Comparison of iPhone 13 Pro's Camera and LiDAR Sensor to UAS Photogrammetric Model of the Great Pyramid of Giza

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ABSTRACT:

Digital documentation of historical sites has always required the use of expensive professional grade sensors capable of collecting large amounts of data to reconstruct cultural sites. These types of projects generally require large budgets and a large team of specialists to successfully generate a digital model. However, with smart devices having sensors capable of mapping on the go, the potential for mapping such historical sites may be more accessible. This study aims to conduct a comprehensive comparison between the iPhone 13 Pro and the Unmanned Aerial Systems (UAS) photogrammetric model of the Great Pyramid of Giza, otherwise known as the Khufu pyramid, located in Giza, Egypt. The purpose of this study is to evaluate the potential of the iPhone 13 Pro's Camera and LiDAR sensor capabilities as a valuable tool for documenting and preserving cultural heritage sites. To accomplish this, data was captured from multiple positions around the pyramid using the Pix4Dcatch app on the iPhone 13 Pro, and the data was processed using Pix4Dmatic to generate a 3D point cloud of the pyramid. This point cloud data is then compared to the reference data obtained through the UAS mapping which generated a 3D photogrammetric model. The comparison aims to identify the strengths and weaknesses of using the iPhone 13 Pro for this type of scanning and to assess the accuracy and precision of the generated data.

1. INTRODUCTION

Preserving world heritage sites is a crucial endeavor in safeguarding our shared human history and cultural legacy. Digitizing these historical sites has become an essential approach to ensuring their conservation and accessibility for future generations. Surveying and geospatial technology play a vital role in this digitization process by providing accurate data and detailed models that capture the intricacies of these sites. One of the most iconic and awe-inspiring structures in the world: The Great Pyramid of Giza, also known as the Khufu Pyramid. Located in Giza, Egypt, which holds immense historical and cultural significance. The pyramid is believed to have been completed around 2560 BCE, making it over 4,500 years old. The choice of the Great Pyramid of Giza as our site of study is its massive scale and precise construction which poses intriguing challenges and opportunities for surveying and geospatial technology to capture its details accurately.

In 2004, a study conducted by Vienna Institute for Archaeological Science (Neubauer et al., 2005) aimed to use advanced terrestrial laser scanners and a calibrated digital camera for high-precision, long-distance topographic scanning in archaeology. The project focused on the Khufu Pyramid and the Sphinx. The collected data were used to create detailed three-dimensional models of the monuments and served as a primary database for their preservation. The hybrid sensor system, combining a high-performance laser scanner and a high-resolution camera, allowed for automatic generation of textured 3D models. The project had three main objectives: collecting topographic data of the Giza plateau, documenting the Khufu Pyramid, and documenting the Sphinx. The data collected were an extension to the Giza Plateau Mapping Project and were intended to be shared with the scientific community.

(Nell et al., 2014) used a Total Station in December 2006 to determine the orientations of the sides of the Giza pyramids and associated structures. The survey focused on measuring points along straight and well-preserved structural segments to accurately estimate their orientation. Instead of relying on simple triangulation, best-fit techniques were employed to provide the most precise estimation. The primary objective of the survey was to clarify the fundamental data regarding the orientation of the pyramids and their associated structures.

The advent of smart devices, such as cellphones equipped with advanced sensors, has revolutionized the field of mapping and preservation of historical sites. These devices, like the iPhone 13 Pro, come with a multitude of sensors, including high-resolution cameras, LiDAR sensors, and GNSS receivers, making them powerful tools for data collection and mapping. One of the significant advantages of utilizing smart devices for mapping historical sites is their widespread accessibility. Nowadays, nearly everyone possesses a smart device, which means that anyone can contribute to the preservation of historical sites by capturing data in a digital format. This crowdsourcing of data collection allows for a more comprehensive and inclusive approach to documenting and preserving our cultural heritage.

(Musicco et al., 2023) explored the use of smartphones in comparison to other digital survey techniques like Terrestrial Laser Scanners and SLR camera photogrammetry. The study focuses on the sepulchral monument of the Pascopepe Lambertini family in the Crypt of Santa Maria della Scala, Trani Cathedral, Italy. The point clouds generated from smartphones are compared based on fitting, density, profiling, and texture quality. The results show that smartphone-based photogrammetry offers a portable and inexpensive alternative for heritage documentation, maintaining acceptable accuracy standards.

However, it is essential to acknowledge that while smart devices provide convenient means for data capture, it is still crucial to adhere to proper methods and techniques to ensure the accuracy and integrity of the collected data. Deploying appropriate surveying practices, utilizing reliable software applications, and adhering to established standards are essential steps in maintaining the quality of the data captured using smart devices.

