FUSION OF UAV-BASED LIDAR AND MOBILE LASER SCANNING DATA FOR CONSTRUCTION OF 3D BUILDING MODEL

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ABSTRACT:

The necessity for object modelling in the three dimensions (3d) is becoming increasingly critical because of the advantage of presenting information in the natural form. In addition, advancements and sophistication in computer technology, programming, and sensors are driving factors in the growing importance of 3D applications. Building modelling is one of the 3D applications in which the data from the 3D model can support authorities in managing national development. Various techniques have been utilized worldwide to model buildings. The LiDAR system is regarded as one of the best because it generates a very accurate and dense point cloud. Nonetheless, numerous LiDAR systems are available worldwide, and it is possible to integrate different sets of point cloud data from several LiDAR platforms to construct an accurate 3D building model. For that reason, the primary purpose of this research is to generate a 3D building model from point clouds collected by different LiDAR systems. Furthermore, the efficacy of integrating point clouds from different LiDAR systems to construct 3D building models will be explored. This research was conducted inside the Ring Road, UTM, which comprises various objects, including buildings, and has topography with a relatively wide slope variation. Mobile laser scanning and UAV-based LiDAR are different LiDAR systems used in the study area to gather a very dense point cloud of building from differing perspectives. The accuracy of the generated 3D building model has been assessed using the statistical approach known as the RMSE equation. As a result, the 3D building models with RMSE error of ±0.015 meters (planimetric) and ±0.009 (horizontal) were successfully constructed. In conclusion, point clouds from integrated LiDAR systems may produce precise 3D building models.

1. INTRODUCTION

1.1 Three-Dimensional Modelling

3D modelling is the process of representing any object or surface in three-dimensional form by altering the polygons, edges, or nodes. Transformation of two-dimensional (2D) into three-dimensional (3D) can be performed either manually or automatically. In manually processing, specialized software was used to construct or edit the polygon, edges, or nodes and scan the object using specialized equipment to convert it into digital form. Several types of 3D software are available on the market, including AutoCAD 3D, ZBrush, 3DS Max, SketchUp, Blender and others.

Commonly, the 3D model can be produced automatically through a geospatial approach. High-resolution satellite imagery, photogrammetry, LiDAR and laser scanning are some methods available for 3D building models. Among these methods, photogrammetry is the most frequently utilized for constructing three-dimensional representations of cities. This is because the photogrammetry method only required a few photographs to build the model. Since the texture, footprint and roof of the building are extracted from the same photographs, the colour balancing of the photos is not required. Furthermore, this method can provide information about the three-dimensional geometry and texture of the ground. It also can take photographs from a very close distance to the object, influencing the quality of the model generated. Fundamentally, the model developed from an apparent and high-resolution photograph may generate a precise and solid 3D model. However, constructing a 3D model from a highly dense point cloud can provide better outcomes than photogrammetry. This is because the point cloud typically obtained using conventional LiDAR has better positional accuracy due to its capability to produce accurate and precise data up to the millimetre level. Nonetheless, this method is highly complicated and expensive and requires managing a massive amount of data and high-end equipment to manipulate and process the data.

The advancement and sophistication of the geospatial approaches, particularly in the UAV photogrammetry and LiDAR system, has opened up the opportunity for the exploration of the integration of the different techniques in the construction of the precise model more efficiently and cost-effectively. Therefore, this research is examined the effectiveness of fusing different systems to construct a 3D building model in the study area

1.2 Light Detection and Ranging

LiDAR is the most accurate method for obtaining precise and dense point clouds of each feature on the earth's surface. LiDAR is an acronym for Light Detection and Ranging, and a laser beam is used to scan objects on the earth's surface to provide a set of point clouds containing information on location and height. It utilizes the approach of transmitting laser light to the target and measuring the reflected light to determine the reflected light's wavelength variation and arrival time. Based on the basic formula in Equation 1, the position and height of the object can be resolved with better accuracy by calculating the light reflection time for each pulse return to the received. It has become a method of obtaining precise and accurate high-density point clouds for three-dimensional topographical surface.

