AN ASSESSMENT OF POINT CLOUD DATA ACQUISITION TECHNIQUES FOR AGGREGATE STOCKPILES AND VOLUMETRIC SURVEYS

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ABSTRACT:

Stockpiling aggregate materials is a common practice within the construction industry and with the demand for aggregates rapidly increasing, stockpile owners have taken a greater interest in the effective determination of volumes of inventory to optimize profit and limit waste. Historically, traditional stockpile measurement techniques were inaccurate but with the increase in demand, a higher quality and more reliable assessment of resources is necessary.

The evolution of point cloud measurement and mapping technology, such as UAV and Terrestrial Laser Scanning (TLS), now means these techniques can be utilized for stockpile measurements. While some of the advantages over traditional techniques have been well documented, there is still a need to ascertain which of these methods is more applicable for volumetric surveys of different types of aggregate stockpiles.

This study involved data collection and analysis from TLS and UAV photogrammetry for volumetric surveys and comparisons with Total Station (TS) measurement of the stockpiles for sharp sand, coarse (gravel) and finer aggregates.

The research suggested that TS surveys could only be effectively utilized on sharp sand and coarse aggregates and was impractical for finer aggregates, and their results produced a general under-reporting of stockpile volumes. TLS and UAV provide non-contact collection with increased accuracy. There are differences in accuracy and appropriateness dependent on the aggregate type. It was observed that the TLS outperformed the TS approach whereas UAV demonstrated promise particularly at a lower altitude with greater overlap.

Additional recommendations are shared to potentially improve productivity and inventory maintenance for Stockpiling Operations.

1. INTRODUCTION

Stockpiling aggregate material is a common practice in the construction industry, and due to the rapid expansion in this sector, there is now a considerable demand for construction aggregates (Singh 2021). Research analysts predicted that the market is estimated to increase by 6.8% in ten years, during the period of 2021–2031 (Singh 2021). As a result, quarry operators and contractors have become increasingly interested in monitoring their aggregate inventory to ensure accountability and efficient management of the materials. Consequently, constant stockpile monitoring has become crucial for effective material management (Herron n.d.).

1.1 Background

Historically, outdated methods, such as visual estimation, tape measures, and manual counting of equipment buckets or truckloads hauled, proved to be inefficient techniques for measuring stockpile aggregate materials and resulted in revenue losses from inaccurate inventory counts (Stockpile Reports 2019). As technology advanced and surveying techniques became more sophisticated, the data gained from equipment such as Total Stations (TS), Global Positioning Systems (GPS), 3D Laser Scanners, and LIDAR sensors mounted to drones became more reliable. The cost of implementing these approaches surpassed that of the obsolete methods significantly, but they provided a higher level of confidence in terms of accuracy (Stockpile Reports 2019).

Traditional surveys typically collect three-dimensional coordinate data (x, y, z) using theodolites, total stations, or GPS. These techniques have been widely accepted for stockpile surveys due to their higher accuracy compared to older and less precise methods (Khomsin 2018). These methods rely on individuals holding poles and prisms or poles and GPS rovers to make observations and such interactions can impact elevation accuracy due to surface disturbances. Theodolite and TS surveys require a line of sight between the equipment and the surveyed points while GPS surveys necessitate clear skies and non-reflective surfaces for accurate measurements (Mantey & Aduah, 2021). Additionally, traditional surveying can be a lengthy and labour-intensive process, often in hazardous or unsafe working conditions, depending on the nature and location of the stockpile. Inaccessibility to certain areas can further compromise data quality (Mantey & Aduah, 2021). Even so, the traditional technique can serve as a non-destructive method if the total station can operate without a reflector or prism. However, this function has limitations, such as requiring the instrument to be set up within a specified range from the stockpile. Excessive light can also hinder the visibility of the laser beam, affecting the user's ability to capture accurate data (Khomsin 2018).

