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Low-Cost LiDAR-GNSS-UAV Technology Development for PT Garam's Three-Dimensional Stockpile Modelling Needs

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Abstract
Unmanned Aerial Vehicles (UAV), Global Navigation Satellite Systems (GNSS), and LiDAR will be combined into one of the newest technologies to cover each other's deficiencies. Surveyors can use UAV, GNSS, and LiDAR multi-sensors to map the stockpile of salt PT Garam, whereas the previous process used manual calculations. LiDAR is a survey tool with a low price, around 999 USD. To minimise operational costs, surveyors can use Low-Cost LiDAR, GNSS, and UAV at around 638 USD. The results of the data obtained are calibrated with pitch, roll, and yaw to get the vertical height of the existing contours.

Keywords: LiDAR, Unmanned Aerial Vehicle, low-cost GNSS, and Contour

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1.0 Introduction

Unmanned Aerial Vehicle (UAV) technology has cost efficiency and data retrieval time advantages to calculate the volume of an object. Some use UAV applications to obtain geometric documentation results and to capture textures that characterise object structures. (Adamopoulos, 2020). LiDAR can be classified based on the number of image acquisitions processed in the software, utilising photogrammetry and structural science principles from motion point cloud technology that enables the creation of point clouds and three-dimensional models. (Barba, et al. 2019).UAV platforms can be equipped with sensors with high-temporal resolution, high-spatial, and high-spectral specifications. Tool in the form of LiDAR can be used in urban areas as observation material by building a suitable model or algorithm based on the spatial, spectral, and angular image features. (Fernández, Hernandez et.al 2015) Therefore, research tools using LiDAR require a tool such as PixHawk for integration with the GPS. (Zhenfeng, 2021) LiDAR has a disadvantage in the form of coordinate data positions that have local references. (Cahyadi., et al. 2019). The data generated by this sensor is a visualisation of an object shape made in three dimensions. This study aims to combine Low-Cost GPS measurements with Low-Cost LiDAR, which are processed using free user software. GPS Low Cost generates data in the form of position-determining latitude and longitude coordinates. The data generates X, Y, and Z values to help georeferencing process the detected object. GPS can assist in determining position and orientation to calculate a specific volume or area. The research conducted by (Malberg, J, A. 2022) to calculate the volume of salt was carried out using LiDAR with the static method by attaching the device above the warehouse ceiling. The LiDAR used is the Velodyne

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type with 30-degree rotation, seven times the acquisition time, and ten times the scanning length. This measurement method still must adapt to the size and area to obtain mass acquisition of some data.

Using technologies such as UAV, GNSS, and LiDAR will later be combined into one of the newest technologies to complete each other's advantages. This integration system aims to increase the accuracy of calculating land stockpile volume PT's Garam (Salt Company). This study uses the Taror 650 Iron Man drone with four propellers, which can fly for 15 minutes. LiDAR has a drawback in the form of coordinate data positions that have local references. LiDAR research must be combined with UAV to overcome data acquisition limitations because it only passes through the right and left sides of the object, mainly when applied to a salt stockpile. The UAV is flown to assist data acquisition with comprehensive coverage with the help of integration of the 200-gram LiDAR system so that the flying angle taken can be optimal during the flight process. Using LiDAR for low-cost mapping surveys will make it easier for surveyors and academics to obtain accurate data at a more economical price. As a survey tool, LiDAR is included in a tool with a low price, around 999 USD; this device can produce detailed data. Therefore, to minimise the operational costs of using LiDAR, surveyors can use Low-Cost LiDAR, GNSS, and UAV at a price of around 638 USD. The integration system aims to increase the accuracy of calculating the stockpile volume of PT. Garam. Therefore, researchers use GNSS, LiDAR, and drone multi-sensor technology carried out by PT to map the stockpile of salt on open land and warehouses annually. Garam twice, where the previous process used terrestrial methods and manual calculations with sacks.

2.0 Literature Review

2.1 Salt

PT Garam is committed to maintaining a continuous supply of products, so it requires technological innovation to monitor salt production results in volume with the help of drone measurement methods. According to (Mahendra, 2018), Salt is produced on the beach in bulk with a large area and depends on the dry season because it relies on the evaporation of seawater from sunlight, which leaves salt deposits. In the rainy season, salt is difficult to make in ponds because water is difficult to evaporate. Salt farmers make salt by making maps for those who have maps. To get good salt yields with large crystals, Salt farmers directly evaporate seawater, which flows on the plots with the help of windmills. The process of making it by evading sunlight is called crystallisation, which separates the mixture/solute from its dissolution using heating or absorption of heat based on its boiling point. In the Salt Land Stockpile, it is deposited for 5 - 10 days with a water depth of ±5 cm.

