TECHNICAL REPORT

OPTIMIZING STOCKPILE MANAGEMENT THROUGH DRONE MAPPING FOR VOLUMETRIC CALCULATION

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ACKNOWLEDGEMENT

We would like to extend my sincerest gratitude to Pens Industries Sdn. Bhd. for awarding the industrial grant and permission to undertake the project for stockpile volumetric calculation by using drone technology. It is a great honor and privilege to be chosen for this opportunity, and I appreciate the confidence that these esteemed organizations have placed in me.

I understand that this project is a crucial and challenging one, and I am committed to utilizing all my knowledge, expertise, and resources to ensure its successful completion. I am confident that with the support and guidance of Pens Industries Sdn. Bhd., I will be able to achieve the desired outcome and contribute to the advancement of technology and innovation.

Once again, I express my sincere appreciation to Pens Industries Sdn. Bhd. for this incredible opportunity, and I look forward to a fruitful collaboration.

PREFACE

Stockpile volumetric calculation is an important aspect in many industries, including construction, mining, and agriculture. Accurate calculation of stockpile volumes is essential for efficient inventory management, logistics planning, and quality control. Traditionally, stockpile volumetric calculation is done using ground-based survey methods, which can be time-consuming, labour-intensive, and often inaccurate. However, with the recent advancements in drone technology, it has become possible to use drones for stockpile volumetric calculation, providing a faster, safer, and more accurate solution.

The duration of this project is one year, from May 1st, 2019, until April 30th, 2020, and is comprised of two primary research components: analyzing the properties and classification of limestone and conducting digital aerial mapping to calculate stockpile volumetrics. The scope of this technical report is specifically limited to the aerial mapping aspect of the project, which was carried out using drones. The project involved two phases, with drone flights taking place during each phase, spaced about six months apart. The first drone flight for data collection occurred on July 12th, 2019, while the second took place on December 15th, 2020.

The project aims to utilize drone technology for stockpile volumetric calculation, providing a more efficient and cost-effective solution. The project will involve the use of advanced drone sensors and imaging technology to capture high-resolution data of the stockpile area. The data will then be processed using sophisticated software algorithms to generate accurate 3D models and volumetric calculations of the stockpile.

The project is made possible by the industrial grant from Pens Industries Sdn. Bhd. (PISB) and permission awarded by Universiti Malaysia Perlis (UniMAP) and supported by the Centre of Excellence for Unmanned Aerial Systems (COE-UAS), UniMAP. This collaboration between academia and industry represents a significant step forward in the application of drone technology in stockpile volumetric calculation. The project will not only provide valuable insights and practical solutions but will also contribute to the development and advancement of technology in this field.

This preface sets the tone for the importance and relevance of the project and highlights the potential benefits of using drone technology for stockpile volumetric calculation. It also acknowledges the support and partnership of the organizations involved in making this project possible.

1. INTRODUCTION

MINING is a primary industry that enables the growth of other industries such as construction, where its products are used in development projects. For mining companies, regularly knowing the stockpile volume of their raw material accurately is very important. This allows them to effectively plan inventory activities.

Quarry company Pens Industries Sdn. Bhd. (PISB), which was established in 1986 as a wholly-owned subsidiary of the Perlis State Economic Development Corporation (PKENPs). The company's core business is limestone quarrying, with a wide range of products such as aggregates, premixes and asphaltic concrete. PISB intends to improve its limestone inventory tracking system. PISB uses conventional methods to calculate and audit limestone stock which is time-consuming, not accurate and sometimes dangerous for engineers. The amount of products produced were just estimated from the weight per lorry that the company sold.

To address the issue of inaccurate inventory tracking, PISB consider implementing a technology-based solution drone-based surveying to measure and map the volume of its stockpiles. These methods provide accurate and precise measurements, which could be used to improve inventory management and planning. Drones, can capture aerial imagery and create 3D maps of the stockpiles. They can also be equipped with sensors that can measure the volume of the material. Implementing this technology would require an investment in equipment and training, but the benefits could outweigh the costs in the long run. Accurate inventory tracking can help the company optimize its operations, reduce waste, and improve efficiency. It can also improve safety by providing a more accurate understanding of the material being handled. Overall, accurate inventory tracking is crucial for mining companies like PISB to optimize their operations and ensure the efficient use of resources. By implementing technology-based solutions PISB can improve its inventory tracking, leading to better business outcomes.

1.1 Digital Mapping for Stockpile Volumetric Calculation

Digital mapping is a process of creating digital representations of physical features, objects, and environments on a map or a computer screen. It involves the use of geographic information systems (GIS) and other software tools to collect, store, manipulate, and analyze geospatial data. Digital mapping is increasingly being used for stockpile volumetric calculation in mining and other industries. By creating accurate digital maps of stockpiles, companies can calculate the exact volume of materials they have on site, which is important for planning inventory activities and managing production levels.

Digital mapping for stockpile volumetric calculation using drones involves using a remote-controlled unmanned aerial vehicle (UAV) equipped with a high-resolution camera to capture aerial imagery of the stockpile. The imagery is then processed using photogrammetry software to create a digital surface model (DSM) and a digital terrain model (DTM).

The DSM is a 3D model of the stockpile, while the DTM is a model of the ground surface underneath the stockpile. By subtracting the DTM from the DSM, the volume of the stockpile can be accurately calculated.

The process of using drones for stockpile volumetric calculation typically involves the following steps:

1. **Flight Planning:** The drone operator plans the flight path for the drone, taking into account factors such as wind speed and direction, weather conditions, and the size and shape of the stockpile.

2. **Aerial Imagery Capture:** The drone is flown over the stockpile, capturing high-resolution aerial imagery using its onboard camera.

3. **Image Processing:** The aerial imagery is processed using photogrammetry software to create a DSM and a DTM of the stockpile.

4. **Volume Calculation:** The DSM and DTM are used to calculate the volume of the stockpile. This can be done using software tools that subtract the DTM from the DSM to create a 3D model of the stockpile, from which the volume can be calculated.

5. **Reporting:** The calculated volume is then reported to the relevant stakeholders, such as management, engineers, or investors. This information can be used to make informed decisions about inventory management and production planning.

1.2 DEM, DSM & DTM: Digital Elevation Model

While Digital Surface Model (DSM) is often associated with Digital Elevation Model (DEM) and Digital Terrain Model (DTM), they are not exactly the same thing. DSM is a type of DEM that represents the height of objects on the earth's surface, including buildings, trees, and other features. It provides a detailed representation of the surface, including all objects and features that are present. On the other hand, DTM represents the bare earth surface, without any objects or features such as buildings or trees. It is created by removing all the non-ground features from the DSM, resulting in a model that represents only the terrain or ground surface. While DSM and DTM are related, they serve different purposes. DSM is used for applications such as urban planning, disaster management, and 3D modeling, where it is important to know the height of all features on the surface. DTM, on the other hand, is used for applications such as hydrological modeling and geological mapping, where it is important to know the bare earth surface. In short, while DSM is a type of DEM that represents the height of all features on the earth's surface, DTM represents only the bare earth surface without any features. Both DSM and DTM are useful for different applications, and their accurate generation and analysis are important for a wide range of industries and fields.

1.3 Objectives

The research objectives of this project are focused on utilizing drone technology for mapping purposes, specifically with the DJI Inspire 2 drone. The objectives are:

1. **To acquire aerial images from DJI Inspire 2:** This objective aims to collect high-quality aerial images using the DJI Inspire 2 drone. To accomplish this, the project will need to consider the optimal flight parameters and camera settings, as well as the appropriate altitude and flight path to capture the necessary data. The objective will require the use of GPS and other positioning technologies to ensure that the aerial images accurately represent the targeted area.

2. **To generate DSM/orthophoto from images acquired by and Inspire 2:** This objective aims to use the collected aerial images to generate digital surface models (DSM) and orthophotos. A DSM is a 3D model that represents the surface of the targeted area, while an orthophoto is a geometrically corrected aerial image that can be used as a map.

3. **To calculate the volumetric of the stockpile**: The project will require consideration of optimal flight parameters and camera settings, as well as the use of GPS and other positioning technologies to ensure accurate mapping results. The resulting DSM/orthophotos can be used in stockpile volumetric calculation to improve decision-making and planning in PISB.

2. STOCKPILE MEASUREMENT METHODS WITH DRONE SURVEYING

The drone needs to be flown to capture site area to be measured. There are a few ways to do this. "Drone surveying," at its core, means using a drone to take aerial photos of the site and some form of GPS and ground control to tie the images down.

2.1 Geospatial Data Collection

Geospatial data collection using drones involves a series of steps and procedures to ensure the accuracy, safety, and reliability of the data collected. The following are some of the key steps involved in collecting geospatial data using drones:

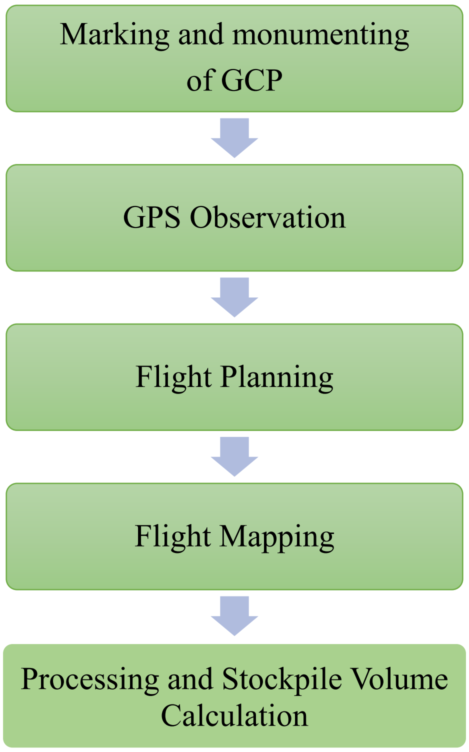

Figure 2.1. Workflow of Geospatial Data Collection.

2.1.1 Marking and Monumenting of GCP

Ground Control Points (GCPs) are points on the ground that are accurately measured and used as reference points for geospatial data collection. The marking and monumenting of GCPs is an important step in ensuring the accuracy of geospatial data collection. Properly marked and monumented GCPs can help improve the quality of geospatial data and ensure that the data can be used effectively for analysis and decision-making.

Below are some steps and guideline for marking and monumenting GCPs:

- The first step is to identify the locations where GCPs will be placed. These locations should be representative of the area being surveyed and should be easily identifiable.

- Once the GCP locations have been identified, mark them using a permanent marker, spray paint, or other marking tools. The markers should be visible and easily identifiable from the air or ground.

- To ensure the accuracy of the GCPs, monumentation is typically installed at each location. This can include concrete markers, metal stakes, or other types of permanent markers. The monumentation should be installed at ground level and should be level and stable.

- After marking and monumenting the GCPs, record the location of each point using GPS or other surveying equipment. This information can be used to accurately position the GCPs in the geospatial data.

- Before using the GCPs for geospatial data collection, it is important to verify their accuracy. This can be done by measuring the distance between the GCPs using surveying equipment and comparing the measurements to the expected values.

2.1.2 GPS Observation

GPS observation refers to the measurement of the distance between a GPS receiver and a set of GPS satellites. GPS observations are used to determine the position of the GPS receiver, as well as to measure the speed and direction of movement. GPS observations are typically made using a GPS receiver, which receives signals from multiple GPS satellites. The GPS receiver uses the signals to determine its distance from each satellite and uses this information to calculate its position on the Earth's surface.

2.1.3 Flight Planning

Flight planning for mapping involves additional considerations beyond the basic steps of route selection and battery optimization. Mapping flights typically involve collecting geospatial data such as aerial imagery, LiDAR point clouds, or other remote sensing data. Therefore, flight planning for mapping must take into account the desired resolution and accuracy of the data to be collected.

The following are some additional steps that involved in flight planning for mapping:

- The first step in flight planning for mapping is to select the appropriate sensors that will be used to collect the desired data. For example, if the goal is to capture high-resolution aerial imagery, a digital camera with appropriate lenses may be selected.

- The flight altitude and speed must be carefully selected to ensure that the desired resolution and accuracy of the data can be achieved. The altitude and speed will depend on the sensor and the terrain being mapped. Including taking into account the flight height limit by Civil Aviation Authority Malaysia (CAAM).

- The flight paths should be planned to ensure that the entire area to be mapped is covered with sufficient overlap between adjacent images to facilitate later image processing. Flight paths can be planned manually or with the help of flight planning software.

- Ground control points (GCPs) are reference points on the ground with known locations that can be used to georeference the collected data. The locations of GCPs should be selected and surveyed before the mapping flight, and their coordinates should be incorporated into the flight plan.

- Weather can significantly affect the quality of the collected data, so it is important to take weather conditions into account during flight planning. Cloud cover, wind speed, and turbulence can all affect the accuracy of the collected data.

Planning for these factors can help ensure that high-quality and accurate data is collected during the flight mapping.

2.1.4 Flight Mapping

Flight mapping for stockpile volumetric calculation involves additional considerations beyond the basic steps of flight planning and data collection. Stockpile volumetric calculation requires the collection of accurate elevation data, which can be used to calculate the volume of material in a stockpile.

The following are some additional steps that may be involved in flight mapping for stockpile volumetric calculation to get accurate result and high quality of the collected data.

- In flight planning, the drone should fly at a consistent altitude to ensure accurate measurements and overlap the images sufficiently to ensure accurate 3D reconstruction.

- The camera settings should be optimized for the conditions on the site, including lighting conditions and the type of material being measured. The camera should be set to capture high-resolution images and videos with accurate color reproduction.

- GCPs are essential to ensure the accuracy of the measurements. GCPs should be placed at strategic locations throughout the site and measured accurately using a high-precision GPS device.

2.1.5 Data Processing and Stockpile Volumetric Calculation

Data processing and stockpile volumetric calculation involve several steps and specialized software. In this project the Pix 4D Software is used. The following are the general steps involved in data processing and stockpile volumetric calculation:

- The collected photogrammetric data, needs to be processed to create a digital elevation model (DEM) of the surveyed area. This involves processing the raw data to remove errors and generate a highly accurate DEM.

- GCPs are reference points on the ground with known elevations that can be used to georeference the collected elevation data. The locations of GCPs should be selected and surveyed before the mapping flight, and their elevations should be incorporated into the data processing.