Modern surveying technology, such as Remote Sensing, Digital Photogrammetry, Satellite Imagery, UAV Photogrammetry, and Terrestrial Laser Scanning (TLS) devices, enables data collection without direct physical contact and in real-time. UAV photogrammetry in particular is a technique that has been investigated and used in stockpile measurements applications, as it is a less expensive and more practical alternative to conventional manned aerial photogrammetry (Colomina et al 2008). UAVs have become more affordable and eliminate the need for a take-off and landing strips, as the rotary propeller allows the UAV to take off and land vertically for missions. Images captured by a UAV can be processed automatically, and the results obtained through the automated programs are reliable and precise, however, there is always room for possible improvements. Outside of automated programs, there is also lab post-processing. Lab post-processing allows for user interaction and is often best for applications that require a high level of accuracy.

One study conducted by Al Tahir and Barran (2020) focused on comparing the use of UAV with traditional surveying techniques for obtaining volumetric measurements. The research aimed to evaluate the impact of UAV based surveys on cost, time, human resource and accuracy compared to the TS surveying. The accuracy of the UAV generated model was evaluated using the RMSE values. The study revealed a 9.26% difference in volumes with the UAV volume being greater. It was also found that the UAV approach was more cost and time effective. and suggested that the introduction of a TLS could have been used to generate a denser point cloud, in order to compare the results more accurately.

TLS has also gained in popularity as many surveyors prefer using it over traditional methods for stockpile surveys. This is essentially because TLS has the potential to collect a larger sample dataset in a shorter timeframe, it allows for non-contact with the material surface, and it is highly automated and extremely accurate (Berberan et al 2011). Notwithstanding that, an individual point captured by a TLS, is less accurate than a single point captured using the traditional method (D Lichti et al 2002). However, the cluster of points collected by the TLS, provides data for more precise and accurate modelling of a stockpile by the end user (Stuart et al 2007).

2. RESEARCH FOCUS

2.1 Study Objectives

The main focus of this research was to investigate to what extent point cloud data acquisition techniques are better suited for volumetric surveys of aggregate stockpile compared to traditional methods. The primary objective was to evaluate and compare different surveying techniques on fine and coarse aggregate stockpiles.

2.2 Test Sites and Materials

Figure 1 shows the locations of the two areas that were used as test sites, one was in eastern Trinidad, within the Sangre Grande region (Site 1), and the other was in central Trinidad, in the Claxton Bay area (Site 2). Both site locations selected for this study possess relatively flat terrain, unobstructed views of the sky, and minimal constraints, facilitating data capture through the three employed techniques and each site contained both fine and coarse aggregate stockpiles.

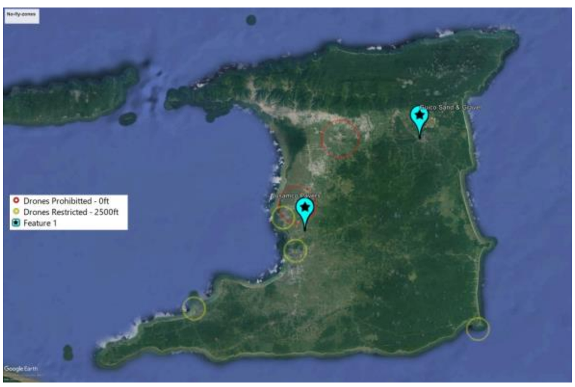

Figure 1. Test site locations in Trinidad

Two general types of aggregates were used in this assessment, fine and coarse.

Fine aggregates typically consist of smaller grain of mineral materials not exceeding 4.75mm in size, which includes all sandy material. Fine aggregate material has a poor weight bearing capacity, which makes it difficult to walk on. They are extensively employed in construction sector, serving as essential component in the production of concrete, mortar and asphalt. Red, white sand stockpiles were used as the fine aggregates in this assessment.

Coarse aggregates typically range in the diameter from 4.75mm and greater, which includes all gravel material. Some major aspects and use of coarse aggregate, include providing strength and load bearing capacity into concrete and other structure. 2 types of gravel were used for the coarse aggregate assessment. Sharp sand stockpiles were also evaluated. Sharp sand can be considered either coarse or fine depending on its consistency.