2.2 LiDAR

LiDAR is an active remote sensing system that uses a laser beam to generate information that has the characteristics of the topography of the land surface in a horizontal and vertical position. LiDAR data can outperform multispectral cameras that produce RGB maps, giving a panoramic view of buildings. Data from a 360-degree panorama is generated from a mobile LiDAR process that moves during the acquisition process so that the resulting photo data is enough to create a point cloud. LiDAR cameras have advantages based on paper (Diego Ronchi et al., 2020).

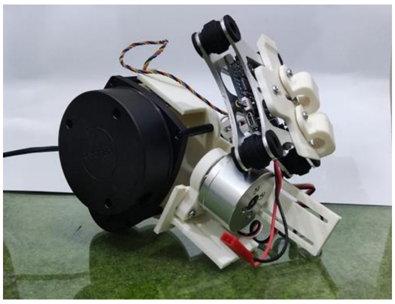


Fig 1. RPLIDAR A1M8-R6

The type of Lidar that is used is in Fig 1. It has an object scanning sensor using a 2D laser beam with a 360-degree angle that SLAMTEC developed. This LiDAR technology can check within 12 meters and have a 360-degree angle range. The resulting data is in a 2D form, which can be used for mapping, localisation, and environmental modelling. The RPLIDAR A1 scan frequency reaches 5.5Hz and can scan up to 360 samples per round, and the frequency can be set up to a maximum of 10Hz. The RPLIDAR A1 operates well in indoor and outdoor environments without sunlight.

2.3 Drone

UAV technology is used to obtain geometric documentation results and capture textures that characterise object structures. (Adamopoulos, 2020). Since the use of the Mobile Mapping method was developed at Ohio State University in the 1990s, it has become a correlation test method and multispectral image processing in geospatial data acquisition in the form of a Digital Terrain Model (DTM) by utilising light and range detection flights in the form of LiDAR (Light Detection and Ranging).) of the UAV (Unmanned Autonomous Vehicle). (Adamopoulos, 2020).

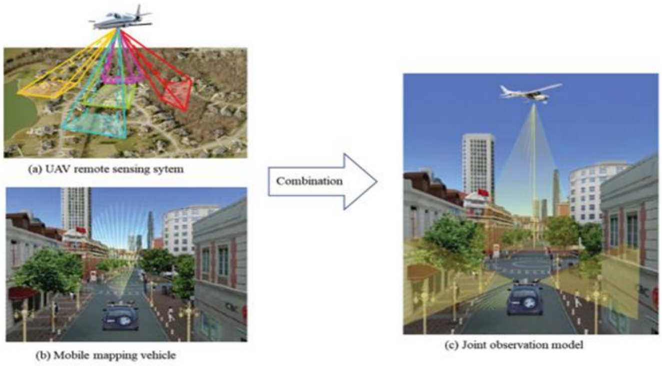


Fig 2. A Spatio-temporal spectral angular observation model that combines observations from UAVs and vehicle cellular mapping.
(Shao, Zhenfeng 2021)

According to (Shao, Zhenfeng 2021), Theoretically, both UAV platforms and mobile mapping vehicle platforms can be equipped with sensors with high-temporal, high-spatial, and high-spectral resolution. Remote sensing is used for urban areas as an observation material achieved by building appropriate models or algorithms based on spatial, spectral, and shape features. Therefore, research conducted by LiDAR uses PixHawk for integration with the GPS. In aerial photogrammetry, images are oriented using ground control points. The movement of the drone vehicle is activated during acquisition, causing 3D scanning distortion; researchers use visual odometry in the form of knowing the perpendicular phase to reduce distortion. In matching point clouds in overlapping images from stereo camera pairs, the researcher determined the correlation coefficient between local image patches at the feature points to the left and right of the overlapping images. (Lasse Klingbeil, 2014)

2.4 IMU (Inertial Measurement Unit)

Groves (2008), IMU generally consists of 2 sensors, namely an accelerometer and a gyroscope, but some IMUs are developed by combining additional inertial sensors to protect against single-sensor failure. The acceleration and velocity information generated by the IMU can then be reduced to position information, although this position information is less accurate than GPS. The UAV platform, as well as the mobile mapping vehicle platform, can be equipped with sensors with high-temporal, high-spatial, and high-spectral resolution. Remote sensing is used for urban areas as an observation material achieved by building appropriate models or algorithms based on spatial, spectral, and shape features.