- Once the DEM has been created, the stockpiles of interest need to be identified and delineated. This is typically done using specialized software that can automatically identify and outline the stockpiles.

- With the stockpiles identified and outlined, the volume of material in each stockpile can be calculated using specialized software. This typically involves comparing the DEM to a reference plane or baseline to determine the height of the stockpile, and then integrating the stockpile shape to calculate the volume.

It's important to note that the accuracy of the stockpile volume calculation is highly dependent on the accuracy of the DEM, the quality of the GCPs, and the quality of the stockpile identification. Therefore, it's important to carefully plan the flight mapping and ground control point surveys, as well as use high-quality data processing and stockpile identification software to ensure accurate results.

3. DRONE PHOTOGRAMMETRY: TURNING ACCQUISITION DATA INTO 3D SURVEY.

3.1 Establishing and Positioning Ground Control Points (GCPs) for Accurate Geospatial Referencing

The structure of the permanent Ground Control Point (GCP) consists of a cement base and a frame to stabilize the station. The established size of this permanent GCP is 12 inches by 12 inches, with a 10-centimeter diameter steel rod at its center, as shown in Figure 3.1 and Figure 3.2 shows the point station on the GCP monument.

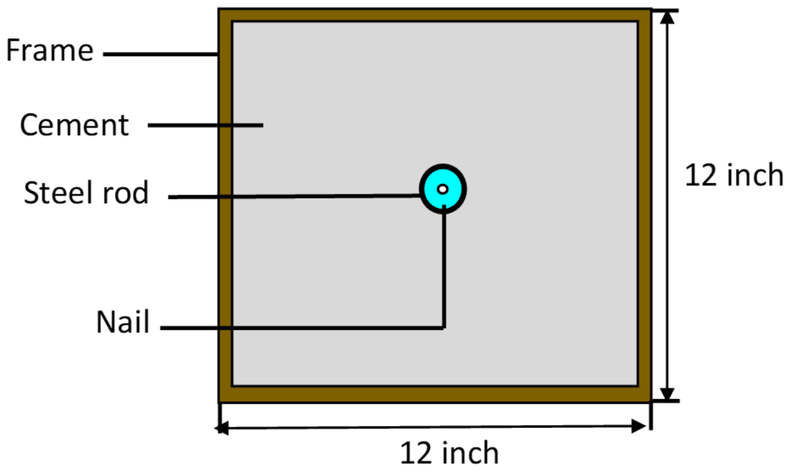

Figure 3.1. Structure of GCP.

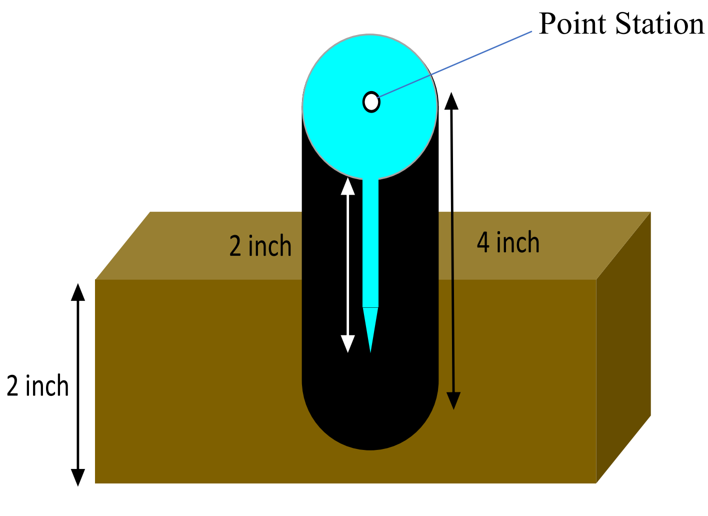

Figure 3.2. Monument of GCP.

3.2 Vertical Control Observation

Global Positioning System Observation involve vertical control which is often established by using benchmarks (BM) with known and verified elevation values. A benchmark is a permanent, fixed point on the ground with a precisely measured and recorded elevation. When conducting a survey or mapping project, the elevation of the nearest benchmark is first determined using precise levelling techniques. This benchmark elevation value is then transferred to nearby temporary benchmarks (TBM) through differential levelling or trigonometric levelling methods. The TBM points are typically temporary and can be moved to different locations as needed during the project.

Once the TBM points have been established, their elevation values are then transferred to other GCP within the project area. The GCPs are point of interest that are used as reference points for measuring elevations or heights of other points in the project area and having precise elevation values is essential for accurate mapping and analysis. It's important to note that benchmarks must be in good condition and approved for use by the relevant authorities to ensure the accuracy and reliability of the elevation values.

3.3 Ground Control Point Observation

In this project, GCPs were established using both conventional surveying and Global Navigation Satellite System (GNSS) methods.

The project involves a total of 7 GCPs, and three phases of GPS observations were conducted using four sets of GPS equipment. The observations were started from the first three GCPs, where a Temporary Benchmark (TBM) was used as the base station (reference station), and the GCPs were used as the rover station.

During each phase of GPS observation, three GCPs were observed simultaneously for 30 minutes using two sets of GPS equipment (R4 and R6). The observation order of the GCPs was different in each phase, as follows: Phase 1: GCP 7, 6, and 5; Phase 2: GCP 4, 3, and 2; Phase 3: GCP 1.

Figure 3.3 shows the setup of the GPS equipment, which is essential for ensuring accurate and precise measurements. It's important to note that the quality and reliability of the GPS data collected during the survey depend on many factors, including the quality of the equipment, the environmental conditions, and the skill and experience of the surveyors.

Figure 3.3. Setting up for GPS Observation.

3.4 Location of Ground Control Points (GCPs)

There are 7 GCPs, and their respective locations are illustrated in the figure below:

Figure 3.4. Location of 7 GCPs.

3.5 Essential Instruments

The main equipment required includes:

Table 3.1 List of Main Equipment

Equipment	Description	Quantity
DJI Inspire 2 	The DJI Inspire 2 is a professional-grade drone designed for aerial cinematography and photography. It is used for capturing 2D aerial footage. The drone also has a top speed of 58 mph (94 km/h) and a maximum flight time of up to 27 minutes.	1 Unit
Zenmuse X5S Camera 	Zenmuse X5S Camera is a professional-grade camera manufactured by DJI. The Zenmuse X5S Camera is designed to be used with DJI's Inspire 2 drone and offers high-quality 4K video recording and 20.8 megapixel still image capture. The camera features a Micro Four Thirds sensor, interchangeable lenses, and advanced image processing capabilities, making it a versatile tool for aerial cinematography and photography.	1 Unit
Trimble R4 GPS 	The Trimble R4 GPS receiver is designed to receive signals from GPS and GLONASS satellites to determine the position and coordinates (X, Y, and Z) of the receiver on the earth's surface. To determine the coordinates, the Trimble R4 GPS uses a process called triangulation, where it receives signals from at least four satellites and calculates the distance between the receiver and each satellite based on the time it takes for the signals to travel. The Trimble R4 GPS can provide centimeter-level accuracy in real-time positioning, making it well-suited for surveying and mapping applications that require precise location data.	2 Sets

Equipment	Description	Quantity
Trimble R6 GPS 	The Trimble R6 GPS is a high-precision GNSS receiver designed to receive signals from GPS, GLONASS, and other satellite constellations to determine the position and coordinates (X, Y, and Z) of the receiver on the earth's surface. Similar to the Trimble R4 GPS, the Trimble R6 GPS uses a process called triangulation to determine the position of the receiver. It receives signals from multiple satellites and calculates the distance between the receiver and each satellite based on the time it takes for the signals to travel. Using this distance information and the known positions of the satellites, the receiver can then determine its own position in three dimensions (X, Y, and Z). It can provide centimeter-level accuracy in real-time positioning, and can also be used for post-processing to improve accuracy even further.	2 Sets
Tripod 	Tripods are a useful accessory for GPS equipment. Tripods are used to hold surveying equipment on the ground, as they can help to stabilize the GPS receiver and ensure accurate measurements which can help to improve the accuracy and precision of the mapping results.	4 Units

3.6 Data Accusations

3.6.1 Before Flying

Before conducting any geospatial mapping using a drone, it is important to ensure that the drone is in good condition and all necessary equipment is available. It is also important to consider weather conditions, as mapping should not be conducted during rainy or windy weather. Once the drone and weather conditions have been verified, the next step is to plan the flight. In this case, the area of the project is 42 hectares. Flight planning was conducted using Mission Planner.

Mission Planner is a popular open-source software application that is commonly used for planning and executing drone flights. It provides a user-friendly interface for creating flight plans and controlling the drone during flight. With Mission Planner, we can create waypoints, set altitude, and speed parameters, and customize the drone's flight path to ensure that it captures the desired aerial imagery.

Figure 3.5 shows the flight paths of the drone, which has been planned using the Mission Planner application. The flight paths are drawn over the 42-hectare area and covers all necessary points for accurate data collection. This flight plan ensures that the drone will cover the entire area and capture all necessary data for the mapping project. Details of the flight planning are as follows:

i. The distance of the flight path is 3.5 kilometers.
ii. The altitude of the drone during flight is 180 meters.
iii. There are 8 flight paths in total.
iv. A total of 146 pictures was taken during the flight.
v. The side lap between pictures is 80%.
vi. The overlap between pictures is 60%.

This information are important for planning the flight path and ensuring that the drone captures all necessary data for the mapping project. The distance of the flight path and altitude are used to determine the coverage area of each image. The number of flight paths and pictures are used to estimate the time and resources needed for the project. Finally, the side lap and overlap between pictures are important for ensuring that there is enough overlap between images for accurate data collection and mapping.

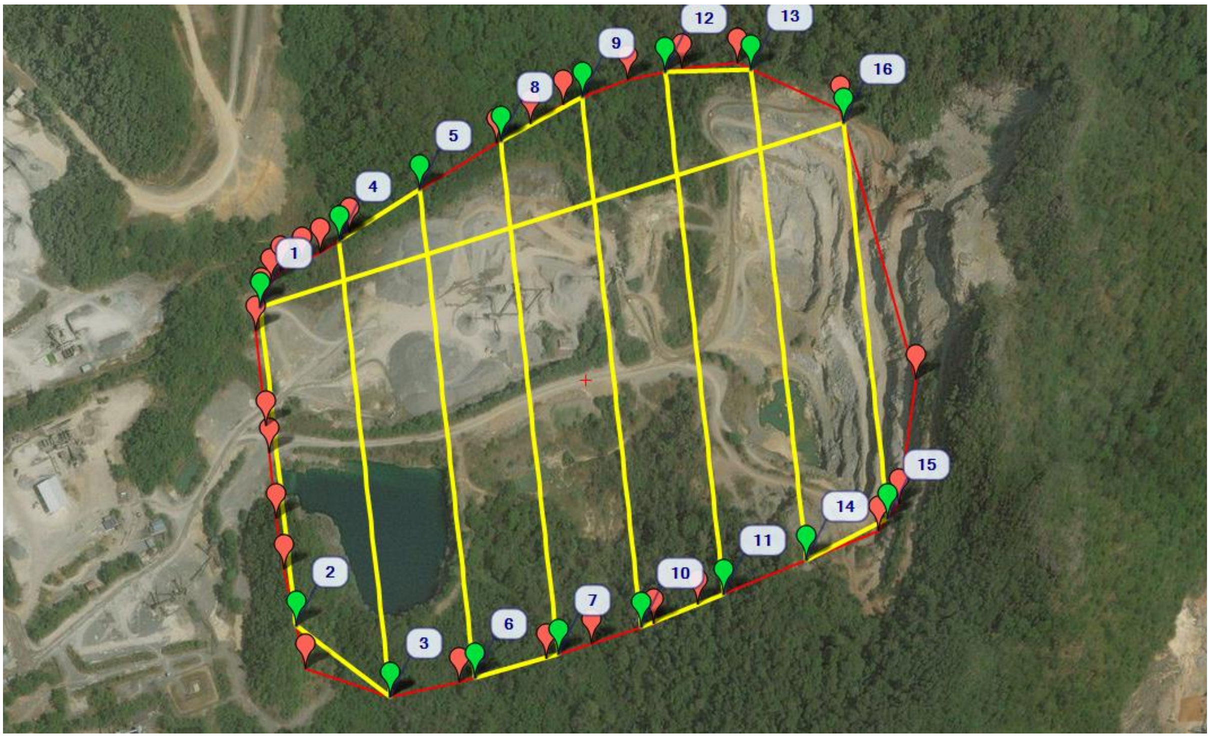

Figure 3.5. Flight Path of Geospatial Mapping.

3.6.2 During Flying

During the flight, it is important to maintain the proper flying height to ensure accurate data collection. In this case, the altitude of the drone during flight is 180 meters, which was determined during flight planning. The surrounding area should also be taken into consideration, as the survey area is located in a hilly region, and there may be obstacles such as mountains that could pose a risk to the drone. Therefore, the pilot must be vigilant and watch out for any potential obstacles that could affect the flight. In addition, it is important to keep an eye on the signal between the device and the drone during the survey. The signal may have the potential to be lost due to various factors such as distance, interference, or technical issues. Therefore, it is important to regularly monitor the signal and be prepared to take action if necessary, such as returning the drone to its starting point or adjusting the flight path to avoid any signal disruptions.

3.6.3 After Flying

After the drone has completed its survey and collected all necessary data, the next step is to process the data. In this case, the Pix4D software will be used to process the entire data set captured by the drone. Pix4D is a powerful photogrammetry software that can be used to create high-quality maps, models, and 3D reconstructions from aerial imagery. The software uses algorithms to process the images captured by the drone and create a georeferenced 3D model of the area surveyed. The software can also be used to extract a range of data from the imagery, such as point clouds, digital surface models, and orthomosaics. The processing stage is a crucial part of the geospatial mapping process, as it involves turning the raw data captured by the drone into usable information. It is important to ensure that the processing is done accurately and efficiently, as this can have a significant impact on the quality of the final output.

3.7 Geospatial Data Processing

Figure 3.6 and Figure 3.7 shows the necessary steps involved in the construction of a textured 3D model, DEM, and orthomosaic from UAV photos in Pix4D software. These steps are crucial to ensure the accuracy and reliability of the resulting data and can be applied to a wide range of applications, including land surveying, mapping, and 3D modeling. Pix4D software is a powerful tool that streamlines this process and makes it more accessible to professionals in various fields.