(Tavani et al. 2022) discusses the digital transition in geological fieldwork, particularly the use of smartphones and tablets equipped with advanced sensors for data acquisition. The focus is on the introduction of the LiDAR scanner in the iPhone 12 Pro and its potential to revolutionize geological fieldwork. The study reviews progress in smartphone/tablet-assisted fieldwork, evaluates the accuracy of the iPhone's GPS receiver and orientation sensors, assesses its imaging capabilities, and tests the performance of the LiDAR scanner in the field. The results demonstrate that smartphones, including the iPhone 12 Pro, can effectively replace traditional geological field tools, offering high-performance data capture and enabling efficient digital documentation of geological features. The study highlights the mature state of the digital transition in geological fieldwork and the increasing importance of smartphones as essential fieldwork devices.

By deploying smart devices for mapping and data collection, we harness the accessibility and capabilities of these devices to engage a wider community in preserving historical sites. However, it is crucial to balance this accessibility with the responsible application of proper data collection methods and rigorous accuracy assessments. This approach ensures that the integrity of the data is maintained, allowing for the accurate preservation and documentation of our invaluable cultural heritage in a digital format.

A similar study conducted on an Egyptian Temple of Taffeh in the Rijksmuseum van Oudheden done by (Voûte et al. 2023) used low-cost equipment and comparing two different techniques for reliability and precision. The methods employed are photogrammetry with a digital mirrorless camera and the use of an iPhone with LiDAR capability. A more advanced mobile laser scanner was also utilized for comparison. The results show promising potential for the method in Egypt, with the photogrammetry model being the most accurate, providing sub-centimeter details, while the iPhone LiDAR model, although less accurate, has a much shorter range than conventional mapping systems, and with lower point density, offered faster results. The research emphasizes the importance of low-cost methods in capturing cultural heritage and optimizing the balance between cost and accuracy. Challenges in digital heritage capture are acknowledged, but the technology shows promise in terms of hardware and software advancements.

One of the major challenges encountered during the research was the difficulty in finding reliable reference data to support the study. This issue is a common problem encountered in heritage sites, particularly when investigating ancient structures like the Giza pyramids. The lack of comprehensive and accurate historical records, combined with the absence of precise measurements or architectural plans, posed significant obstacles in determining the orientations of the pyramids and associated structures. The reliance on limited available data required meticulous analysis and the utilization of best-fit techniques to estimate orientations based on measured points. The scarcity of reliable reference data highlights the importance of conducting thorough field surveys and employing advanced measurement techniques to gather as much precise information as possible for accurate analysis and interpretation of heritage sites.

2. METHODS

2.1 Equipment and Setup

2.1.1 iPhone 13 Pro

The iPhone 13 Pro serves as our mapping system for data collection on the pyramid. Equipped with a built-in 12-megapixel camera and a LiDAR sensor, the iPhone 13 Pro offers valuable capabilities for capturing visual and depth information. Although the iPhone 13 Pro's built-in GNSS receiver collects single frequency L1 band, it operates with an accuracy level of about 3-5 meters. This accuracy level is considered relatively low for precise mapping purposes.

However, the iPhone 13 Pro leverages its built-in Inertial Measurement Unit (IMU) and utilizes Simultaneous Localization and Mapping (SLAM) techniques to estimate trajectory errors. By combining data from the IMU with the visual and depth information captured by the camera and LiDAR sensor, the iPhone 13 Pro can estimate its trajectory and improve the precision of the collected data. Figure 1 shows the iPhone 13 Pro in relation to the Khufu Pyramid while scanning one of the sides.

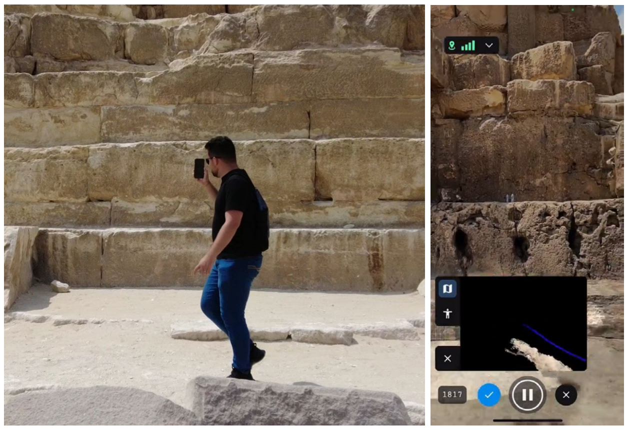

Figure 1. (left) scanning of the Great Pyrmid of Giza (right) live view of the data collection on iPhone 13 Pro

2.1.2 Reference Data

In March of 2023, Arqueomodel3D, a specialized Spanish company focusing on the preservation of world heritage sites, conducted an aerial flight of the pyramids in Giza, Egypt. Employing a UAS, they acquired imagery of the pyramids and subsequently processed it to generate a comprehensive 3D model. Arqueomodel3D's expertise in the field of heritage preservation ensured the accuracy and quality of the acquired data.