2.5 3D Modelling Level Of Detail

Biljecki (2013), in geomatics and cartography, illustrates that the map scale is the ratio of the distance on paper to the distance from the mapped real-world object. The following is the level of detail: LoD 0 For each building or building represented by a horizontal polygon with a well-defined absolute and constant height.

Fig 3. Visualisation of the detected salt *Biljecki (2013),*

Salt represents the product in level one detail as if in Figure 3. Salt is visualised in the form of a group of details because it is enough to give an overview of salt that does not have a certain level of detail. For each building or building part, a simple geometric outermost is represented by a horizontal or vertical outer surface and a simplified roof shape. All types of surfaces and ancillary building elements can be described as defined objects.

3.0 Methodology

3.1 Flow Chart Acquisition

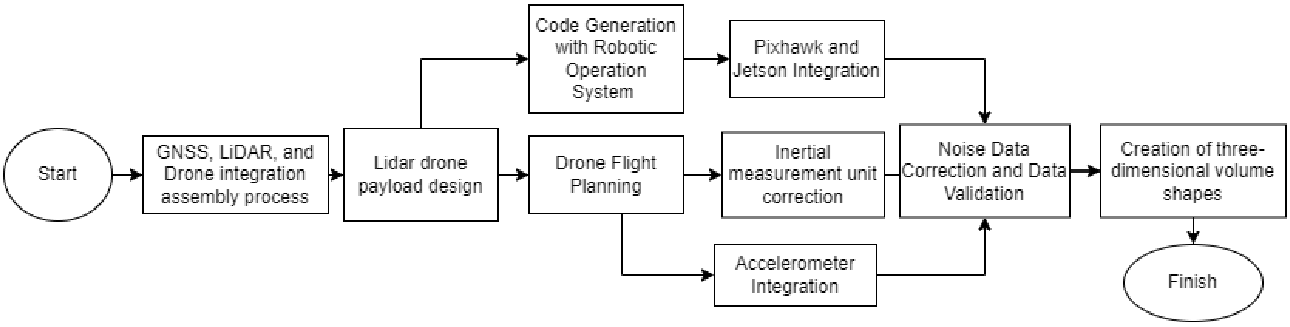


Fig 4. Flow Chart of Data Acquisition

Figure 4 shares how the low-cost GPS generates data in position-determining latitude and longitude coordinates to help georeferencing process the detected object. An accelerometer is an IMU inertial sensor to measure the orientation of a moving vehicle with angular velocity output. The acceleration and speed information generated by the IMU is reduced to position information, although it is less accurate than GPS. PixHawk and Jetson for integration with GPS and LiDAR systems. Photogrammetric data processing is then used as an input model in the form of 3 dimensions in the form of spatial, spectral, and shape data.