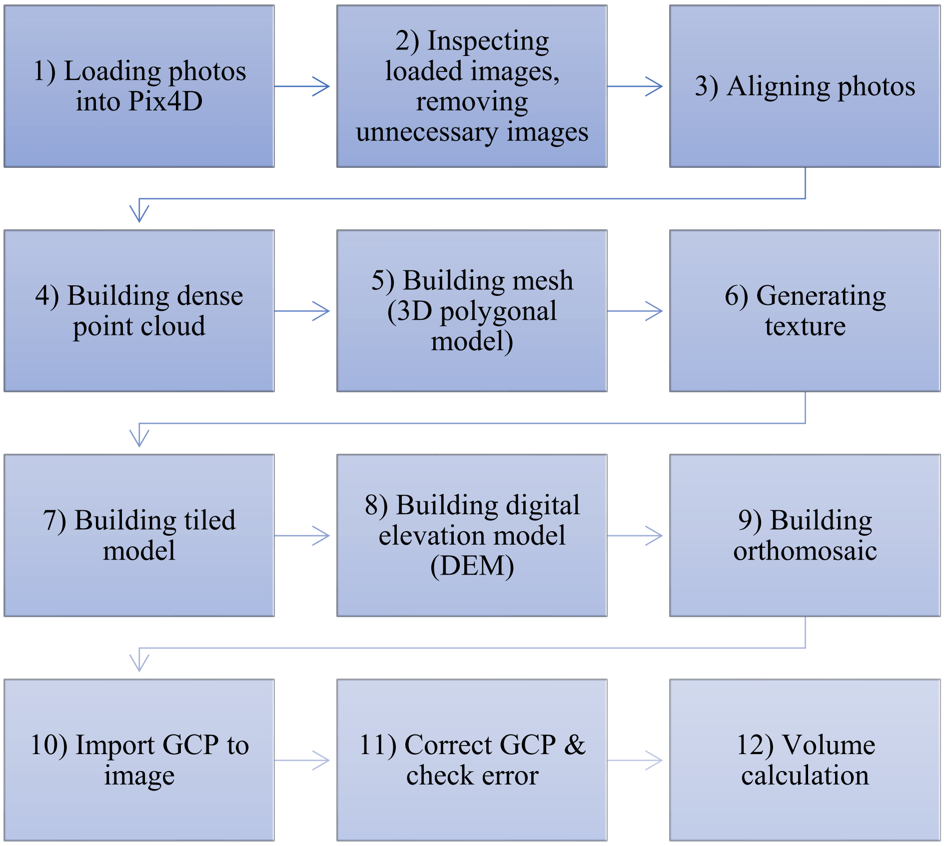

Figure 3.6. Data Processing Flow.

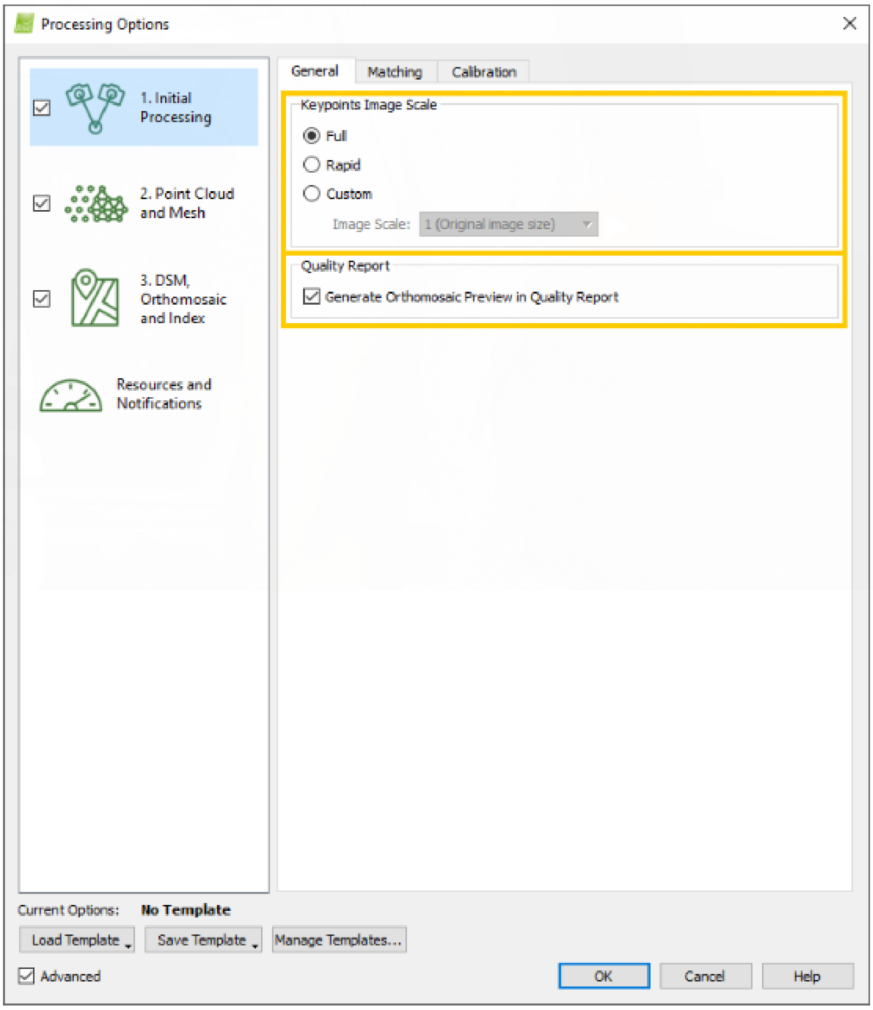

Figure 3.7. Processing in Pix4D.

3.8 Volume Calculation

The volume of the stockpiles was computed from the volume base by using Pix4D software. There are 6 types of product which is Crusher Run (A), Crusher Run (B), Crusher Run (C), 3/8 in limestone, 3/4 in limestone and 28 mm limestone. The volume of a stockpile is computed using Digital Surface Mapping (DSM) by creating the base taking into account of altitude of each vertex. Figure 3.8 show the volume base of a stockpile. Figure 3.9 show the location of stockpiles.

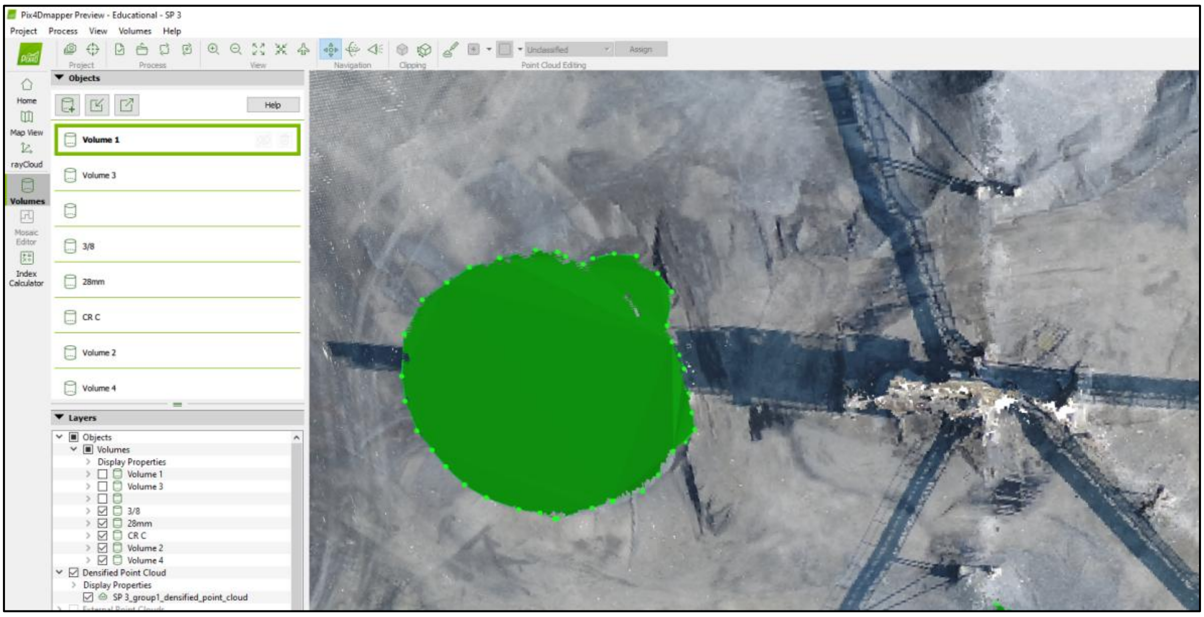

Figure 3.8. Volume base of a stockpile.

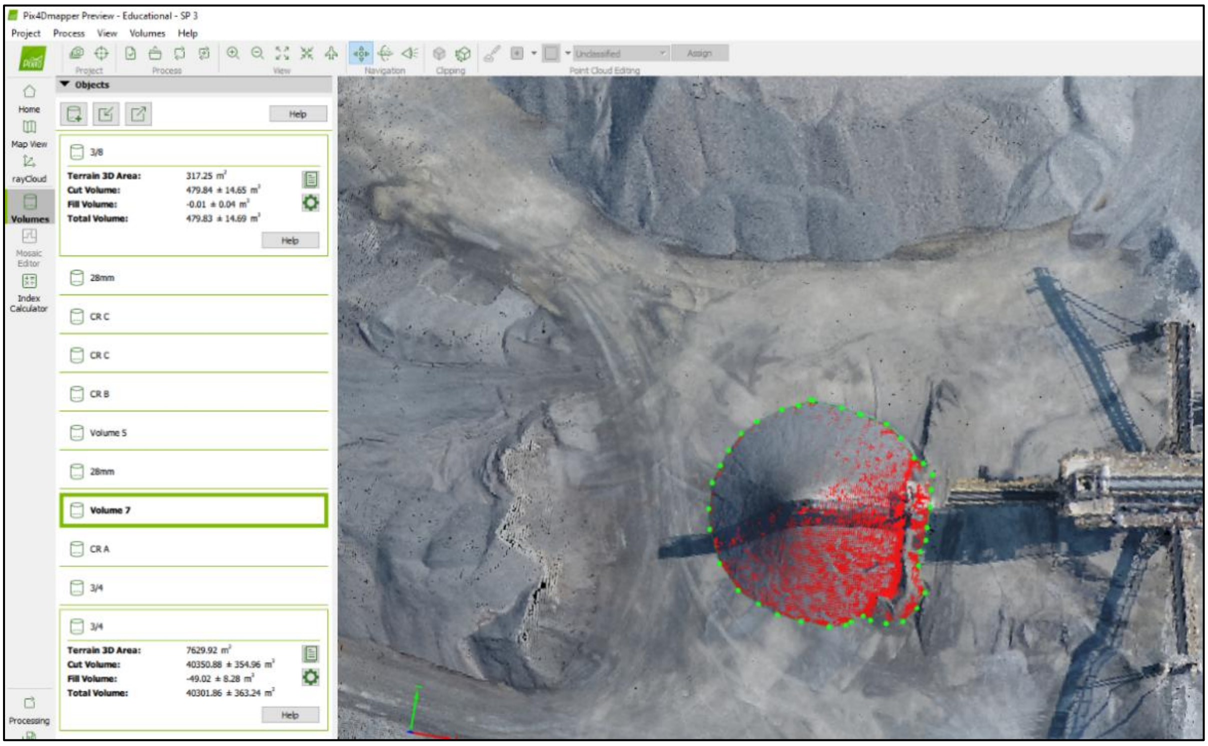

Figure 3.9. Volume Calculation for 3/8 inch Limestone (Top View).

4. RESULT

This chapter will provide an overview of the output of the project, including the coordination of Ground Control Points (GCPs), pre-processing output, and volume calculation of stockpile products. The GCPs are a set of reference points with known coordinates that are used to align the aerial imagery or data to a known coordinate system. In this project, the coordinates of the GCPs will be provided as output to ensure accurate georeferencing of the imagery or data. Pre-processing output refers to the intermediate results obtained during data processing before the final output is generated. For instance, during the pre-processing stage, the raw data from the drone may be cleaned up, filtered, and adjusted to improve the accuracy of the final output. The volume calculation of stockpile products is another important output of the project. This involves using Pix4D software to create a 3D model of the stockpile and then using the Digital Surface Mapping (DSM) method to determine the volume of each type of product in the stockpile. The accuracy of the volume calculation is critical for inventory management and cost control purposes.

4.1 Geospatial Data Mapping

4.1.1 GPS Observation on Ground Control Point

In this project, GPS observations were made on Ground Control Points (GCPs) using three different coordinate systems: Geodetic Datum Malaysia 2000 (GDM2000), World Geodetic System 1984 (WGS84), and Malaysia RSO Geocentric (Peninsular).

GDM2000 is a geodetic datum used in Malaysia that is based on the International Terrestrial Reference Frame (ITRF). It is commonly used for surveying and mapping applications in the country. WGS84 is a global geodetic reference system that is widely used in GPS applications worldwide. It provides a consistent coordinate system for navigation, mapping, and other location-based services. Malaysia RSO Geocentric (Peninsular) is a coordinate system that is commonly used for mapping and surveying in Peninsular Malaysia. It is based on the Transverse Mercator projection and is used to represent locations in a Cartesian coordinate system. The use of multiple coordinate systems in this project provides flexibility in data analysis and interpretation. It allows the data to be compared and integrated with other data sources that may use different coordinate systems. It is important to ensure that the coordinate systems are well-defined and accurate, to ensure that the GPS observations are consistent and reliable.

Table 4.1, Table 4.2, and Table 4.3 shows the coordinates of seven Ground Control Points (GCPs) in three different coordinate systems: Geodetic Datum Malaysia 2000 (GDM2000), World Geodetic System 1984 (WGS84), and Malaysia RSO Geocentric (Peninsular).