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$$D = r * (t/2) \quad \text{Equation 1}$$

Where,

D = distance from sensor to target
r = speed of light (3×10^8 m/s)
t = time taken for the pulse return to received

In the LiDAR principle, the laser beam does not require energy from the sun to scan objects since it uses an active sensor and does not have time constraints to collect the point cloud data. High-resolution and accurate data production enable more efficient mapping activities for various applications, including 3D modelling, planning, topography mapping, slope analysis, forestry, and others. In addition, the LiDAR system comprises essential components, including a platform, sensor, Global Navigation Satellite System (GNSS), Inertial Measurement Units (IMU) and workstation.

LiDAR is classified into three types: airborne, terrestrial, and mobile. In airborne LiDAR, aircraft or UAVs carry the sensor in collecting point clouds for the object on the earth's surface, with the sensor pointing to the nadir perspective. The point cloud acquired from this type is comprised of the top structure of the object, such as the roof or canopy of a tree. Acquiring point cloud data for vertical structural is challenging because the scanning angle is limited due to obstructions such as the solid object located close to the target object.

Therefore, in order to obtain complete point cloud data, scanning should be conducted from a horizontal perspective. For this reason, terrestrial or mobile LiDAR should be utilised because both types scan the object from a horizontal perspective. According to American Standard Code for Information Interchange (ASCII), LiDAR data is usually saved in laser format (.las). Furthermore, LasTools has introduced another format for LiDAR data known as Laz format (.laz), which is compressed of laser format (.las). Meanwhile, the output data generated from scanned data are saved in a file with the extension ".tiff.

2. METHODOLOGY

2.1 Study Area

The study area was conducted in the central part of Universiti Teknologi Malaysia (UTM), having an area of 60 hectares. This area is the main campus area of the university campus is built on a small hill, and a ring road surrounds it. The ring road is known as Lingkaran Ilmu. It is bounded by coordinates 172957.69m (Top), 347951.55m (Left), 349070.48m (Right) and 171999.49m (Bottom) based on the Universal Transverse Mercator zone 48N coordinate system. According to Najad et al. (2018), this area was developed based on the radial concept, where it is built on a hill and has a gentle slope. This area's elevation varies from 20 m to 107 m above the mean sea level (MSL). This study area comprises five faculties, two administration buildings, a mosque, a library and the main hall. The buildings were built inside this study area such as the Faculty of Built Environment and Surveying, Faculty of Science, Faculty of Civil Engineering, Faculty of Mechanical, Faculty of Science Social, Masjid Sultan Ismail, Dewan Sultan Iskandar, Canselor building, Student Welfare building and Sultanah Zanariah Library. The entire buildings block located in this area is more than 20 blocks. These blocks have a complex structure and surrounding by trees, roads and grassy. Figure 1 illustrates the location of the study area.

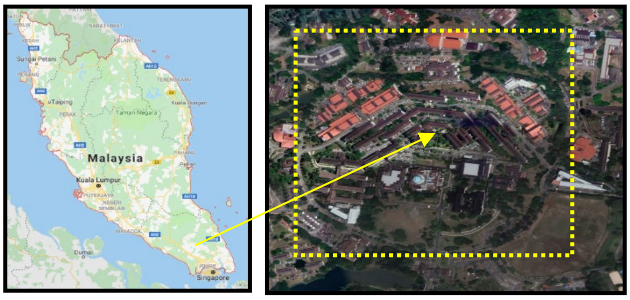


Figure 1 Location of study area on the map

2.2 Data Acquisition

To achieve the objective of this study, the entire building blocks were scanned using two different LiDAR systems, i.e. UAV LiDAR and MLS LiDAR, to acquire the 3D points cloud. UAV LiDAR system has difficulty and limitations in scanning the entire building due to the presence of objects such as high crown trees and the proximity of each building. In order to overcome this issue, the MLS LiDAR system was utilised to scan the building's structure that the UAV LiDAR system could not reach.