3.2 Integration Drone Flow Diagram

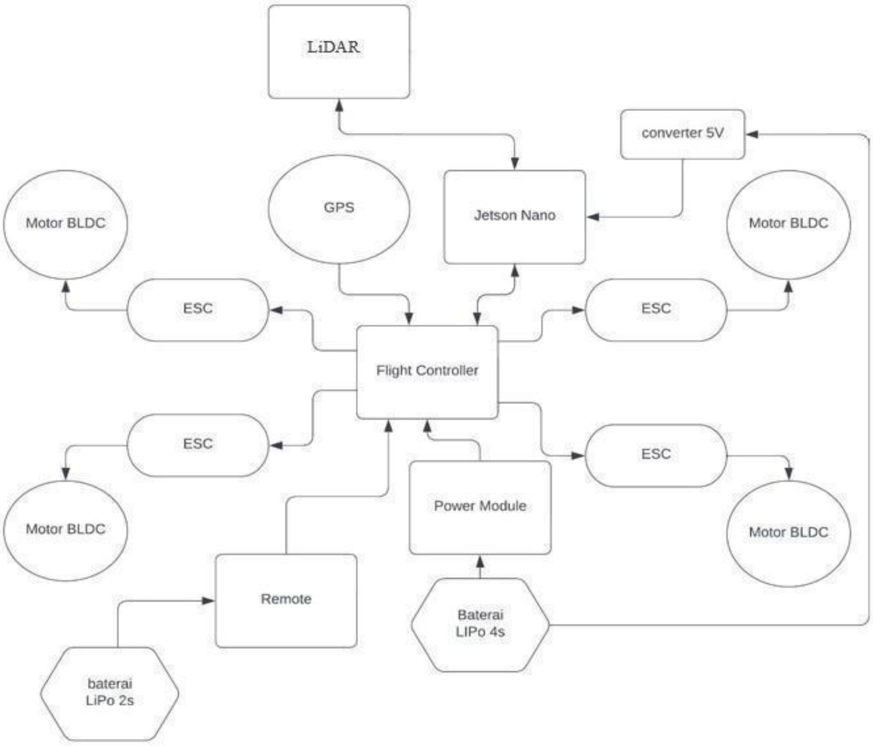


Fig 5. Flow Diagram of Drone Integration

Based on Figure 5, The picture explains the integration system with the Flight Controller. This system is integrated with three main components, namely BLDC motor, GPS for positioning, and Power modulo for energy source. Tarot Iron Man 650 Rack adopts Toray 3K carbon fibre cloth woven carbon fibre board with 3K hollow twill pure carbon fibre tube. CNC machining standards are higher than similar products, and the full racks weigh only 476 grams. Electronic stability control is a computerised technology that improves a vehicle's stability by detecting and reducing Fraction loss. RPLIDAR A1M8-R6 is a type of Lidar that has an object scanning sensor using a 2D laser beam with a 360-degree angle that was SLAMTEC developed. This LiDAR technology can scan within 12 meters and have a 360-degree angle range. The resulting data is in a 2D form, which can be used for mapping, localisation, and environmental modelling. The RPLIDAR A1 scan frequency reaches 5.5Hz and can scan up to 360 samples per round, and the frequency can be set up to a maximum of 10Hz.

4.0 Findings

4.1 Low-Cost Drone Multi-Sensor

Low-cost LiDAR drone technology integrates low-cost GPS and low-cost LiDAR built with components integrated with the Payload. Support in the form of a power module, Jetson Nano, Gimbal, and Pixhawk. The measurement has a data acquisition range in the form of a Logitech C270 camera with an 8 cm LiDAR detection capability. The LiDAR data obtained information on time, roll, pitch, yaw, altitude, latitude, longitude, compass, and lidar data with an angle range of 140-220 degrees. In data acquisition, there are 2 data points at each angle, so at a measurement of 140-220 degrees (80 degrees), there are 160 data points for each data collection. The Low-Cost Drone LiDAR has a computing capability of 100,000 pulses/second to get the volume from a stockpile with an area of 10 x 10 meters. It requires a sweeping process of 100 times.

Fig 6. Low-Cost Drone LiDAR

The Low-Cost Drone Experiment has carried out five flight tests on the roof of the building to map objects. The results of the Low-Cost Drone trial produced object coordinate data recorded in the form of a LiDAR point cloud and object coordinates X, Y, and Z. The flight experiment was conducted for 15 minutes, with a flying height of around 8-12 meters. Contours from lidar data are made based on LiDAR point cloud results obtained from measurements.

Fig 6. Data Acquisition Process

The application in Figure 6. is to plot data as a global mapper. The application can visualise point cloud data and flight paths resulting from the acquisition. Lidar inf data capability of 5 cm detects an object thickness of 0.14 meters. Lidar data acquisition based on the range of the Landing Gear drone. The results of the data obtained are calibrated with pitch, roll, and yaw to get the vertical height of the existing contours. This study conducted an experimental process on the roof of a building with a radius of approximately 30 meters.

Table 1. Data of LiDAR

Time	Roll	Pitch	Yaw	Altitude	Latitude	Longitude	Kompas	Data LiDAR
51:15,5	-0,19528	-0,33557	-168,817	47,824	-7,28396	112,7965	258,82	[‘inf:140’, ‘inf:140’,
51:15,6	-0,19531	-0,24201	-168,785	47,824	-7,28396	112,7965	258,82	[‘inf:140’, ‘inf:140’,
51:15,7	-0,18911	-0,25619	-168,761	47,824	-7,28396	112,7965	258,77	[‘inf:140’, ‘inf:140’,
51:15,8	-0,19395	-0,25374	-168,747	47,824	-7,28396	112,7965	258,75	[‘inf:140’, ‘inf:140’,
51:15,9	-0,19767	-0,27466	-168,715	47,824	-7,28396	112,7965	258,75	[‘inf:140’, ‘inf:140’,
51:16,0	-0,24257	-0,33645	-168,746	47,824	-7,28396	112,7965	258,72	[‘inf:140’, ‘inf:140’,
51:16,1	-0,25505	-0,43915	-168,74	47,814	-7,28396	112,7965	258,74	[‘inf:140’, ‘inf:140’,
51:16,2	-0,25130	-0,33767	-168,704	47,814	-7,28396	112,7965	258,71	[‘inf:140’, ‘inf:140’,
51:16,3	-0,25012	-0,43556	-168,688	47,814	-7,28396	112,7965	258,69	[‘inf:140’, ‘inf:140’,
51:15,5	-0,19528	-0,33557	-168,817	47,824	-7,28396	112,7965	258,82	[‘inf:140’, ‘inf:140’,