The study evaluated the effectiveness of different surveying techniques, specifically TLS and the UAV method for volumetric surveys on both fine and coarse aggregate stockpile at both locations.

3. METHODOLOGY

To collect the data for the study, GCPs were first identified and observed at each site, showing a clear line of sight between the GCPs and stockpiles. For the UAV data collection, 2 systems were used, a DJI Mavic 3 and an Autel EVO II Pro, both outfitted with 20 megapixel cameras. Four campaigns were flown at each site, varying the altitude (30m and 40m) and overlap settings (60%, 80% and 90% forward and side overlap).

TLS was carried out with a Leica Nova MS60 using a multistation approach. The equipment was set up in appropriate areas and the scans were conducted while moving around the heaps in one direction. The scans were performed in such a way that the vertical edges of the previous scan of the same heap overlapped, ensuring that no voids remained in the data after it was collected. The TLS scan were completed at a rate of 30,000 points per second.

The TS survey followed a similar approach to TLS, using the resection method for orienting the equipment each time. Poles and prisms were used to collect data for this method, and the person holding the pole would have come into direct contact with the material surfaces. During this method, the best representation of the undulation of the material surface was attempted to be captured. To represent the surface, points were taken approximately 0.5 metre apart in most cases and in some cases even closer over the entire heap, making this process very time consuming. At the first site, only two aggregate heaps out of four heaps were surveyed using this method, as walking on the two heaps containing the fine aggregate material was difficult, and the pole was sinking approximately 0.2 metres or more into the heaps when attempting to capture the data, so the heaps with the fine aggregates were not captured by the TS method. As a result, the traditional method could only be used to capture the other two heaps containing coarse aggregates.

The data collected from the TLS and TS was processed using Leica Infinity software. The TS survey points were used to create surfaces for the stockpile, while points clouds were generated for the stockpile captured via the TLS. Volumetric reports were then generated based on the surfaces.

UAV images were processed by third party using Pix 4D software. However, there were some challenges encountered during the process so data for all of the sites and combinations was not available.

4. RESULTS & ANALYSIS

4.1 Flight Parameter and Survey Time Analysis

Table 4.1 presents the Root Mean Square Error (RMSE) values obtained from the report generated by Pix4D for each flight conducted at the two specific locations. All of the processing was done using 4 Ground Control Points (GCPs). For the flight conducted at the 30m altitude, the RMSE values were fairly similar at 0.008 meters for the imagery taken with an 80% front and side overlap and a slightly higher RMSE value of 0.009 meters for the imagery taken with the 90% overlap. There was an overall increase in the RMSE values at the 40m flight altitude, with the 80% overlap imagery RMSE value increased to 0.017 meters, and the 90% overlap imagery RMSE value at 0.012 meters, indicating slightly higher accuracies for the lower altitudes with larger overlaps.

Flight Parameter	RMSE
30 m – 80% front & side overlaps	0.008 m
30 m – 90% front & side overlap	0.009 m
40 m – 80% front & side overlap	0.017 m
40 m – 90% front & side overlap	0.012 m

Table 1. Obtained RMSE Values from varying flights.

Tables 2 and 3 presents the time required for the various surveys for Site 1 (Table 2) and Site 2 (Table 3). The surveys included establishing ground control, TS surveys as well as UAV and TLS data collection and processing for the data in different surveying techniques. The same ground control was used for all of the techniques, so the time taken for the establishment of ground control was the same for all of the techniques, 1 hour and 57 minutes for Site 1 and 1 hour for Site 2. These times are therefore not included in the tables.

Techniques	Acquisition Time	Processing Time	Total Time
TS	2 hrs 5 mins	10 mins	4 hrs 12 mins
TLS	1 hr 57 mins	10 mins	4 hrs 4 mins
UAV 30m 60%	6 mins	7 mins	2 hrs 10 mins
UAV 30m 80%	11 mins	21 mins	2 hrs 29 mins

Table 2. Times taken to complete the surveys at Site 1.