Table 4.1 Coordinate of 7 GCP in Geodetic Datum Malaysia 2000 (GDM2000)

GCP	Latitude (°)	Longitude (°)	Height (m)
GCP1	6.517783648	100.1797014	34.493
GCP2	6.516176573	100.1790220	34.970
GCP3	6.514821882	100.1805800	47.740
GCP4	6.516488976	100.1809054	44.430
GCP5	6.517078148	100.1832397	64.425
GCP6	6.518352454	100.1826213	52.334
GCP7	5.520462173	100.1842140	102.186

Table 4.2 Coordinate of 7 GCP in World Geodetic System 1984 (WGS84)

GCP	Latitude (°)	Longitude (°)	Height (m)
GCP1	6.5177962394	100.1796900516	34.493
GCP2	6.5161891638	100.1790106516	34.970
GCP3	6.5148344727	100.1805686524	47.740
GCP4	6.5165015673	100.1808940522	44.430
GCP5	6.5170907398	100.1832283529	64.425
GCP6	6.5183650461	100.1826099524	52.334
GCP7	6.5204747659	100.1842026527	102.186

Table 4.3 Coordinate of 7 GCP in Malaysia RSO Geocentric (Peninsular)

GCP	Latitude (°)	Longitude (°)	Height (m)
GCP1	244323.325	721606.664	34.493
GCP2	244247.264	721429.361	34.970
GCP3	244418.780	721278.677	47.740
GCP4	244455.723	721462.820	44.430
GCP5	244714.200	721526.623	64.425
GCP6	244646.544	721667.878	52.334
GCP7	244823.891	721900.234	102.186

These tables provide the precise location of each GCP in each of the three coordinate systems. This information is critical for accurate georeferencing of the aerial imagery.

4.1.2 Geospatial Data Mapping

Geospatial data mapping is the process of creating accurate maps from aerial imagery. In this project, Pix4D software was used to process the aerial imagery and create the geospatial data products. The quality report generated from the Pix4D processing provides information about the accuracy and quality of the data products. One important metric in this report is the Root Mean Square (RMS) error, which is a measure of the difference between the actual ground control point locations and the locations determined from the aerial imagery. In this project, the RMS error was calculated and found to be within the allowable tolerance, as stated in Appendix.

4.1.2.1 Orthomosaic

An orthomosaic is a high-resolution, georeferenced image made by stitching together multiple overlapping images of the same area. It can be generated using photogrammetry software like Pix4D, which uses algorithms to reconstruct the 3D geometry of the scene and create a seamless mosaic. By creating a detailed and accurate representation of the area, they can help identify features such as land use, vegetation health, and changes over time.

Seamline editing is an important step in orthomosaic processing, as it can help improve the visual quality of the final product. Seamlines are the boundaries between individual images that make up the mosaic, and editing them can help eliminate visible artifacts and create a more seamless appearance. Pix4D offers tools to edit seamlines manually, or through automatic detection and correction.

4.1.2.2 Contour

Figure 4.1 show a contour map. It is a type of map that shows the elevation of the ground surface. It does this by using contour lines, which are lines that connect points of equal elevation. The contour interval is the vertical distance between contour lines. The contour interval is 10 meters, which means that there is a contour line for every 10 meters of elevation change. The highest contour line in this project area is 85 meters, which means that the highest point in the area is at an elevation of 85 meters above sea level. The lowest contour line is 10 meters, which means that the lowest point in the area is at an elevation of 10 meters above sea level. The contour lines in between show the gradual changes in elevation between these two points.

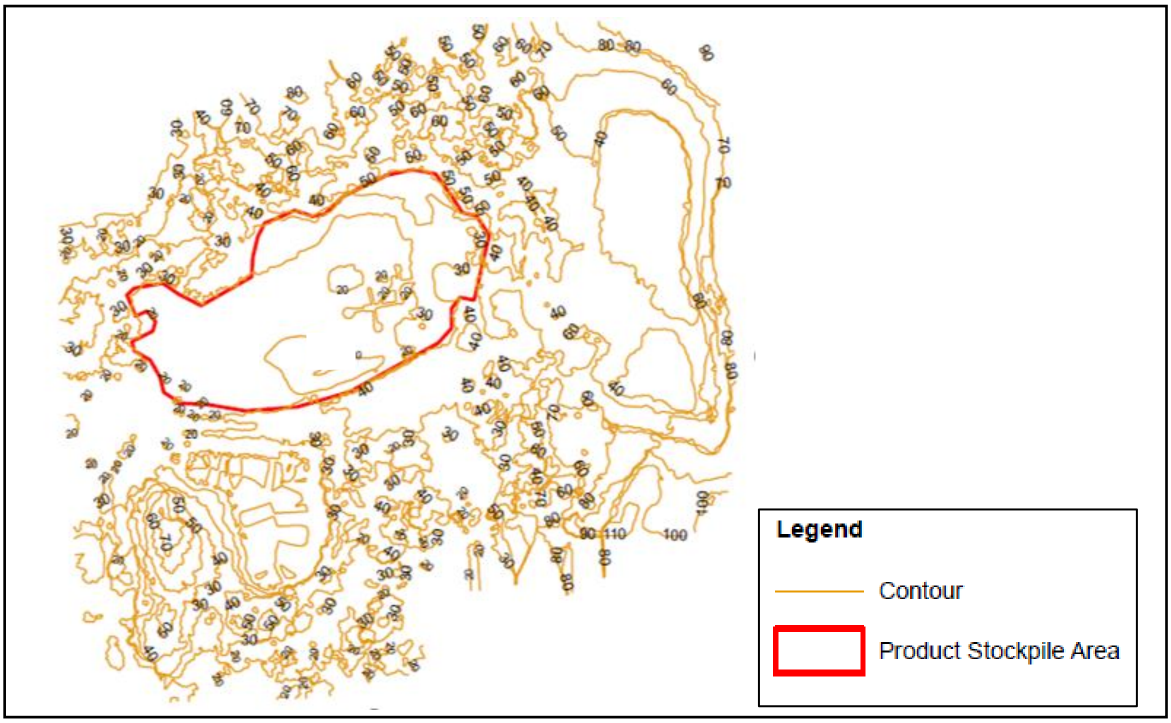

Figure 4.1 Contour of Project Area.

4.1.2.3 Digital Surface Mapping

A Digital Surface Model (DSM) have been generated by using a dense cloud or mesh model. The DSM provides information about the height of the earth's surface, including its highest and lowest points. It's important to note that the coordinate system used for referencing the model is WGS 84/ UTM zone 47N. This means that the coordinates of each point in the model are referenced to a global coordinate system, which is commonly used for geographic information systems (GIS). The highest point in the DSM is 40.709 m and the lowest point is 17.4769 m. Figure 4.2 show the DSM of project area.

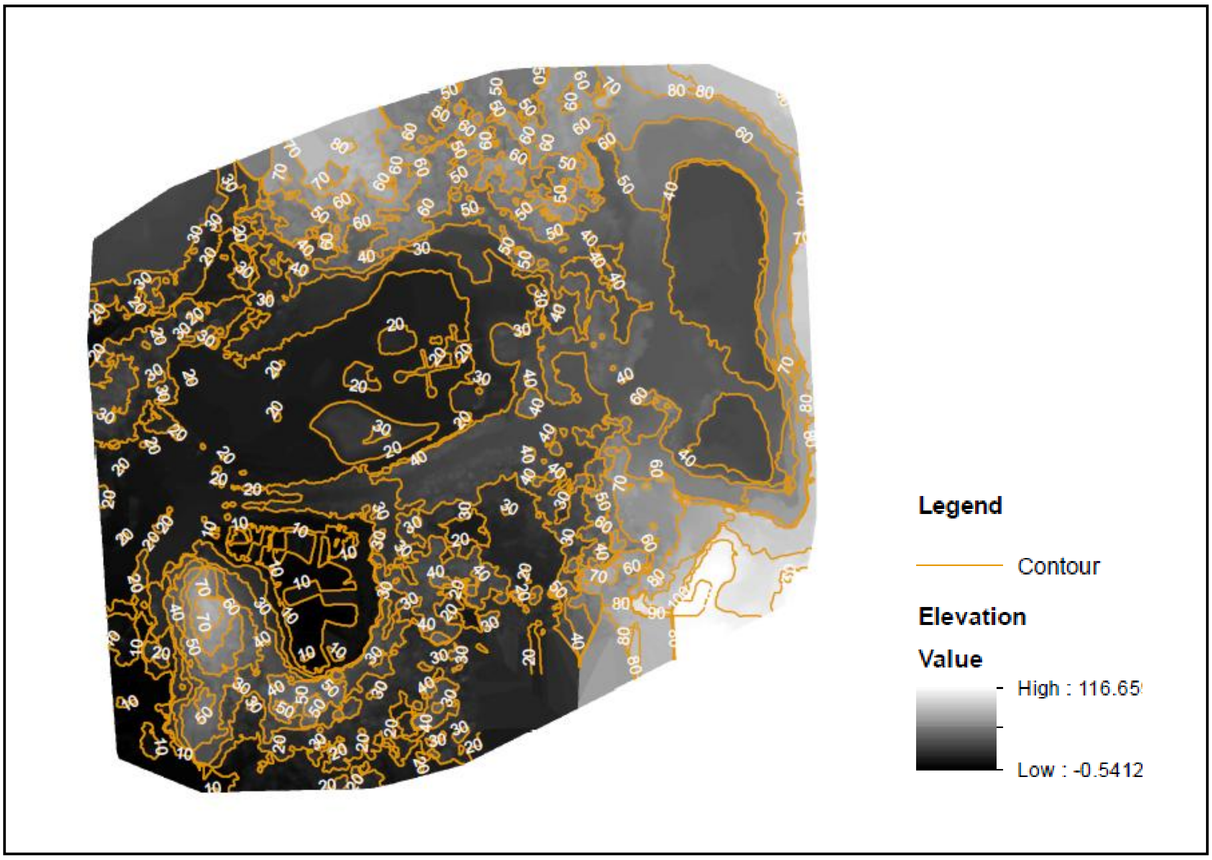

Figure 4 2. Digital Surface Model (DSM) of Project Area.

4.1.2.4 Volume Calculation

The total volume of stockpile was shown in Table 4.4 below. In volume calculations for stockpiles, the cut volume is typically measured above a reference or base level, while the fill volume is measured below the same base level. The base level is usually a horizontal plane or surface that serves as a reference for volume calculations.

Table 4.4 Volume Calculation of Stockpile

Label	Product	Volumes (m^3)		Volume (m^3)
		Cut	Fill	
1	Crusher Run 2 in Limestone (A)	192.62	0.08	192.54
2	Crusher Run 2 in Limestone (A)	727.48	1.64	725.84
3	Crusher Run 2 in Limestone (A)	5,703.24	38.03	5,665.21
4	Crusher Run 2 in Limestone (B)	298.01	0.58	297.43
5	Crusher Run 2 in Limestone (B)	2,472.32	1.06	2471.26
6	Crusher Run 2 in Limestone (B)	176.18	0.67	175.51
7	Crusher Run 2 in Limestone (C)	6,897.96	49.62	6,848.34
8	28 mm	6,001.71	2.26	5,999.45
9	28 mm	574.85	1.53	573.32
10	3/8 in Limestone	845.68	1.95	843.73
11	3/8 in Limestone	800.41	0.67	799.74
12	3/4 in Limestone	28,334.04	12.79	28,321.25
13	3/4 in Limestone	1,160.96	9.01	1,151.95
14	3/4 in Limestone	1,016.9	1.19	1,015.71
Total volume (m^3)				**55,081.28**

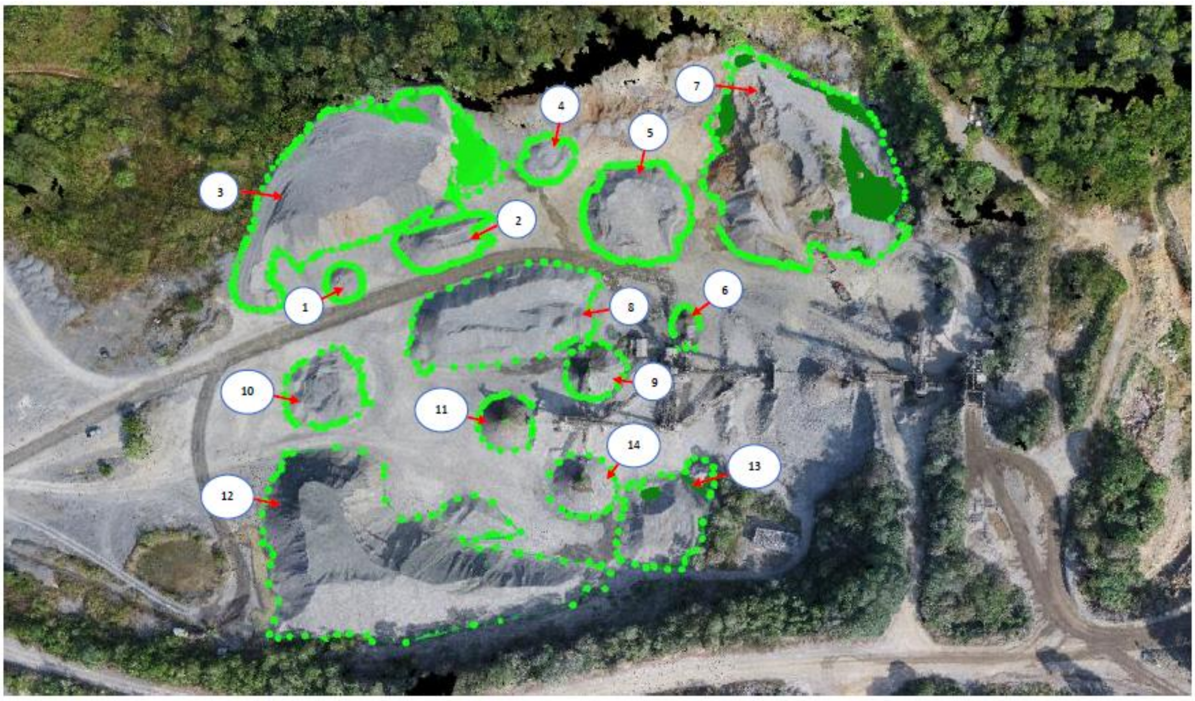

Figure 4.3. Location of Stockpile.