During point cloud collection, the UAV was outfitted with a LiDAR sensor and a 24-megapixel SONY digital camera. The UAV was flown using manual mode at 100 metres altitude from the ground using a standard flight line. The camera angle was fixed to 45 degrees to obtain an aerial photo of buildings in the study area. These aerial photos were used to colourise the point cloud of the building. UAV LiDAR can only scan the top of a building and part of the building's vertical structure.

MLS LiDAR technology was used to scan the building from the side view to obtain the building's complete structure. This system included two different sensors, a LiDAR sensor and a 360-degree camera. Similar to the UAV LiDAR system, the photos were utilised to colourise the point cloud. Both sensors were transported using a four-by-four vehicle. The vehicle must constantly drive to ensure the sensors can scan every building in the study area. Otherwise, some of the point clouds are unable to colourise. Figure 2 and Figure 3 show the UAV RiEGL RICOPTER and LiDAR sensors, respectively. Meanwhile, Figure 4 depicts the LiDAR sensor for the MLS system.

Figure 2 RiEGL RICOPTER Octocopter

Figure 3 RiEGL VUX-1UAV (LiDAR Sensor**)**

Figure 4 RiEGL VHQ-1HA (MLS)

In addition to cloud point data, it is necessary to establish control points for use in geometric rectification and accuracy assessment. Ground control points (GCPs) and checkpoints (CPs) are the two sorts of control points used, and both are established using the rapid static method. This method can produce coordinate information, including Northing, Easting and Elevation, after post-processing with the Trimble Total Control (TTC) software, which provides an accuracy of 1 to 10 centimetres. Then these coordinates were converted to X, Y (planimetry) and Z(height). Establishing GCPs is crucial for sustaining the precision and accuracy of final outputs. There are 20 control points, of which 10 GCPs were utilised for geometric rectification and the other 10 CPs for accuracy assessment. Figure 5 depicts the distribution of GCPs and CPs measured using the study area's rapid static technique.

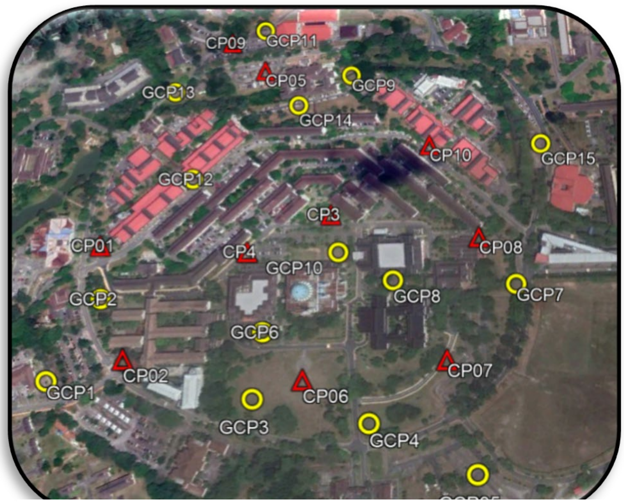


Figure 7 Location of GCPs (yellow circle) and CPs (red triangle) in the study area

Each point was observed from 35 minutes to 45 minutes, and the height instrument at each point was measured. Theoretically, longer observation can produce a more accurate result. In this study, 35 to 45 minutes of observation is enough for GPS observation because the location of each point is quite close to one another. The target made of plastic with dimensions of the 1-meter length and 1-meter width is used as a marker to represent GCPs and CPs on the digital orthophoto. The X symbol is printed on the top of the target to ensure the target's centre is easily identified on the image during geometric rectification and accuracy assessment.

2.3 Data Processing

RiEGL RiSCAN Pro software was utilised for processing points cloud acquired from UAV LiDAR and MLS LiDAR systems. Several steps involve filtration, geometric correction, colouring, and exporting. During the filtering step, any noise or error was removed. This elimination approach was accomplished in two ways: automatically and manually. Following the completion of the filtering procedure, the cloud points must undergo a geometric correction using the GCPs established in the study area. Then, the corrected point cloud was projected into the UTM Zone 48 N coordinate system. To colourise every point cloud, aerial photographs obtained with a digital camera and a 360-degree camera were used as a reference. The point cloud was then exported in LiDAR's standard format, LAS. Figure 6 shows the flow chart of point cloud processing using RiEGL RiSCAN PRO software.