It is important to acknowledge certain limitations in our understanding of the specifics of Arqueomodel3D's data acquisition process. We do not have detailed information regarding the specific type of drone used or the precise quality of the acquired data. The georeferencing in this local mapping frame of the data remains unknown to us. But within the 3D model, we can rely on the relative distances observed and captured within the model. It provides a detailed representation of the pyramids' architecture and structural elements, offering a comprehensive view of the pyramids from an aerial perspective. This documentation allows for comparative assessments and provides a broader context for evaluating the data acquired using the iPhone 13 Pro. Figure 2 shows the overall data set of the entire complex.

Figure 2. Giza Pyramids complex data collected from a UAS (Arqueomodel3D)

Obtaining a high-resolution data set of the pyramids can be a challenging task due to the strict regulations imposed by the Egyptian authorities. Egypt has implemented stringent rules regarding commercial activities around the pyramids, prioritizing their security and preservation. These regulations prohibit the use of drones, surveying equipment, or any activities that may pose a threat to the pyramids' security and integrity. This restrictive environment makes the utilization of smart devices like the iPhone 13 Pro an excellent method for data collection. Since smartphones are widely accepted as personal devices, they are less likely to be perceived as posing security concerns around the pyramids. This allows for discreet and non-intrusive data capture without violating the established regulations.

By incorporating Arqueomodel3D's reference data into our analysis, we gain the advantage of leveraging their expertise and reliable benchmark for assessing the accuracy and precision of the data generated through alternative data collection methods. Although we may lack specific information regarding the drone type, data quality, and projection, the relative distances within the model remain valuable for our comparative evaluation.

2.2 Methodology

2.2.1 Data Acquisition and Processing

For data acquisition, we utilized the Pix4Dcatch app on the iPhone 13 Pro, which effectively integrates all the sensors in harmony to acquire comprehensive data. In our study, we conducted three separate data sets, each capturing one of the assessable sides of the Khufu pyramid. By covering multiple sides, we aimed to capture a more complete representation of the pyramid. It is important to note that due to logistical constraints and limited access permissions, the scanning efforts were limited to three sides of the Khufu pyramid. Unfortunately, we were unable to capture data for the other two great pyramids in the complex, the Khafre pyramid, and the Menkaure pyramid. Figure 3 shows the trajectories of the data collected around the Khufu Pyramid.

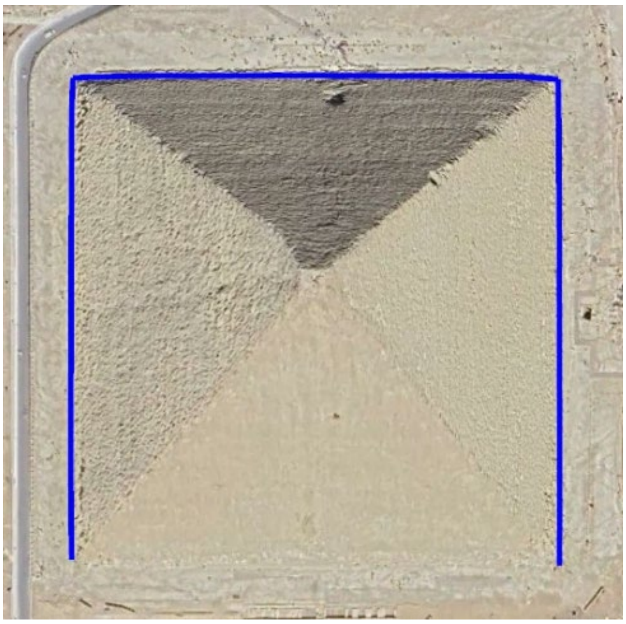

Figure 3. The trajectory of the iPhone during the 3 scans around the Khufu Pyramid, starting in the southeast corner to the southwest corner.

Afterwards, we brought all three scans into Pix4Dmatic for the fusion of photogrammetric image processing with the LiDAR data collected. Pix4Dmatic leverages advanced algorithms to align and stitch together the captured images and LiDAR data. The software combines precisely the visual and depth information to reconstruct the geometry and texture of the pyramid. By fusing these data sources, we can achieve a more robust and comprehensive representation of the pyramid in the resulting 3D model.