Techniques	Acquisition Time	Processing Time	Total Time
TS	1 hr 50 mins	10 mins	3 hrs
TLS	1 hr 15 mins	10 mins	2 hrs 25 mins
UAV 30m 80%	8 mins	nil	nil
UAV 30m 90%	40 mins	2hrs 56 mins 37 sec	4 hrs 37 mins
UAV 40m 80%	7 mins	23 mins	1 hr 30 mins
UAV 40m 90%	17 mins	1 hr 34 mins 5 sec	2 hrs 51 mins

Table 3. Times taken to complete the surveys at Site 2.

These results show there were no significant time savings between the TLS and TS, but these times were almost cut in half using the UAV at 80% overlap for both 30m and 40m flying heights. There were no time savings for the UAV at 90% overlap compared with the TS or TLS. These time savings can potentially have a significant impact on project workflows and battery resource requirements.

4.2 Volumetric Determination Analysis

Figure 2 provides a comparison of TS and point cloud techniques. A summary of the key results is as follows:

For the fine aggregate White sand, the TLS yield was 14.62m^3, the UAV @ 30m with 60% overlap yield was 11.63m^3, and the UAV @ 30m with 80% overlap yield was 13.71m^3.

For the fine aggregate Red sand, the TLS yield was 13.61m^3, the UAV @ 30m with 60% overlap yield was 14.32m^3, and the UAV @ 30m with 80% overlap yield was 14.07m^3

For the Sharp sand, the TS yield was 16.80m^3, the TLS yield was 20.75m^3, the UAV @ 30m with 60% overlap yield was 19.19m^3, and the UAV @ 30m with 80% overlap yield was 18.87m^3.

For the coarse aggregate Gravel 1, the TS yield was 73.16m^3, the TLS yield was 77.43m^3, the UAV @ 30m with 60% overlap yield was 75.08m^3, and the UAV @ 30m with 80% overlap yield was 79.77m^3

For the coarse aggregate Gravel 2, the TS yield was 210.93m^3, the TLS yield was 230.05m^3, the UAV @ 30m with 90% overlap yield was 228.44m^3, the UAV @ 40m with 80% overlap yield was 218.71m^3, and the UAV @ 40m with 90% overlap yield was 227.96m^3

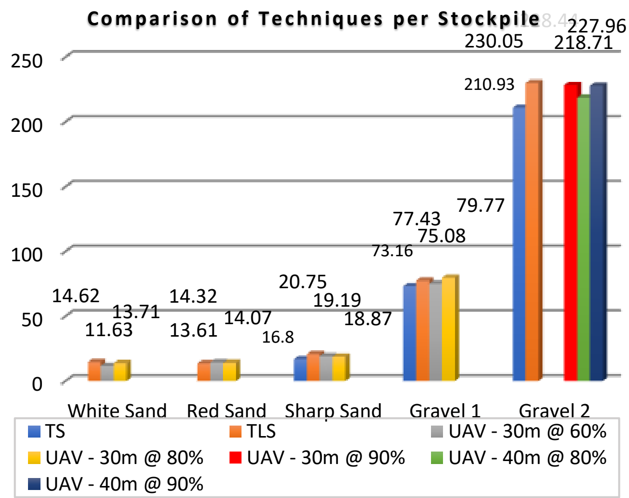

Figure 2 Comparison of Volume Yields by Techniques per Stockpile

Generally, we see that the TS methods yield the lowest volumes for all of the measurement techniques. This suggests that there may be an under-representation of volumes if Total Station techniques are relied upon. On average, TLS generated higher volumes compared to the other techniques. Note that the TS method was impractical for obtaining volume measurements for the white and red sand.