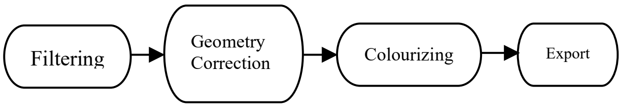
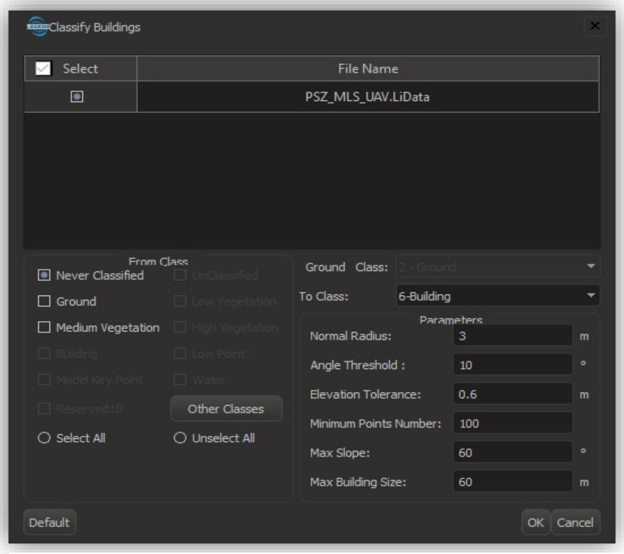


Figure 5 Flow chart of LiDAR processing using RiEGL RiSCAN PRO

This RiEGL RiSCAN Pro software is limited only to pre-processing steps, as depicted in Figure 6. LiDAR 360 software was utilised for merging, classification and export for the post-processing part. In the merging stage, UAV LiDAR's point clouds were combined with MSL LiDAR's point clouds to construct a 3D model with a complete structure. Then, these point clouds were classified into three classes: ground, tree and building. This classification step was completed automatically by configuring the necessary parameters, as indicated in Figure 7. In the final phase, only the building's class was exported as a 3D model. The flow of post-processing is shown in Figure 8.



☑ Select	File Name
☒	PSZ_MLS_UAV.LiData

From Class
☒ Never Classified
☐ UnClassified
☐ Ground
☐ Low Vegetation
☐ Medium Vegetation
☐ High Vegetation
☐ Building
☐ Low Point
☐ Model Key Point
☐ Water
☐ Reserved10
○ Select All
○ Unselect All

Ground Class: 2 - Ground
To Class: 6-Building

Parameters
Normal Radius: 3 m
Angle Threshold : 10 °
Elevation Tolerance: 0.6 m
Minimum Points Number: 100
Max Slope: 60 °
Max Building Size: 60 m

Figure 6 List of Parameters need to set in the automatic classification step

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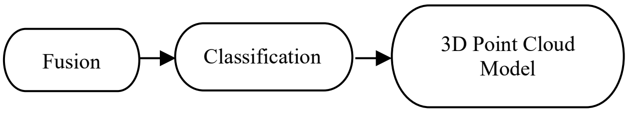

Figure 9 Flow chart of post-processing using LiDAR 360

For fusion, the two sets have different data; the transformation method was used to fuse the dense point cloud data of UAV-based LiDAR and MLS LiDAR systems. This method is available in the LiDAR360, where the data are rectified based on homologous points visible on both data sets. The cubic polynomial technique was used to merge the data because the number of homologous points is greater than ten. For accuracy assessment, statistical approaches were used to evaluate the quality of the final output. In this case study, the evaluation only considers quantitative analysis. The Root Mean Squared Error (RMSE) equation was used, and it is shown in equation 2 and equation 3. This equation can be defined as the standard deviation of the residuals or prediction errors (Chai and Draxler, 2014). Residuals are a measure of how far from the regression line data points. It is a measure of how to spread out these residuals. This equation is commonly used for evaluating the quality of photogrammetry products, including 3D models (Tahar, 2015; Udin et al., 2012). Equation 1 was used to evaluate the accuracy from a planimetry perspective, while equation 2 was used to evaluate the accuracy from a height perspective. To perform this accuracy assessment, 10 CPs were used, and the result is shown in Tables 1 and 2.