4.1.2.5 Density and Mass Calculation

No	Product	Volume, v (m^3)	Weight product in cage, w (kg)	Density, d (kg/m^3) d = w/x	Density, D (ton/m^3) D = d/1000	Weight, W (ton) W = v × D
1	Crusher Run 2 in Limestone (A)	6,583.59	1090	1,509.33	1.51	9,936.79
2	Crusher Run 2 in Limestone (B)	2,944.2	1190	1,647.80	1.65	4,851.45
3	Crusher Run 2 in Limestone (C)	6,848.34	1060	1,467.79	1.47	10,051.90
4	3/8 inch Limestone	1,643.47	1080	1,495.48	1.50	2,457.78
5	3/4 inch Limestone	30,488.91	1030	1,426.25	1.43	43,484.66
6	28 mm Limestone	6,572.77	990	1,370.86	1.37	9,010.33
Total volume (m^3)		55,081.28		Total weight of product (ton)		79,792.90

Dimension of cage

Length (m)	1.12
Width (m)	1.04
Height (m)	0.62

** Volume of cage (m^3) = 1.12 × 1.04 × 0.62

x = 0.722176

4.1.2.6 Comparison of volume stockpile in Phase 1 and Phase 2.

The table below show the volume of products in Phase 1 and Phase 2. The volume of products in Phase 1 and Phase 2 has been compared, and it has been observed that there is a decrease in the volumes of 3/8 inch and 3/4-inch limestone, while the volumes of the other products have increased. The total difference in volume between Phase 1 and Phase 2 is 8,951.34 m³.

Table 4.5 List of Volume by Product for Phase 1 and Phase 2

No	Product	Volume, v (m³) Phase 1	Volume, v (m³) Phase 2
1	Crusher Run 2 in Limestone (A)	5,020.360	6,583.59
2	Crusher Run 2 in Limestone (B)	945.290	2,944.2
3	Crusher Run 2 in Limestone (C)	6,770.840	6,848.34
4	3/8 inch Limestone	3,883.490	1,643.47
5	3/4 inch Limestone	43,264.450	30,488.91
6	28 mm Limestone	4,148.190	6,572.77
	Total (m³)	**64,032.620**	**55,081.28**
	Difference of total volume of product (m³)	**8,951.34**	

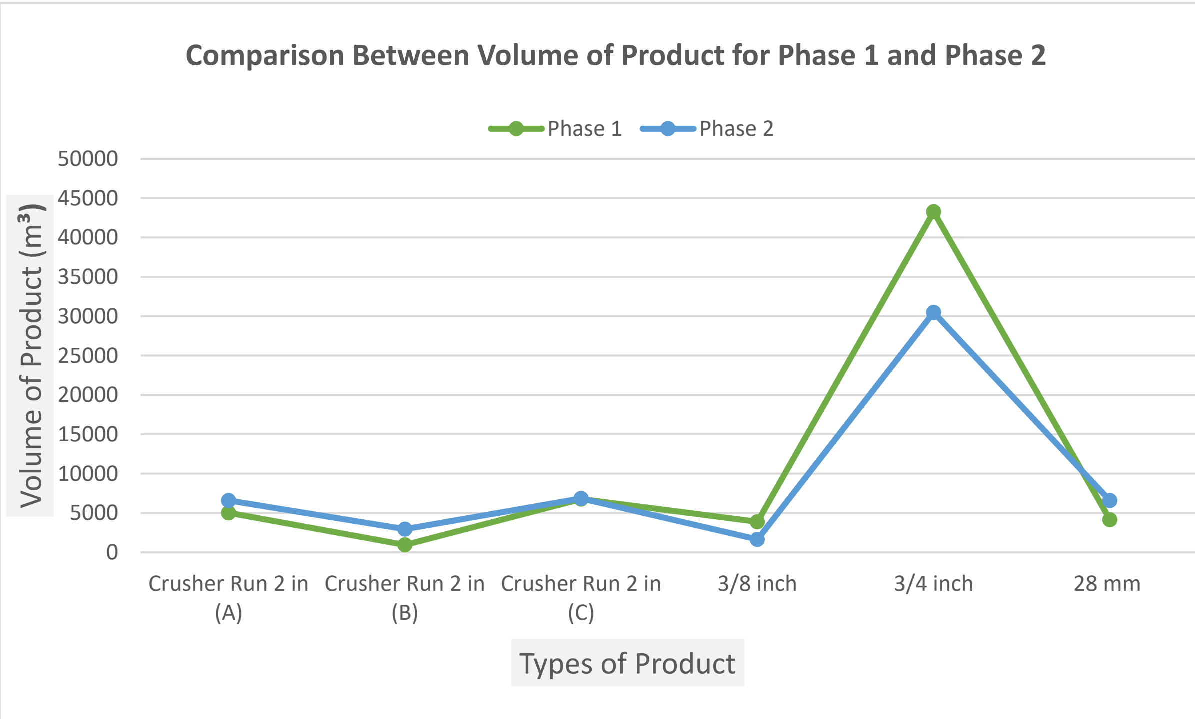

Figure 4.4. Comparison between Volume Products Phase 1 and Phase 2.

Table 4.6 List of Weight by Product for Phase 1 and Phase 2

No	Product	Weight of product, (ton) Phase 1	Weight of product (ton) Phase 2
1	Crusher Run 2 in Limestone (A)	7,577.367	9,936.79
2	Crusher Run 2 in Limestone (B)	1,557.647	4,851.45
3	Crusher Run 2 in Limestone (C)	9,938.146	10,051.90
4	3/8 inch Limestone	5,807.683	2,457.78
5	3/4 inch Limestone	61,705.711	43,484.66
6	28 mm Limestone	5,686.575	9,010.33
	Total (ton)	**92,273.128**	**79,792.90**
	Difference of total Weight of product (ton)	**12,480.228**	

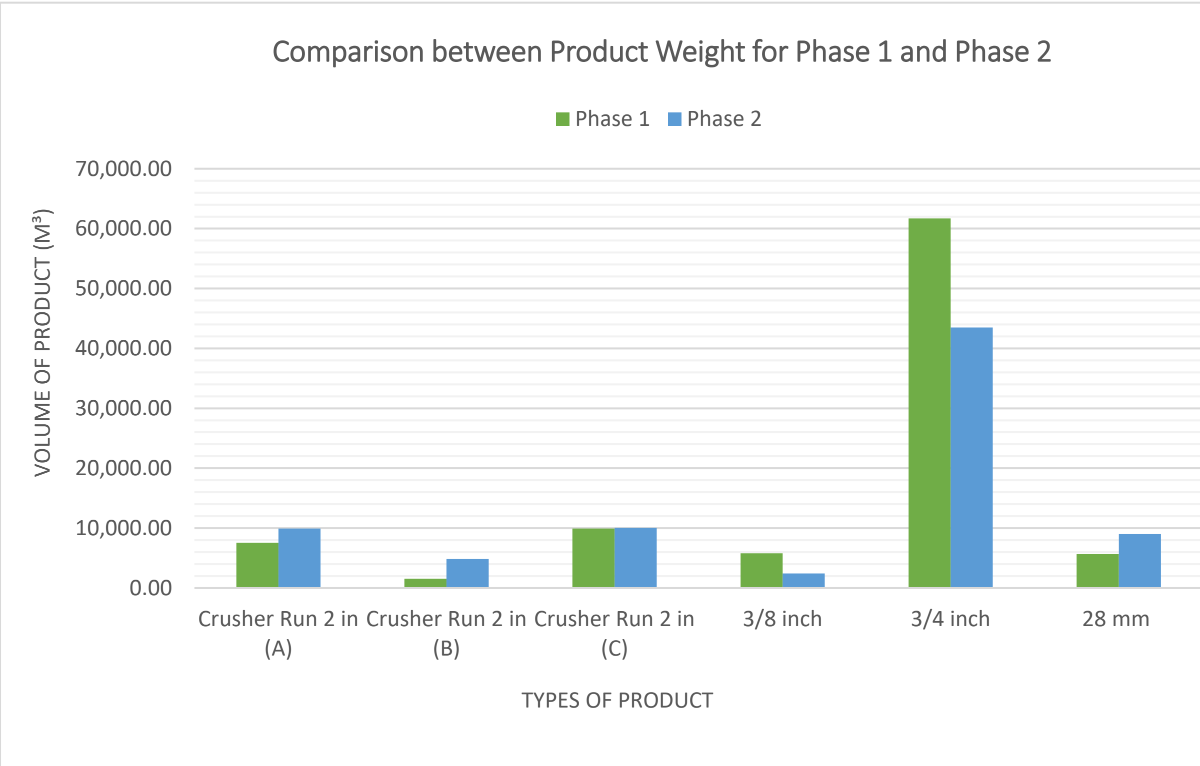

Figure 4.5. Comparison between Phase 1 and Phase 2 Products Weight Plot.

5. CONCLUSION

In conclusion, the use of drone mapping for volumetric calculations has proven to be a valuable tool in optimizing stockpile management. Through aerial data collection, the accuracy and efficiency of stock volume calculation have been significantly improved compared to conventional methods. This project has demonstrated the benefits of using drones for data collection and analysis.

The project's two-phase approach allowed for a more comprehensive analysis of the reserve stock, and the results have highlighted the importance of periodic drone mapping for accurate and up-to-date volumetric calculations. This approach enables the company to calculate the stock for each product without having to rely on post-sales data collection by counting the number of trucks that leave. With this method, stockpile management and administration are more effective, contributing to cost savings and increased productivity.

The findings of this project provide a basis for future research in the field of stockpile management and drone mapping, and they have practical implications for the mining and construction industries. The successful implementation of this technology can result in more efficient and effective stockpile management, improving operations, and reducing risks in these industries.

APPENDIX

LABEL	PRODUCT	VOLUMES (m³)		VOLUME (m³)
		CUT	FILL	
1	Crusher Run 2 in Limestone (A)	192.62	0.08	192.54
2	Crusher Run 2 in Limestone (A)	727.48	1.64	725.84
3	Crusher Run 2 in Limestone (A)	5,703.24	38.03	5,665.21
4	Crusher Run 2 in Limestone (B)	298.01	0.58	297.43
5	Crusher Run 2 in Limestone (B)	2,472.32	1.06	2471.26
6	Crusher Run 2 in Limestone (B)	176.18	0.67	175.51
7	Crusher Run 2 in Limestone (C)	6,897.96	49.62	6,848.34
8	28 mm	6,001.71	2.26	5,999.45
9	28 mm	574.85	1.53	573.32
10	3/8 in Limestone	845.68	1.95	843.73
11	3/8 in Limestone	800.41	0.67	799.74
12	3/4 in Limestone	28,334.04	12.79	28,321.25
13	3/4 in Limestone	1,160.96	9.01	1,151.95
14	3/4 in Limestone	1,016.9	1.19	1,015.71

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JALAN KANGAR-ALOR SETAR,
01000 KANGAR, PERLIS.

PENS INDUSTRIES SDN. BHD.
KM5, JALAN BUKIT AYER,
SUNGAI BATU PAHAT,
01000 KANGAR, PERLIS.

TITLE:

VOLUME AREAS TABLE OF PENS INDUSTRIES SDN. BHD. STOCKPILE PRODUCT

SCALE: (1 : 6,000)

NOTE:
1. This area was surveyed by Unmanned Aerial System (UAS).
2. Ground Sampling Distance (GSD) is 3.94 cm.
3. All measurement are in meters (m).
4. Coordinate system in Geodetic Datum Malaysia 2000 (GDM2000).
5. Contour interval 5 meters Height above mean sea level in meters.
6. This map is NOT an authority on boundaries.

FILE NO: COEUAS/PISB/VAT/20200120

No	Product	Volume, **v** (m³)	Weight per cage ,**w** (kg)	Density, **d** (kg/m³) **d** = w/x	Density, **D** (ton/m³) **D** = d/1000	Weight, **W** (ton) **W** = v × D
1	Crusher Run 2 in Limestone (A)	6,583.59	1090	1,509.33	1.51	9,936.79
2	Crusher Run 2 in Limestone (B)	2,944.2	1190	1,647.80	1.65	4,851.45
3	Crusher Run 2 in Limestone (C)	6,848.34	1060	1,467.79	1.47	10,051.90
4	3/8 inch Limestone	1,643.47	1080	1,495.48	1.50	2,457.78
5	3/4 inch Limestone	30,488.91	1030	1,426.25	1.43	43,484.66
6	28 mm Limestone	6,572.77	990	1,370.86	1.37	9,010.33
Total of volume (m³)		55,081.28		Total of weight (ton)		79,792.90

INFORMATION:
1. The volume of cage, x is 0.722176 m³.

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01000 KANGAR, PERLIS.

PENS INDUSTRIES SDN. BHD.
KM5, JALAN BUKIT AYER,
SUNGAI BATU PAHAT,
01000 KANGAR, PERLIS.