2.2.2 Analyzing the Data

We start by estimating the ground sampling distance (GSD) of the iPhone 13 Pro. The GSD refers to the distance on the ground that each pixel in the imagery represents. To calculate the GSD, we used the formula:

$$GSD = \frac{h \times SW}{f \times IMW} \quad (1)$$

where h is the distance from the terrain or object, SW is the sensor width, f is the focal point, and IMW is the image width in pixels.

By determining the GSD, we were able to assess the level of detail captured by the iPhone. This assessment provided valuable information about the resolution and clarity of the imagery obtained from the iPhone 13 Pro in comparison to the average GSD obtained from a UAS flighting tens or hundreds of meters in the air, contributing to a comprehensive understanding of their performance in capturing fine details of the historical site.

We further assessed the alignment between the UAS data and the iPhone 13 Pro data. By visually overlaying the two datasets, we assessed the accuracy of the SLAM trajectories estimated by the iPhone 13 Pro and identified any potential alignment discrepancies. This evaluation provided valuable insights into the consistency and reliability of the iPhone 13 Pro's trajectory estimation techniques, enabling us to ascertain the precision of its spatial positioning relative to the UAS data set.

Finding the volume of the pyramid is a crucial aspect in assessing the accuracy of the iPhone as it provides a measure of the pyramid's spatial extent and geometric properties. It allows us to validate the iPhone's sensor and evaluate its ability to capture intricate details and accurately represent the monument. To estimate the volume of the pyramid, we used the three sides that were scanned using the iPhone 13 Pro. Utilizing these sides, we calculated the volume by using the formula for finding the volume of a pyramid with four different sides. To estimate the fourth side, we interpolated between the generated points along the three sides. This interpolation allowed us to approximate the measurements of the missing side, thus completing the pyramid for volume calculations. Using the photogrammetric model from the iPhone's dataset, we can accurately locate the top of the pyramid. Combining this information with the change in elevation from the surrounding terrain, we can measure the height of the pyramid. The formula is as follows:

$$V = \frac{h}{3}\left(\frac{a+c}{2} \times \frac{b+d}{2}\right) \quad (2)$$

where, h represents the height of the pyramid, while $a, b,$ and c denote the lengths of the three known sides, and d is the interpolated fourth side. By substituting these values into the formula and assuming all sloping from the top of the pyramid to the ground is ideal, we were able to calculate the volume of the pyramid.

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By comparing the volume calculation derived from the iPhone 13 Pro data with the corresponding volume data from the UAS dataset, we tested the reliability of the iPhone 13 Pro's measurements. Figure 4 shows the 3D reconstructed model of the UAS data set, and Figure 5 shows the 3D reconstructed model of the iPhone 13 Pro's data set.

Figure 4. UAS data of the Great Pyramid of Giza

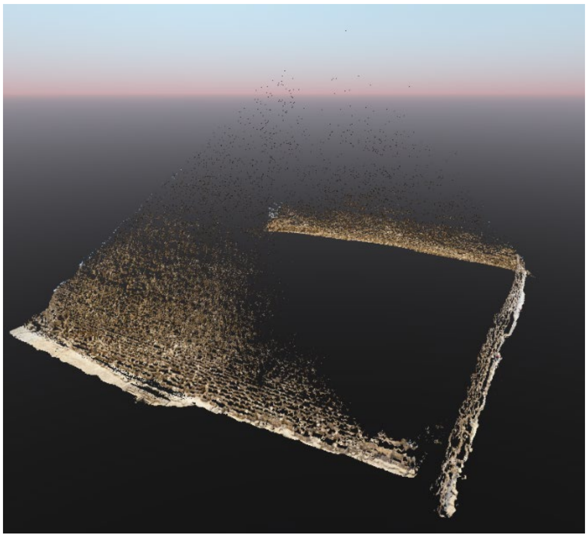

Figure 5. iPhone data of the Great Pyramid of Giza

A relative accuracy test was conducted to evaluate the iPhone 13 Pro's ability to maintain the relative distances between different sides of the pyramid. We calculated the Euclidean distance between corresponding points on each side in both the UAS and iPhone 13 Pro datasets. By comparing the distances, we assessed the accuracy of the iPhone 13 Pro in reconstructing the relative distance relationships. The formula is as follows:

$$\begin{aligned} &relative\ error \\ &= \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \\ &- \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2} \end{aligned} \quad (3)$$

where x_1, y_1, z_1 and x_2, y_2, z_2 are the coordinate pairs between two points on the UAS dataset, and a_1, b, c_1 and a_2, b_2, c_2 are the coordinate pairs between two points on the iPhone dataset.