4.2 3D Volume Salt Stock Pile

Data collection was carried out using the drone photogrammetry method and also the terrestrial method using a Total Station (TS). This measurement was carried out on November 12, 2022, from 13.00 to 16.00 in one of the salt stockpiles at PT. Pamekasan Regency land salt. Data was collected using a drone for 15 minutes, while the TS measurement was carried out for 1 hour. The following results in determining the stockpile volume of salt between drone photogrammetry and terrestrial methods using a total station (TS).

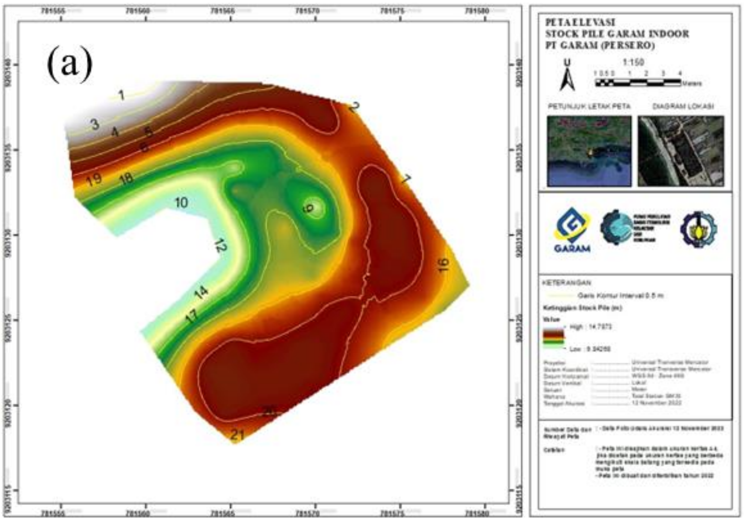


Fig 7. Volume using Total Station

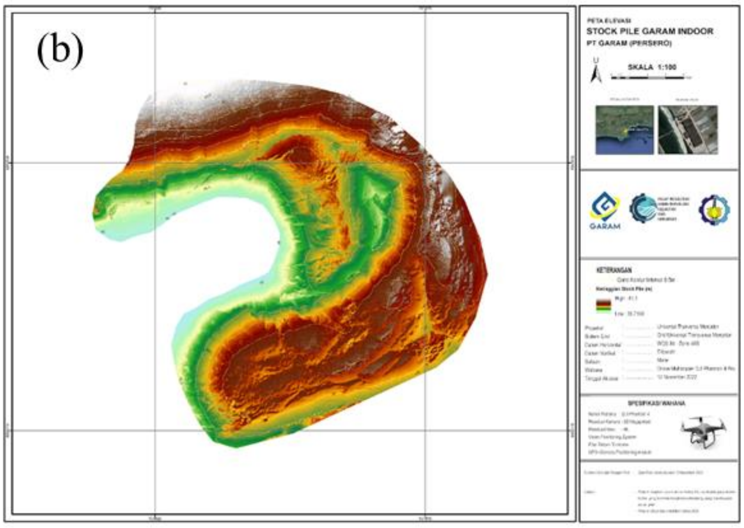


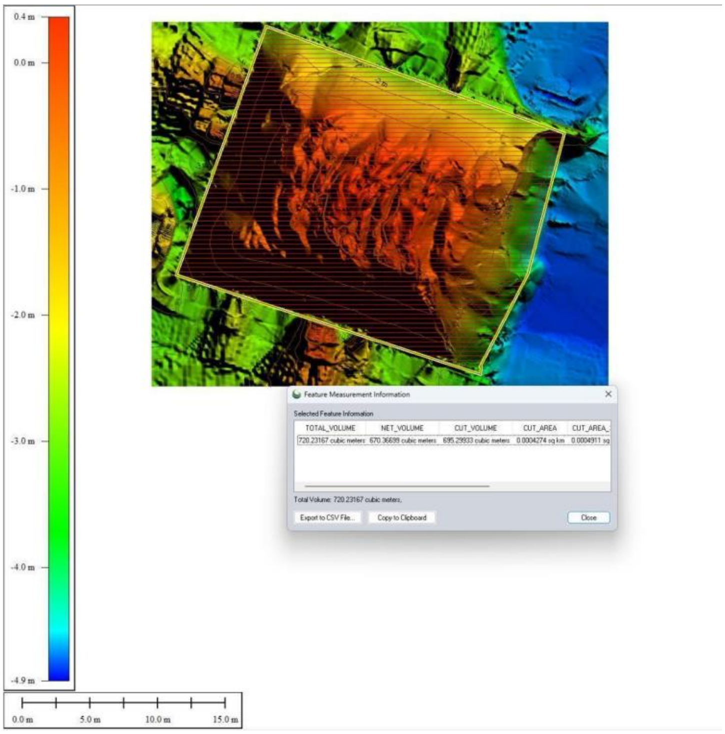
Fig 8. Stockpile Volume Using Drones

Table 2. Comparison of Salt Stockpile Volume Results

Total Station Volume (m^3)	Drone Volume (m^3)	Difference Volume (m^3)
604,423	608,757	4,334

According to Ghilani and Wolf (2015), direct volume measurements are rarely used in surveys because it is challenging to apply units of measurement to the materials involved. On the other hand, indirect measurements are obtained by measuring the length and area that are related to the desired volume. Three principles are used in volume calculations, including the average cross-section method, borrow-pit, and contour (Ghilani & Wolf, 2015). This study uses the average cross-sectional method because the shape of the salt volume is not symmetrical and has the same base area.

Fig. 9 Salt Stockpile Measurements with LiDAR Drones



Selected Feature Information

TOTAL_VOLUME	NET_VOLUME	CUT_VOLUME	CUT_AREA	CUT_AREA_
720.23167 cubic meters	670.36699 cubic meters	695.29933 cubic meters	0.0004274 sq km	0.0004911 sq

Total Volume: 720.23167 cubic meters.

Fig. 10 Calculation of Lidar Volumes

In Figure 10. Contours and volumes are made based on LiDAR point cloud results obtained from measurements. Contour calculations are processed in the Global Mapper software with adjusted contour intervals based on the point spacing of the LiDAR point cloud that has been generated from measurement trials. The volume of salt produced is 720.23167 cubic meters. These measurements produce more accurate measurements because they can measure volume with point clouds; if using a drone, it is only based on image processing from aerial photographs, and the total station method requires a large number of measurement points.

5.0 Discussion