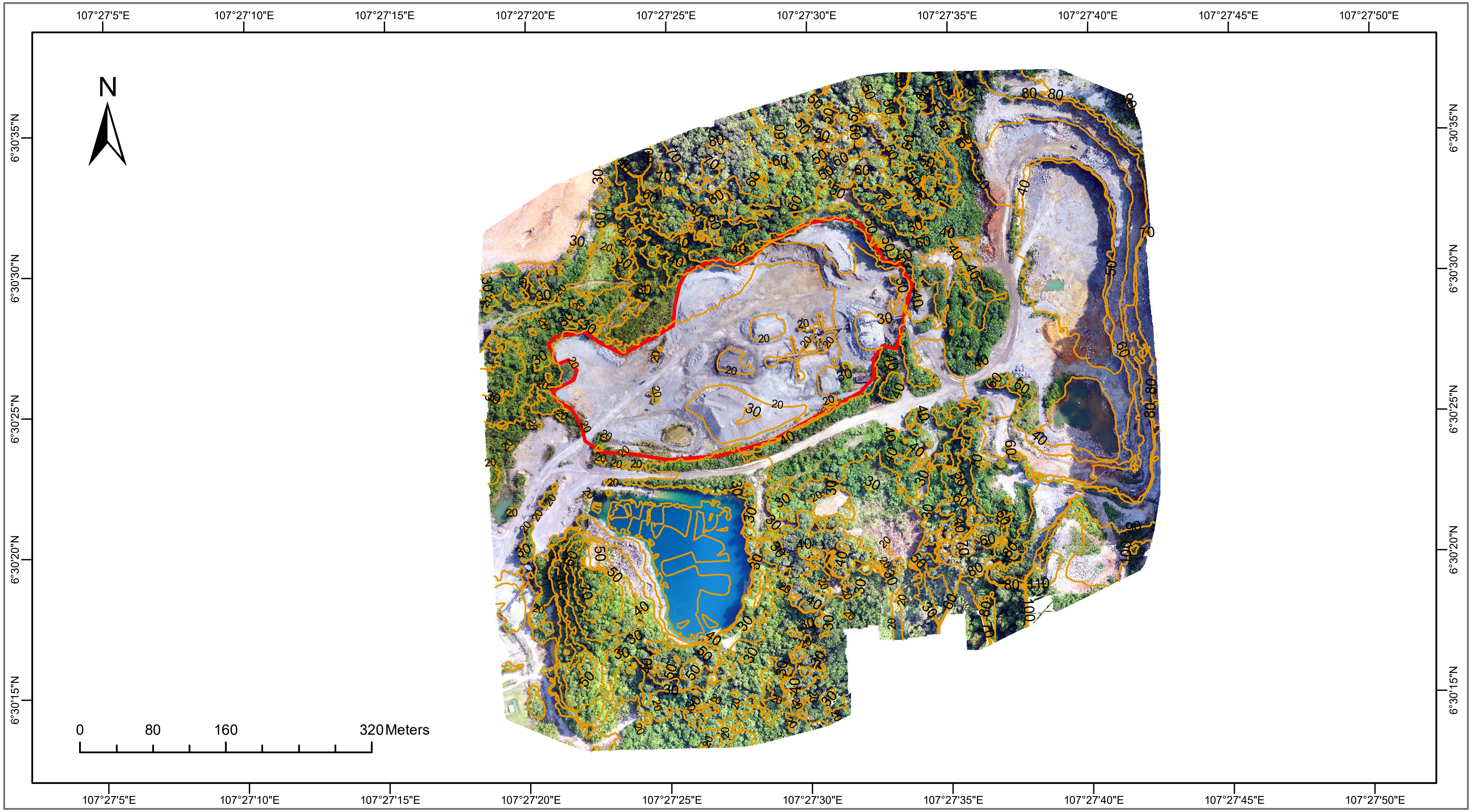
TITLE:

DENSITY AND MASS CALCULATION OF PENS INDUSTRIES SDN. BHD. STOCKPILE PRODUCT

SCALE: (1 : 6,000)

NOTE:
1. The total volume of stockpile product is 55,081.28 m³.
2. The total weight of stockpile product is 79,792.90 tons.

FILE NO: COEUAS/PISB/DMC/20200120



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JALAN KANGAR-ALOR SETAR,
01000 KANGAR, PERLIS

TITLE:

ORTHOPHOTO PLAN OF PENS INDUSTRIES SDN. BHD. STOCKPILE PRODUCT

SCALE: (1 : 6,000)

NOTE:

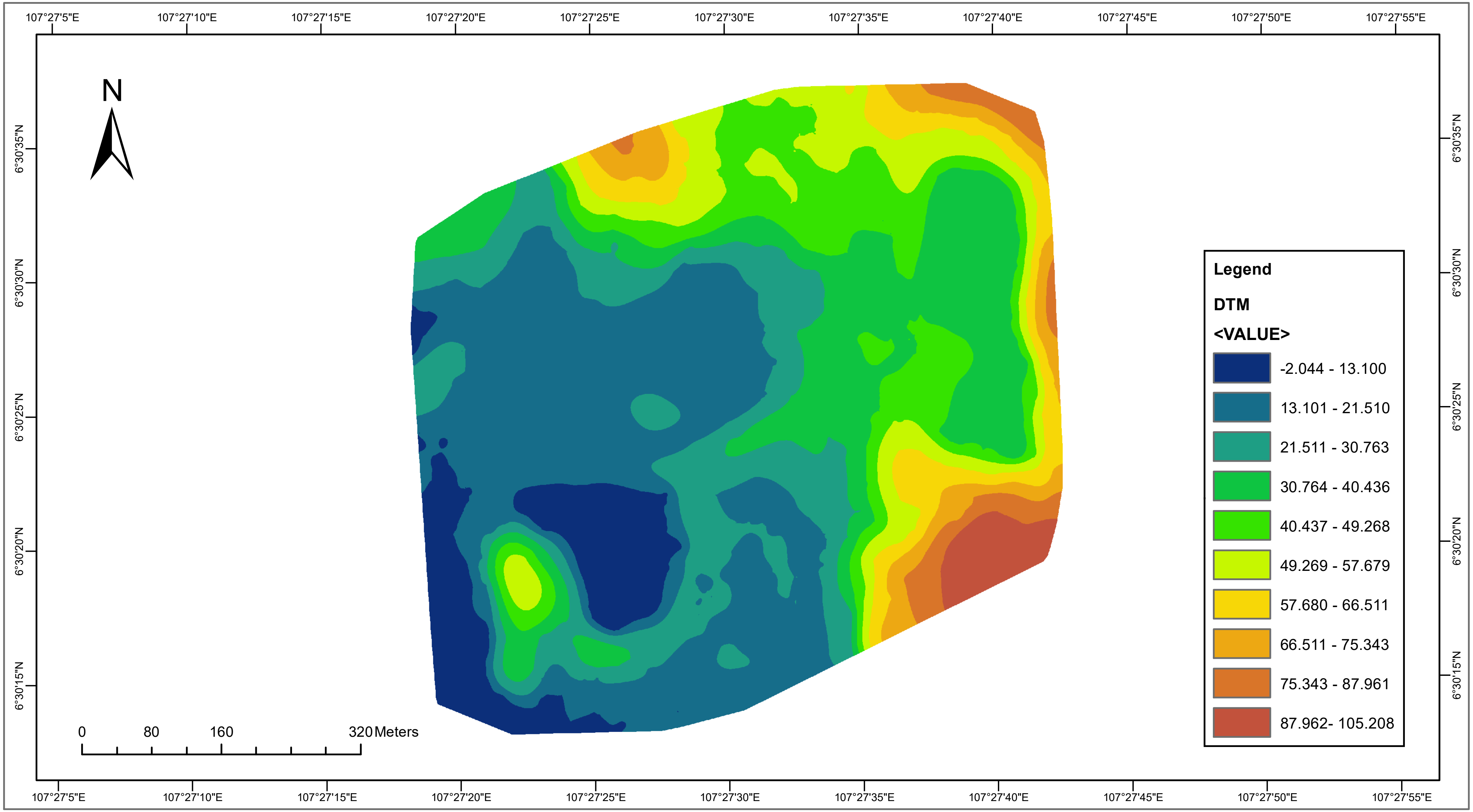
1. This area was surveyed by Unmanned Aerial System (UAS).
2. Ground Sampling Distance (GSD) is 3.94 cm.
3. All measurement are in meters (m).
4. Coordinate system in World Geodetic System 1984 (WGS84).
5. Contour interval 10 meters Height above mean sea level in meters.
6. This map is NOT an authority on boundaries.

FILE NO: COEUAS/PISB/OP/20200120

Legend

Contour

Product Stockpile Area



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01000 KANGAR, PERLIS

PENS INDUSTRIES SDN BHD (PKENPs)
KM 5 JALAN BUKIT AYER,
SG. BATU PAHAT,
01000 KANGAR, PERLIS

TITLE:

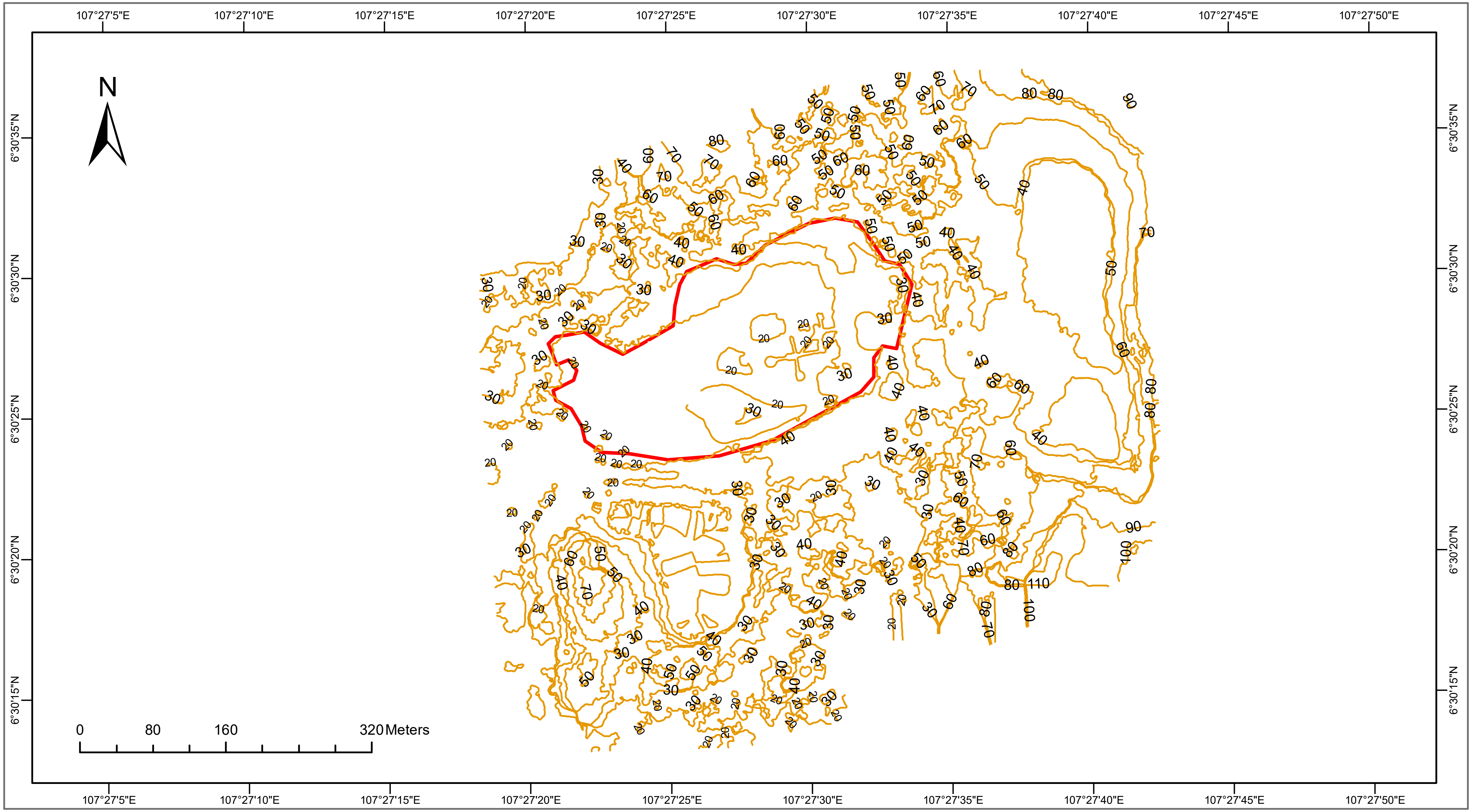
DIGITAL TERRAIN MODEL (DTM) OF PENS INDUSTRIES SDN. BHD. STOCKPILE PRODUCT

NOTE:

1. This area was surveyed by Unmanned Aerial System (UAS).
2. Ground Sampling Distance (GSD) is 3.94 cm.
3. All measurement are in meters (m).
4. Coordinate system in World Geodetic System 1984 (WGS84).
5. Contour interval 10 meters Height above mean sea level in meters.
6. This map is NOT an authority on boundaries.

SCALE: (1 : 6,000)

FILE NO: COEUAS/PISB/DTMP/20200129



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JALAN KANGAR-ALOR SETAR,
01000 KANGAR, PERLIS

TITLE:

CONTOUR PLAN OF PENS INDUSTRIES SDN. BHD. STOCKPILE PRODUCT

SCALE: (1 : 6,000)

NOTE:

1. This area was surveyed by Unmanned Aerial System (UAS).
2. Ground Sampling Distance (GSD) is 3.94 cm.
3. All measurement are in meters (m).
4. Coordinate system in World Geodetic System 1984 (WGS84).
5. Contour interval 10 meters Height above mean sea level in meters.
6. This map is NOT an authority on boundaries.