Through these comprehensive comparisons and assessments, we aimed to understand the strengths, limitations, and overall performance of the iPhone 13 Pro in reference to UAS data. Our analyses focused on the level of detail, alignment, volume calculations, and relative accuracy, providing valuable insights into the quality and reliability of the data captured by the iPhone 13 Pro for documenting and reconstructing this historical site.

3. RESULTS

3.1 Ground Sampling Distance Comparison

To assess the GSD of the UAS data, it is important to note that we do not have specific specifications for the UAS used in this study. However, based on conservative estimations, if the UAS is flying at 200 meters AGL to clear the top of the pyramid, the GSD for the UAS data could range between 5 and 12 cm/pixel. This estimation considers the typical range of GSD values observed in UAS-based mapping applications at higher altitudes.

For the iPhone 13 Pro data, we determined the average distance from the pyramid to be approximately 3 meters. Leveraging the sensor and image dimensions provided by Apple's website, we calculated that the average GSD for the iPhone 13 Pro data is approximately 0.3 cm/pixel. This demonstrates a significant advantage of using a smartphone mapping system, as it provides a high level of resolution for the captured data. Although a UAS can fly lower altitudes to increase the GSD, the efficiency of collecting data becomes a concern as it will take a lot longer to fly the same mission. To maintain the same GSD with varying heights, such as the slopes of the pyramid, an experienced pilot will need to fly manually to position the UAS at different altitudes to maintain the same GSD. This would be a logistical nightmare, especially in a high security historical site, like the Pyramids of Giza, hence the use of smartphone mapping is much more variable.

Figure 6 showcases the level of detail that can be observed with the images captured by the UAS. In comparison, Figure 7 showcases an image captured by the iPhone 13 Pro in the same area on the Khufu Pyramid. The higher GSD of the UAS data can be discerned in the figure, highlighting the superior resolution offered by the iPhone 13 Pro for capturing fine details.

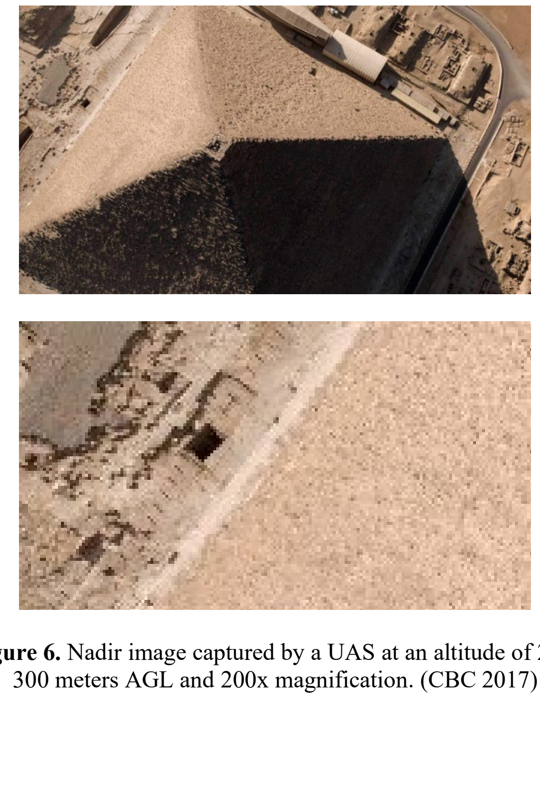

Figure 6. Nadir image captured by a UAS at an altitude of 200-300 meters AGL and 200x magnification. (CBC 2017)

Figure 7. Image captured from the iPhone 13 Pro with 0.3 cm/pixel GSD and 200x magnification.

3.2 Alignment to Reference Data

The trajectory data of the iPhone plays a crucial role in ensuring accurate alignment and registration of the three scans conducted. However, during our analysis, it became apparent that the trajectory data of each individual scan had inherent errors, resulting in a relative misalignment between the three datasets. During the scan itself, the iPhone would use SLAM to correct the trajectories seamlessly, but with three different scans, they each had their own trajectory errors, making it challenging to achieve a seamless alignment. Even after processing the data, we observed a misalignment in the vertical dimension between the three scans. This misalignment compromises the overall relative accuracy of the data, as the scans are not correctly aligned. This is due to the heavy reliance on SLAM and having lower accuracy GNSS observation. The scanned area commonly looks similar, making it harder to estimate the correct trajectories. Therefore, manual alignment becomes necessary to accurately assess the collected data and ensure its reliability. Figure 8 shows the misalignment between the point clouds.

To achieve proper alignment, we needed to identify common features between different sides of the pyramid. By meticulously identifying these shared features and correlating them, we can superimpose the positions of the data and align the scans correctly. Manual alignment allows us to rectify the misalignments caused by the trajectory errors and ensure accurate registration of the data.