The research results show that the combination of LiDAR, GNSS, and GPS can be used as a reference to measure the volume of salt in outdoor situations because they can move around freely. The more points that can be identified as tie points in each photo, the more detailed and faster the reconstruction processes will be. All pixels in all images are used so that the compact model has a resolution similar to the raw photo (100 - 1000 dots/sqm). Measuring the volume of salt carried out using a combination of drones can produce a volume difference between conventional and aerial methods with a value of 4,334 m^3. This Measurement produces a tool that is easier to use than previous research. In research that has been conducted previously, Measurement that Malberg, J used. A (2022) could be effectively carried out inside the room. However, the method has less mobility since the device is only static in one room.

6.0 Conclusion and Recommendations

For better performance, LiDAR data must be cleaned of noise. The height of the cloud point is depicted through colouring, where the red point is the highest point of the detected object. The function of this representation is to show the dynamics of the object height, which is modelled based on one of the object height data in the field. Salt stockpile volume measurements were carried out using several methods, one of which is using a low-cost lidar drone. The results show that in the same coverage area, low-cost LIDAR drones require a shorter time to acquire data, which is only 15 minutes, compared to the terrestrial method, which takes 1 hour. Drone measurements are more optimally carried out in open fields on a mass measurement scale, total station measurements are carried out when drones cannot be flown because of dense salt fields, and Low-Cost GNSS measurements can be carried out in open fields. 4. The results of the research analysis can be used as a reference regarding the development of salt production areas, especially in the Pamekasan Regency, to increase regional productivity. Low-cost drone Measurements require improvements to determine the reference flight height and adjustments to the acquisition time to make data filtering easier.

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Paper Contribution to Related Field of Study

Imply a technological initiative to develop cost-effective LiDAR-GNSS-UAV (Light Detection and Ranging-Global Navigation Satellite System-Unmanned Aerial Vehicle) technology tailored for three-dimensional stockpile modelling requirements at PT Garam.

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