming, especially for irregular piles and large coverage areas, and they can pose significant safety risks. Therefore, the iPhone LiDAR method has emerged as an alternative method to mitigate the limitations of conventional methods.

This study was conducted to assess the capabilities of iPhone LiDAR to estimate the volume of both regular and irregular stockpiles. Accordingly, five regular-shaped physical models were prepared and used with one irregularly shaped sand stockpile for this study. Based on the obtained results, it can be concluded that iPhone LiDAR can be used to estimate the volume of both irregularly and regularly shaped stockpiles with acceptable accuracy. Further, it can be concluded that volume estimation depends on relative or local accuracy and scale, not on global positional accuracy.

Nevertheless, this study was conducted under several limitations. This study does not consider underground stockpiles, which are maintained inside a confined environment. Even though stockpiles in industries present a wide variety of regular and irregular shapes, only five regular shapes, including pyramid, triangular prism, cone, cube, and cylinder, as well as one irregular shape, were considered in this study. In the future, additional analyses with georeferenced point clouds can further evaluate potential accuracy gains. In addition, the capability of iPhone LiDAR for SVE can further be tested for actual regular and irregular stockpiles.

Competing Interests

The authors declare that they have no conflict of interest.

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