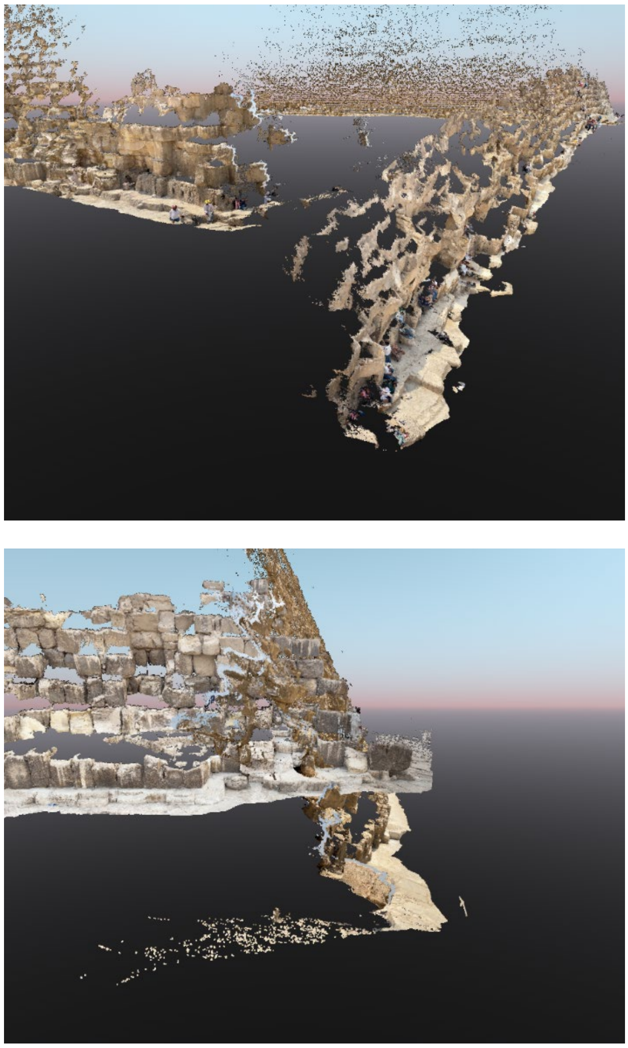

Figure 8. The two connecting corners between the three scans.

3.3 Volume Calculations

The volume calculations performed using the iPhone data set involved several approaches, starting with referencing the volume calculations derived from the UAS data set as a baseline. Subsequently, we explored different methods to calculate the volume based on the iPhone data set.

The first approach involved employing mathematical calculations of an ideal pyramid geometry model using the formula mentioned earlier, considering the measured dimensions, and interpolating the missing side. This method allowed us to estimate the volume directly from the geometric measurements obtained from the iPhone data set. Figure 9 shows the reconstructed model of the Khufu Pyramid from the iPhone data. We found the volume of the Great Pyramid of Giza to be 2.258 million cubic meters using this method.

The interpolated side of the pyramid appears relatively planar compared to the other sides that were directly scanned using the iPhone 13 Pro. This can be attributed to the difference in data density and the resulting triangulation. The Triangulated Irregular Network (TIN) lines on the interpolated side connect vertices that are relatively far apart from each other compared to the sides that were directly scanned. As a result, the longer TIN lines on the interpolated side may exhibit less precision and smoothness in representing the surface geometry. The availability of more data points on the directly scanned sides allows for shorter TIN lines, resulting in a more accurate representation of the intricate details and surface variations.

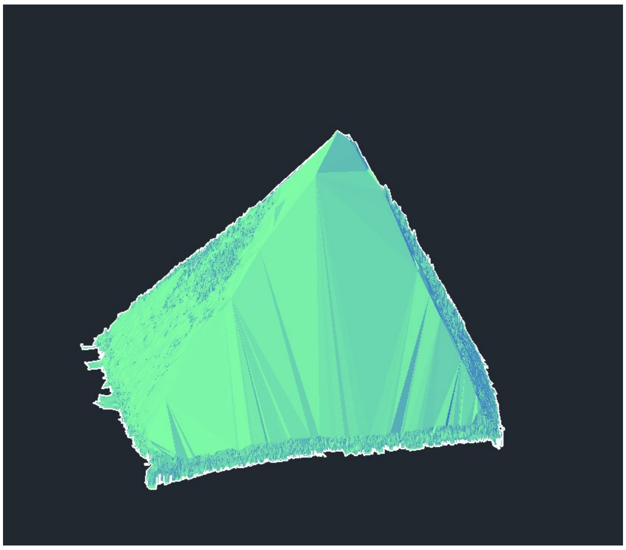

Figure 9. 3D reconstruction of the Khufu Pyramid just from the data collected on the iPhone 13 Pro.