FILE NO: COEUAS/PISB/CP/20200120

Legend

Contour

Product Stockpile Area

Quality Report

Generated with Pix4Dmapper version 4.3.15 Preview

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	SP 3
Processed	2019-07-16 16:49:12
Camera Model Name(s)	FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(1), FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(2), FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(3)
Average Ground Sampling Distance (GSD)	3.83 cm / 1.51 in
Area Covered	0.435 km^2 / 43.4791 ha / 0.17 sq. mi. / 107.4948 acres

Quality Check

Images	median of 59754 keypoints per image	✔
Dataset	146 out of 146 images calibrated (100%), all images enabled	✔
Camera Optimization	1.95% relative difference between initial and optimized internal camera parameters	✔
Matching	median of 17783.4 matches per calibrated image	✔
Georeferencing	yes, 6 GCPs (6 3D), mean RMS error = 0.009 m	✔

Preview

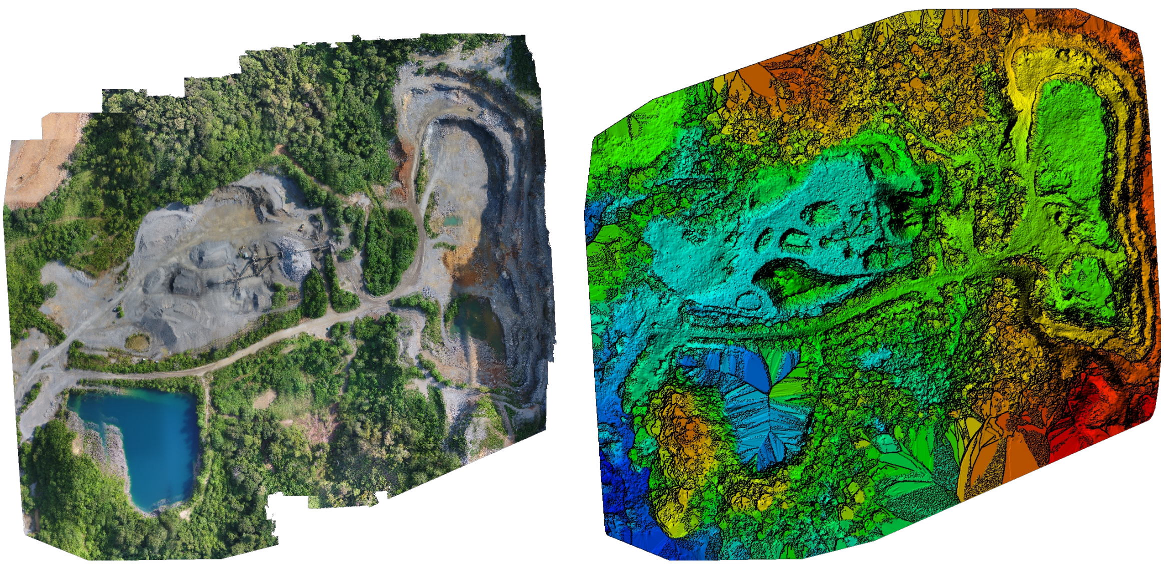


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	146 out of 146
Number of Geolocated Images	146 out of 146

Initial Image Positions

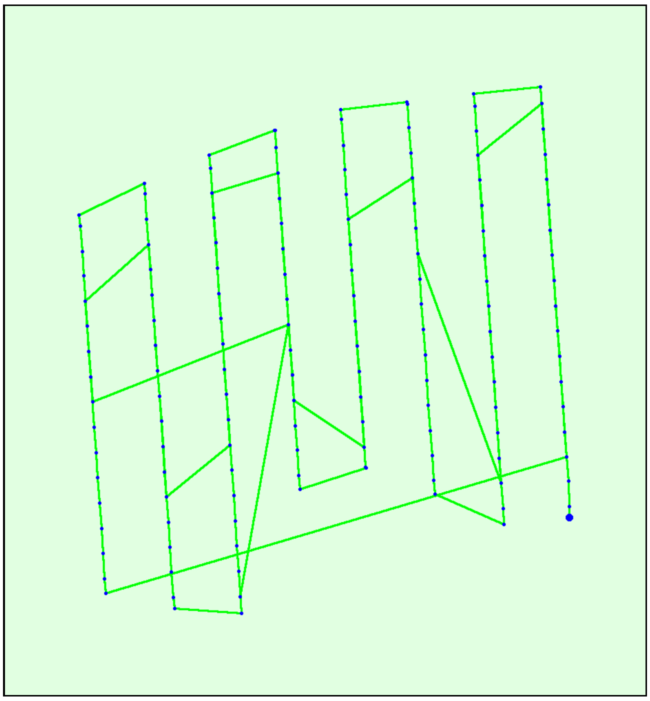
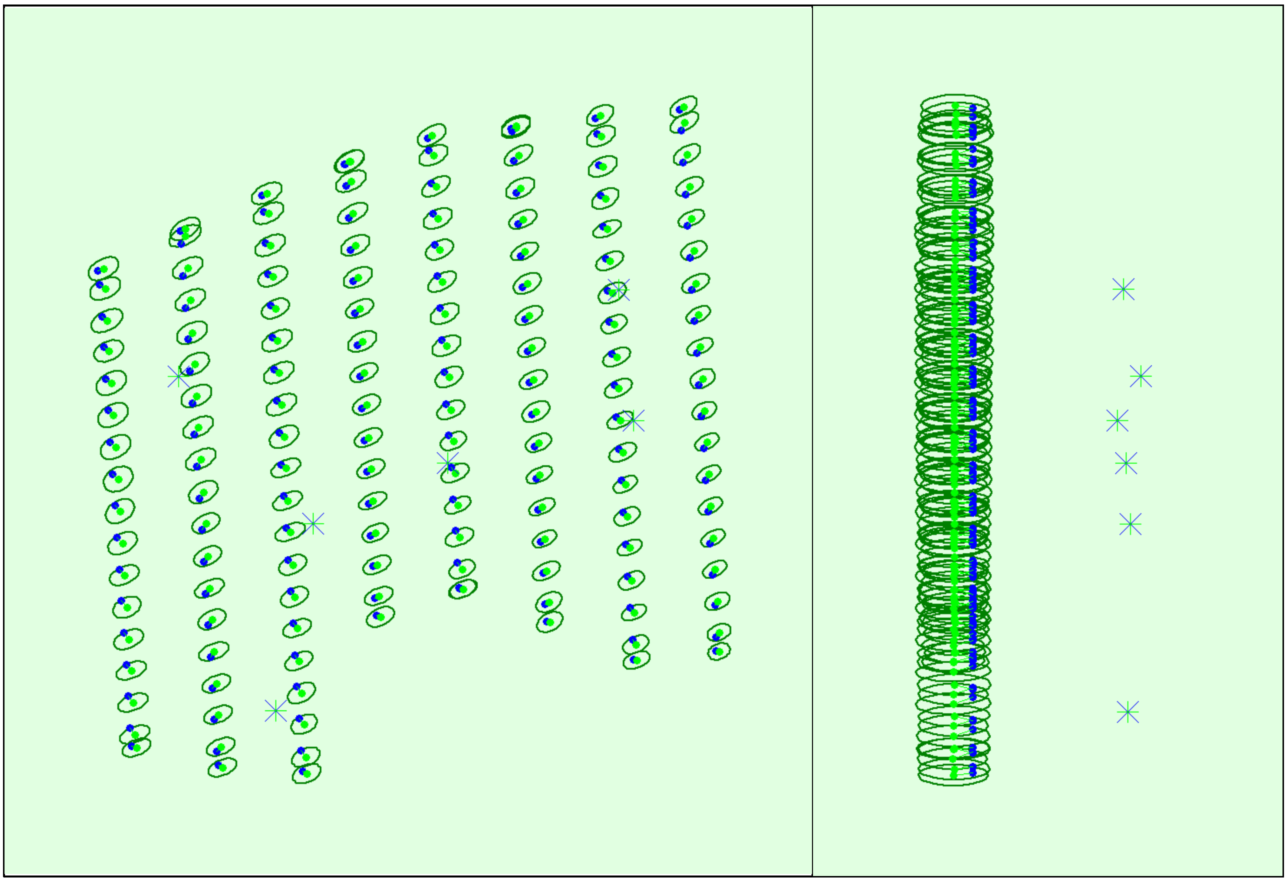
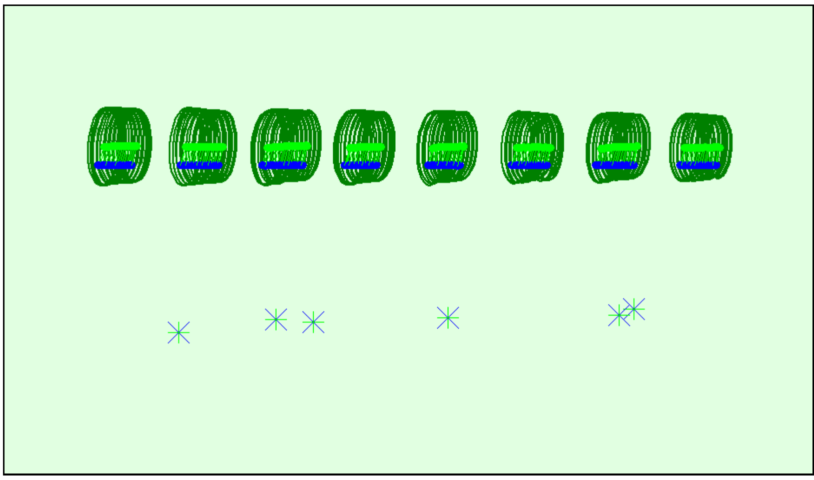


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions





Uncertainty ellipses 100x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]	Camera Displacement X[m]	Camera Displacement Y[m]	Camera Displacement Z[m]
Mean	0.139	0.103	0.345	0.013	0.007	0.003	0.005	0.006	0.017
Sigma	0.008	0.008	0.020	0.005	0.001	0.001	0.002	0.002	0.007

Overlap

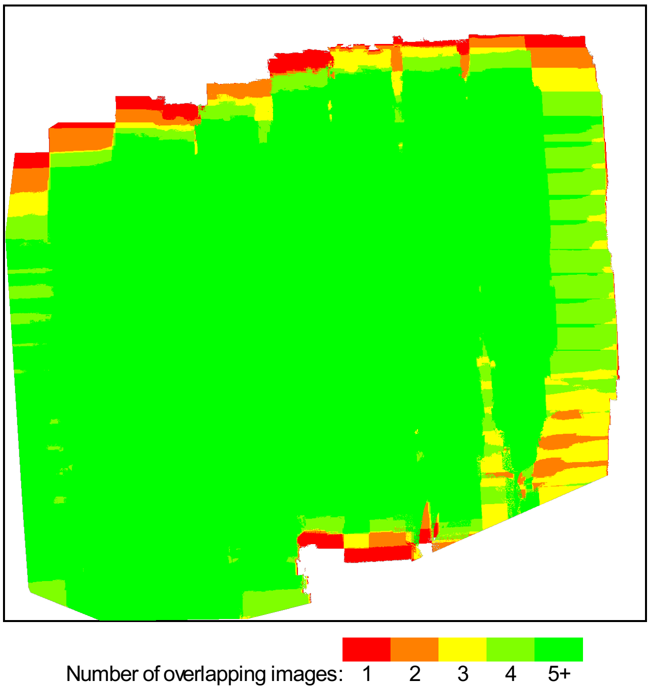


**Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).**

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	2617010
Number of 3D Points for Bundle Block Adjustment	988932

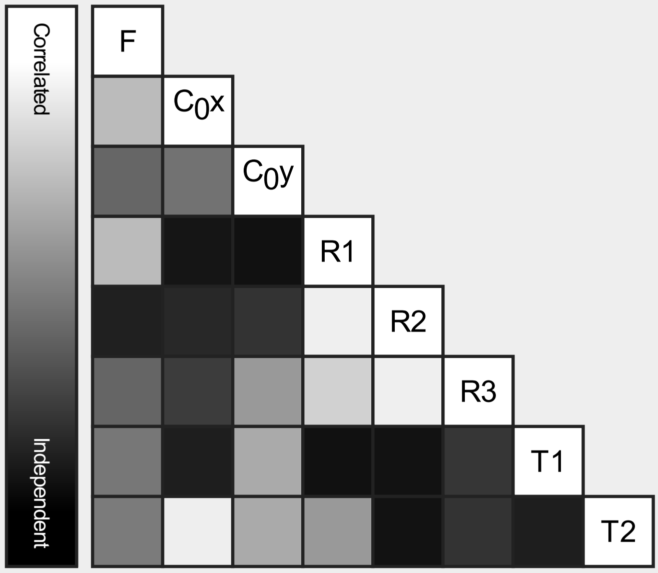
Mean Reprojection Error [pixels]	0.153

Internal Camera Parameters

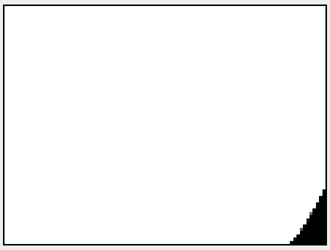
FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(1). Sensor Dimensions: 17.500 [mm] x 13.112 [mm]

EXIF ID: FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	4564.399 [pixel] 15.128 [mm]	2698.159 [pixel] 8.943 [mm]	1910.765 [pixel] 6.333 [mm]	-0.004	-0.043	0.087	-0.003	0.004
Optimized Values	4475.700 [pixel] 14.834 [mm]	2874.597 [pixel] 9.528 [mm]	2065.679 [pixel] 6.846 [mm]	0.001	-0.006	0.014	0.003	0.003
Uncertainties (Sigma)	9.113 [pixel] 0.030 [mm]	3.653 [pixel] 0.012 [mm]	2.468 [pixel] 0.008 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



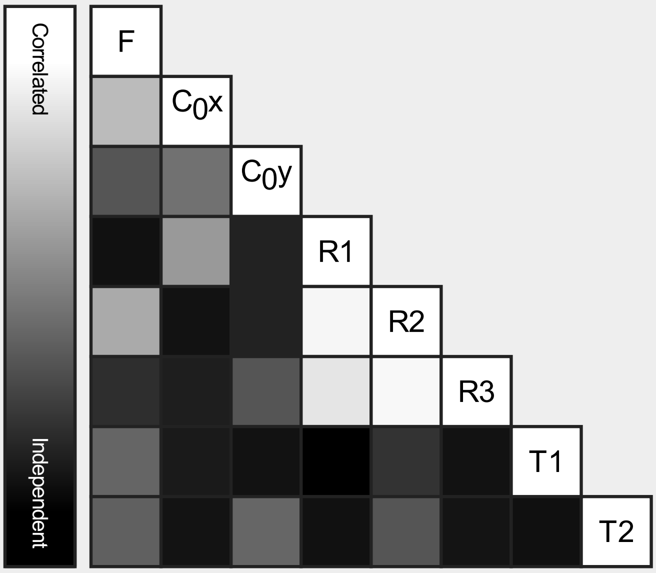
The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to the see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

Internal Camera Parameters

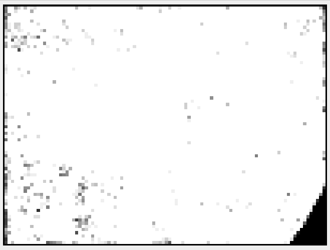
FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(2). Sensor Dimensions: 17.500 [mm] x 13.112 [mm]

EXIF ID: FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	4564.399 [pixel] 15.128 [mm]	2698.159 [pixel] 8.943 [mm]	1910.765 [pixel] 6.333 [mm]	-0.004	-0.043	0.087	-0.003	0.004
Optimized Values	4474.540 [pixel] 14.830 [mm]	2874.680 [pixel] 9.528 [mm]	2065.925 [pixel] 6.847 [mm]	0.000	-0.004	0.012	0.003	0.003
Uncertainties (Sigma)	9.111 [pixel] 0.030 [mm]	3.657 [pixel] 0.012 [mm]	2.550 [pixel] 0.008 [mm]	0.000	0.001	0.001	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



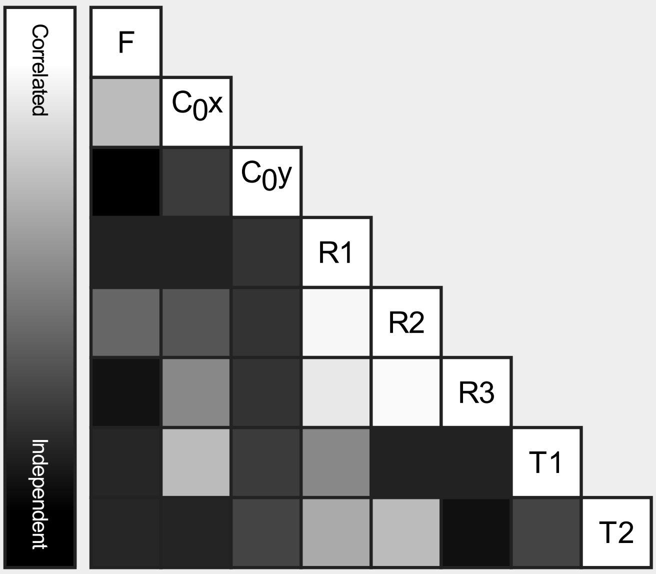
The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to the see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

Internal Camera Parameters

FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(3). Sensor Dimensions: 17.500 [mm] x 13.112 [mm]

EXIF ID: FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	4564.399 [pixel] 15.128 [mm]	2698.159 [pixel] 8.943 [mm]	1910.765 [pixel] 6.333 [mm]	-0.004	-0.043	0.087	-0.003	0.004
Optimized Values	4475.277 [pixel] 14.833 [mm]	2874.006 [pixel] 9.526 [mm]	2051.525 [pixel] 6.800 [mm]	0.003	-0.012	0.020	0.003	0.004
Uncertainties (Sigma)	9.175 [pixel] 0.030 [mm]	3.706 [pixel] 0.012 [mm]	4.402 [pixel] 0.015 [mm]	0.001	0.002	0.003	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.