Diving deeper into these results, Figure 3 shows the percentage comparison made between the flight combination and the TLS for both sets of aggregates. Volume differences of less than 10% between the TLS and TS and UAV and TS are achieved for the coarse aggregates. For the fine aggregates however, there are differences of 12% (UAV @ 30m with 80% overlap), 14% (UAV @ 30m with 60% overlap) and 24% in the TLS. This further demonstrates the variability and possible unreliability in the TS assessments for fine aggregates.

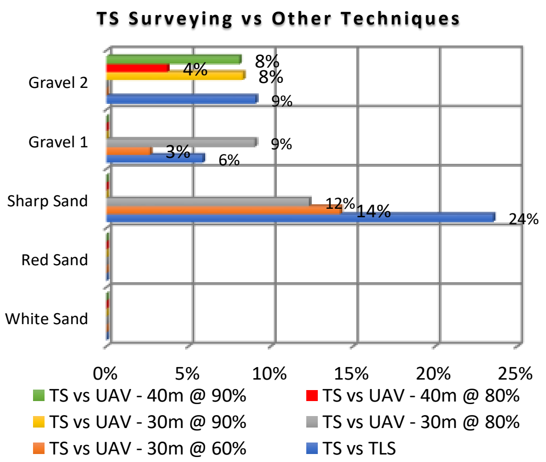

Figure 3 Comparison of TS Volumes against Other Techniques

Figure 4 now presents the direct percentage comparison between the point cloud techniques. While there is general agreement with differences ranging between -9 to +5%, the most notable result is the flight of the 30 meters altitude with the 60% overlap resulted in 20% variation for the white sand. Generally, the 60% overlap gave the least consistent results. These findings highlighted the influence of the altitude, overlap, and specific aggregate materials on the volume estimate. These results are generally in agreement with previous work such as Al Tahir and Barran (2020).

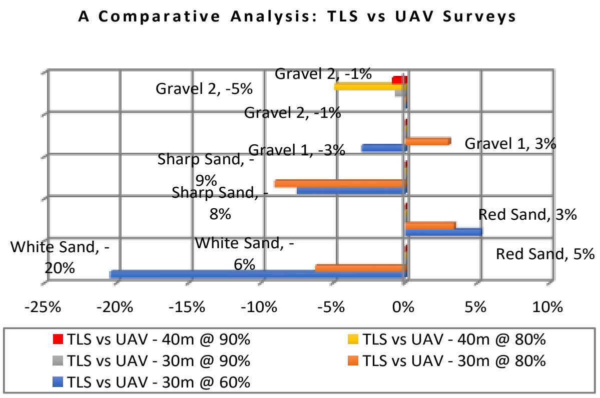

Figure 4 Comparison of TLS vs UAV Volumes by Stockpiles

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Aggregate material stockpiling is widespread in the construction sector. Visual estimates of volumes, for example, is an outdated method that is inefficient. TS approaches are labour intensive and had difficulty capturing fine aggregates. Profit and material management can be improved by precise measurement through modern surveying methods based on point cloud data acquisition. They have proven to be both cost effective and time efficient with operational and HSE advantages.

TLS and the UAV method provide non-contact collection, automated and increased accuracy. There are differences in accuracy and appropriateness dependent on the aggregate type. It was observed that the TLS outperformed the TS approach whereas UAV demonstrated promise particularly at a lower altitude with great overlap. Technique selection should take altitude overlap and aggregate type into consideration.

5.2 Recommendations

In order to evaluate the suitability of modern surveying methods utilizing point cloud data for volumetric surveys of aggregate stockpiles, the following recommendations are provided.

- Traditional methods generally underreport volumes and should be utilized solely for coarse aggregates, while alternative methods should be explored for fine aggregates.
- For more detailed volume assessment, the use of UAVs is recommended. Conducting flight at the lowest feasible altitude with the highest reasonable percentage overlap, noting that overlaps above a certain threshold may increase time but not necessarily accuracy.
- Maintaining consistency with parameters at each location is crucial to enable accurate comparison between the field data.
- Further research into the performance related to different aggregate stockpiles needs to be conducted.

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