In addition to the mathematical calculations, we utilized Pix4Dsurvey's algorithm to calculate the volume. By leveraging the capabilities of Pix4Dsurvey, we obtained a comprehensive volume analysis based on its proprietary algorithms and workflows. This provided an alternative method to estimate the volume from the iPhone data set, enhancing the reliability of our results. Pix4DSurvey estimated the volume to be 2.377 million cubic meters.

Furthermore, the surface generated from the iPhone data set was exported from Pix4Dsurvey and imported into AutoCAD Civil 3D, where a detailed volume analysis was conducted. AutoCAD Civil 3D provided additional tools and functionalities to accurately assess the volume based on the surface data generated from the iPhone scans. Civil 3D found the volume to be 2.323 million cubic meters.

The estimated volume obtained from the reference UAS data was approximately 2.592 million cubic meters. This result also matches many other estimations of the Great Pyramid of Giza. The geometry model calculation had a difference of 334,000 cubic meters, a 13% difference. The Pix4Dsurvey surface volume calculation algorithm had a difference of 214,000 cubic meters, a 8% difference. And the Civil 3D surface volume calculation algorithm had a difference of 268,000 cubic meters, a 10% difference. The three methods employed in volume calculation for the iPhone data set consistently yielded results in the range of 2.2 to 2.4 million cubic meters, giving variation of 8-13%. This indicates that our volume calculations utilizing the iPhone 13 Pro data were fairly accurate for a device of this nature and provided a reliable assessment of the pyramid's volume. Figure 10 shows a representation of the volume calculations from each of the methods.

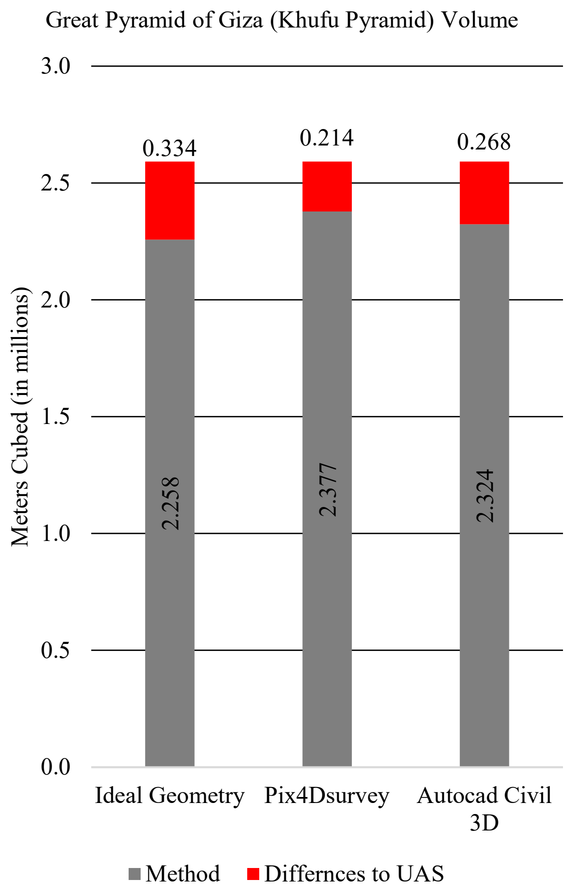

Figure 10. Volume calculations based on various methods.

3.4 Accuracy Assessment

The relative accuracy assessment between the iPhone 13 Pro's data set and the reference UAS data set involved taking measurements along each of the four corners of the pyramid, as well as the slope distance from each corner to the top of the pyramid. These measurements served as reference values for evaluating the accuracy of the iPhone 13 Pro's data. Figure 11 shows the locations of each of the points on the pyramid.

Figure 11. Positions of points used for the relative accuracy assessment.

During the assessment, we observed differences in measurements ranging from 15 to 25 meters between the iPhone 13 Pro and the UAS data sets. These variations can be attributed to the inherent drifting of the iPhone's SLAM trajectories over longer distances. While the iPhone 13 Pro excels in maintaining relative accuracy within shorter distances, it encounters challenges in accurately estimating trajectories for longer mapping distances. The difference between these differences can be seen in Table 1 and Figure 12.