The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to the see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	59754	17783
Min	36967	6551
Max	79752	43089
Mean	59515	17925

2D Keypoints Table for Camera FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(1)

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	60205	17886
Min	39121	6551
Max	79752	43089
Mean	59959	17962

2D Keypoints Table for Camera FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(2)

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	57195	17350
Min	36967	8155
Max	79430	30517
Mean	57420	17456

2D Keypoints Table for Camera FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB)(3)

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	72706	0
Min	43334	20398
Max	72706	22237
Mean	58020	21318

Median / 75%/ Maximal Number of Matches Between Camera Models

	FC6520_DJIMF...(RGB) (1)	FC6520_DJIMF...(RGB) (2)	FC6520_DJIMF...(RGB) (3)
FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB) (1)	297 / 1511 / 40803	435 / 1689 / 21672	257 / 2478 / 17113
FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB) (2)		470 / 1486 / 6340	557 / 680 / 3246
FC6520_DJIMFT15mmF1.7ASPH_15.0_5280x3956 (RGB) (3)			

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	706419
In 3 Images	149527
In 4 Images	57213
In 5 Images	27299
In 6 Images	13944

In 7 Images	10031
In 8 Images	8211
In 9 Images	6411
In 10 Images	4434
In 11 Images	1809
In 12 Images	1103
In 13 Images	970
In 14 Images	728
In 15 Images	646
In 16 Images	170
In 17 Images	17

2D Keypoint Matches

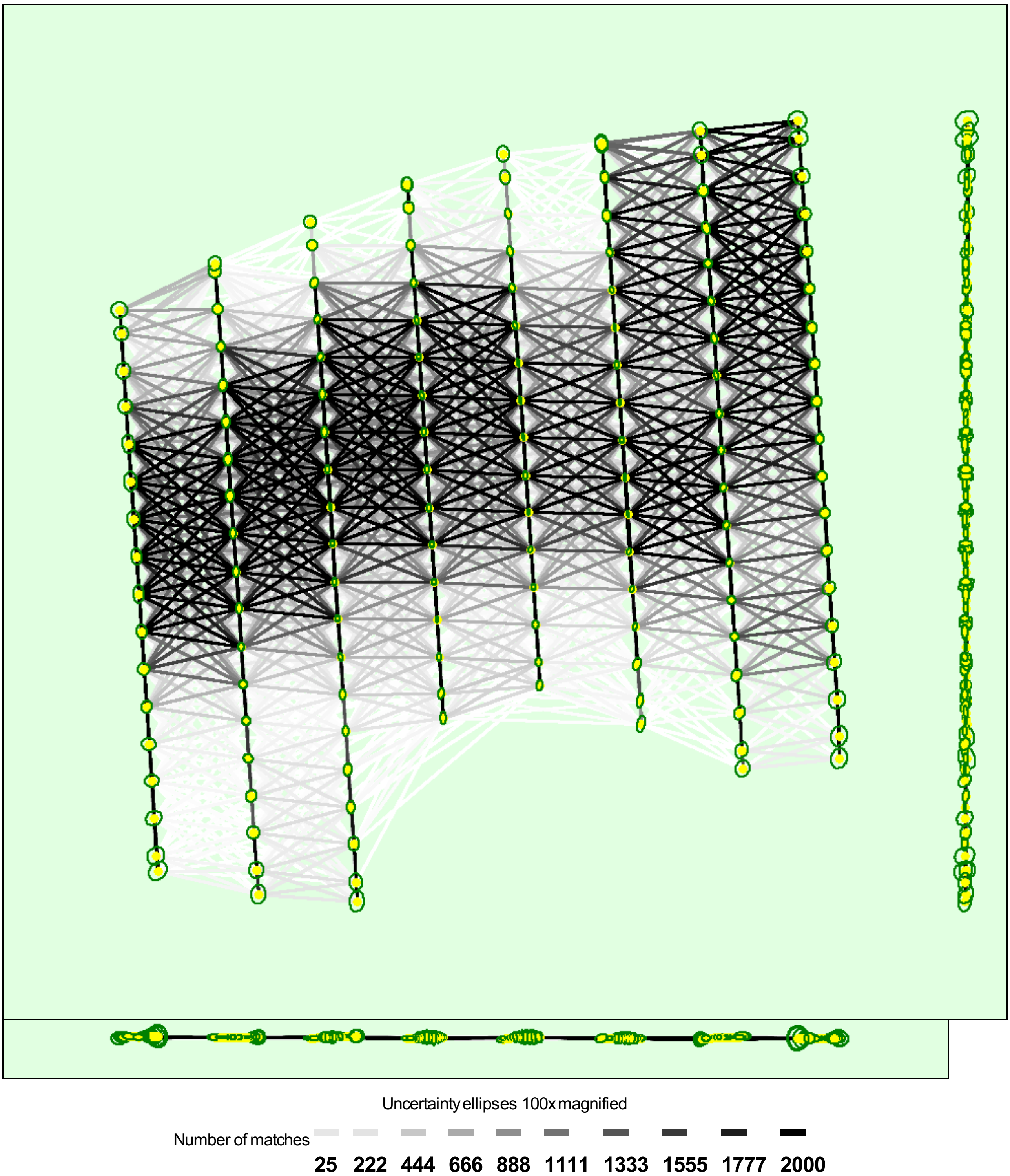


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]	Camera Displacement X [m]	Camera Displacement Y [m]	Camera Displacement Z [m]
Mean	0.037	0.049	0.034	0.023	0.021	0.013	0.006	0.011	0.017
Sigma	0.018	0.017	0.019	0.007	0.008	0.005	0.002	0.001	0.004

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
GCP1 (3D)	0.020/ 0.020	0.001	0.002	-0.002	0.160	15 / 15
GCP2 (3D)	0.020/ 0.020	0.007	-0.003	0.018	0.112	8 / 8
GCP3 (3D)	0.020/ 0.020	-0.001	-0.000	-0.002	0.134	7 / 7
GCP4 (3D)	0.020/ 0.020	-0.005	-0.007	-0.002	0.158	12 / 12
GCP5 (3D)	0.020/ 0.020	-0.011	0.007	-0.011	0.195	10 / 10
GCP6 (3D)	0.020/ 0.020	0.015	0.005	0.033	0.190	4 / 4
Mean [m]		0.001039	0.000532	0.005754		
Sigma [m]		0.008274	0.004609	0.015148		
RMS Error [m]		0.008339	0.004639	0.016204		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	11.64	0.00
-6.00	-3.00	0.00	22.60	0.00
-3.00	0.00	55.48	15.75	49.32
0.00	3.00	44.52	13.70	50.68
3.00	6.00	0.00	28.08	0.00
6.00	9.00	0.00	8.22	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-4.545160	-0.043112	-18.001694
Sigma [m]		0.578433	4.614224	0.609974
RMS Error [m]		4.581819	4.614426	18.012025

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Geolocation Bias	X	Y	Z
Translation [m]	-4.545160	-0.043112	-18.001694

Bias between image initial and computed geolocation given in output coordinate system.

Relative Geolocation Variance

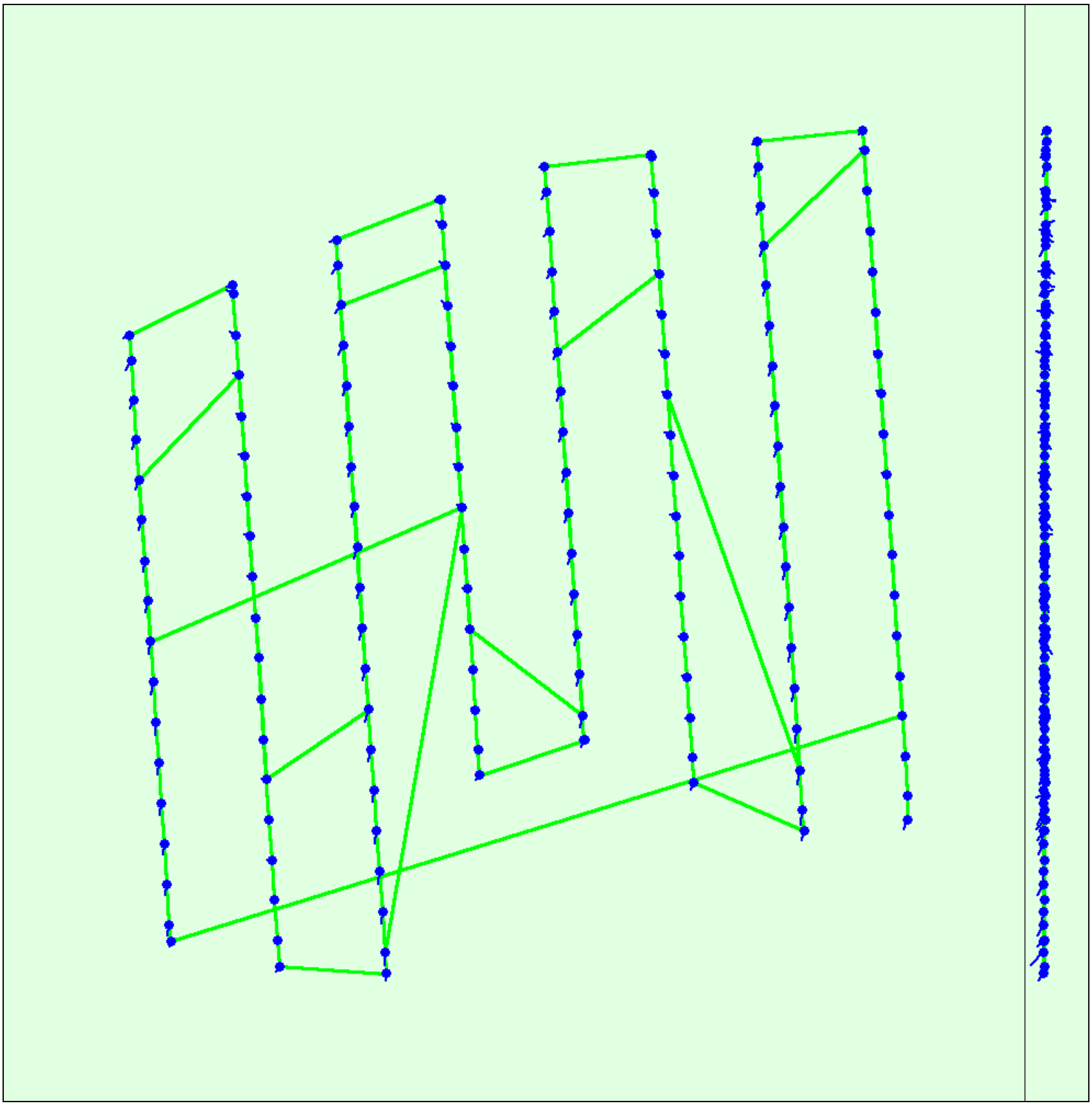
Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	59.59	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.925
Phi	0.280
Kappa	1.013

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Rolling Shutter Statistics



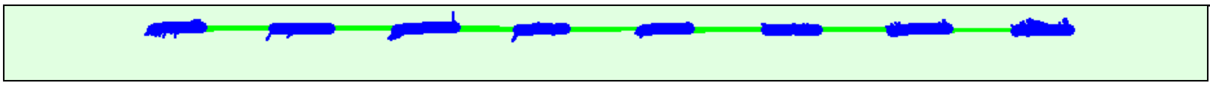


Figure 6: Camera movement estimated by the rolling shutter camera model. The green line follows the computed image positions. The blue dots represent the camera position at the start of the exposure. The blue lines represent the camera motion during the rolling shutter readout, re-scaled by a project dependant scaling factor for better visibility.

Median Camera Speed	7.8084 [m/s]
Median Camera Displacement During Sensor Readout)	0.4667 [m]
Median Rolling Shutter Readout Time	69.5295 [ms]

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-7700 CPU @ 3.60GHz RAM: 32GB GPU: Intel(R) HD Graphics 630 (Driver: 25.20.100.6373), NVIDIA Quadro P600 (Driver: 23.21.13.8816)
Operating System	Windows 10 Pro, 64-bit

Coordinate Systems

Image Coordinate System	WGS 84 (EGM96 Geoid)
Ground Control Point (GCP) Coordinate System	WGS 84 (EGM96 Geoid)
Output Coordinate System	GDM2000 / Peninsula RSO (EGM96 Geoid)

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes

Results

Number of Generated Tiles	1
Number of 3D Densified Points	25593103
Average Density (per m^3)	45