The difficulties in maintaining relative accuracy with longer distances can have implications for the accuracy of the mapping results. One possible reason for this is the scale or range of the measurements. The iPhone 13 Pro's trajectory estimation may be less precise over longer distances, leading to errors in the spatial positioning of the scanned data. These errors can result in a significant variation in the volume calculations. In this case, the volume calculations derived from the iPhone 13 Pro data tend to underestimate the true value of the pyramid's volume. The limitations in accurately estimating the trajectories over longer distances can introduce discrepancies in the mapping results, highlighting the importance of carefully considering the scale and range of measurements when utilizing the iPhone 13 Pro or similar devices for mapping purposes.

Points	UAS (m)	iPhone (m)	Δ (m)
1-2	230.5	209.6	-20.9
2-3	230.5	212.6	-17.9
3-4	230.5	215.2	-15.3
4-2	230.5	205.8	-24.7
1-5	273.2	246.6	-26.6
2-5	273.2	249.2	-24.0
3-5	273.2	251.4	-21.8
4-5	273.2	243.4	-29.8

Table 1. Relative differences between points with the UAS and iPhone data sets.

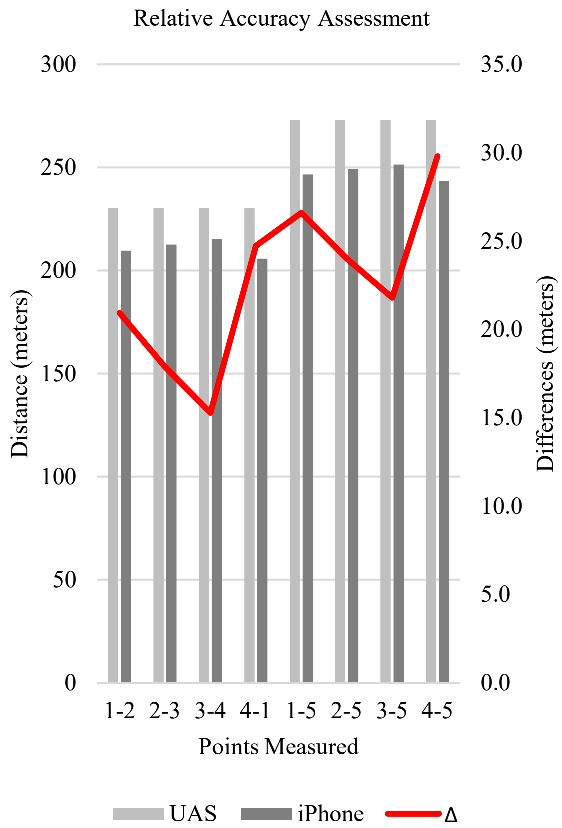

Figure 12. Differences shown between the iPhone and reference UAS data with respect to relative accuracy.

4. DISCUSSION AND CONCLUSIONS

The iPhone 13 Pro presents a promising solution for capturing high-resolution data of historical sites, offering accessibility and convenience for data collection. However, it is essential to consider the limitations of trajectory estimation and the challenges associated with maintaining relative accuracy over longer distances. Through comprehensive analysis and assessments, several key findings emerged. The iPhone 13 Pro demonstrated its potential as a mapping tool by providing a high-resolution data set, down to a GSD of approximately 0.3 cm/pixel. This highlighted the advantage of using a smartphone with sensors for capturing fine details of historical sites in short ranges. We encountered challenges in aligning the three iPhone 13 Pro scans due to trajectory estimation errors with longer ranged scans. The inherent drifting of SLAM trajectories over longer distances contributed to misalignments, particularly in the vertical dimension. Manual alignment became necessary to ensure accurate assessment of the collected data.

The volume calculations based on the iPhone 13 Pro data yielded results in the range of 15%. Although these calculations aligned well with estimates from other sources, the trajectory estimation challenges affected the overall volume accuracy, leading to an underestimation of the true value. The relative accuracy assessment between the iPhone 13 Pro's data set and the reference UAS data set revealed differences in measurements ranging from 15 to 30 meters. These variations could be attributed to the drifting trajectories and the iPhone's limitations in maintaining relative accuracy over longer distances.

One crucial improvement is the inclusion of Real-Time Kinematic (RTK) corrections to the trajectories obtained from the iPhone 13 Pro's GNSS receiver. By integrating RTK, we can significantly enhance the positioning accuracy, reducing errors and improving the overall trajectory estimation. The utilization of RTK corrections would provide more precise and consistent positioning data, mitigating the misalignment issues observed in our study. Another enhancement would involve setting up control points on-site. Establishing accurate and well-distributed control points in the vicinity of the pyramid would serve as reference points for georeferencing the collected data.

This study serves as a steppingstone towards leveraging smartphones as valuable tools for documenting and preserving historical sites. With continued research and technological advancements, smartphone mapping systems hold significant potential for crowdsourcing the documentation of cultural heritage and contributing to the preservation of our collective history.

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