$$\mathbf{RMSE}\ (\mathbf{X}, \mathbf{Y}) = \pm\sqrt{\sum \frac{(\mathcal{X}-\mathcal{x})^2 + (\mathcal{Y}-\mathcal{y})^2}{\mathbf{N}}} \quad \text{.................Equation 2}$$

$$\mathbf{RMSE}\ (\mathbf{Z}) = \pm\sqrt{\sum \frac{(\mathcal{Z}-\mathcal{z})^2}{\mathbf{N}}} \quad \text{.............................. Equation 3}$$

Where

X, Y= Planimetry coordinate observed on the ground (m).
Z = Height coordinate observed on the ground (m).
x,y = Planimetry coordinate on the model (m).
z = Height value on the model (m).
N = Number of check point (CP) (m).

3. RESULT AND ANALYSIS

In this study, the end result is the 3D point cloud from the UAV LiDAR and MLS LiDAR system that contains information about the building, tree, slope area, road and terrain in the study area.

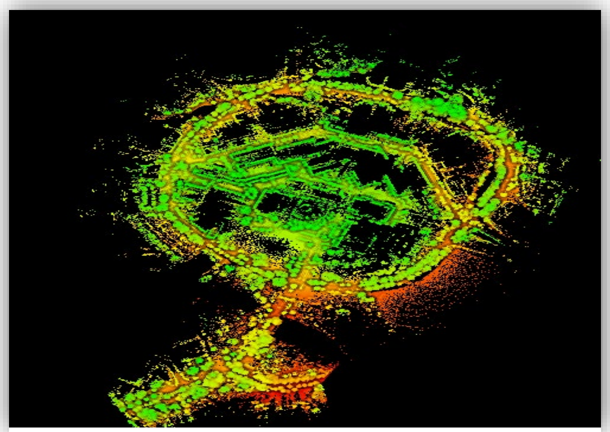

Figure 10 The 3D Point Cloud of MLS LiDAR System

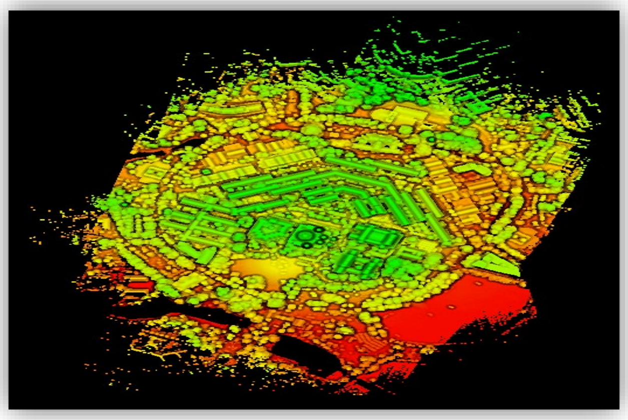

Figure 8 The 3D Point Cloud of UAV LiDAR System

Figure 9 and Figure 10 depict the outcomes of these two LiDAR systems.

According to Figure 9, the point cloud was generated by laser scanning utilising the MLS system consisting of vertical structures or façade parts of the building. The MLS sensor was installed parallel to the platform, which is in the horizontal position during the scanning. In this configuration, the sensor is more efficiently scanning the vertical structure of the building while mobile. The MLS system utilised in this case study can scan the features at 270-degree. Therefore, the system can scan many features in the prominent area within seconds. However, the system is not equipped with a GPS, which is used for projecting each point cloud onto the local coordinate system. The transformation technique was employed using the UAV LiDAR points cloud as a reference to perform this process. As discussed in the pre-processing section, the geometry of the UAV LiDAR points cloud was corrected using the GPS data. During the transformation step, the cubic polynomial equation and 18 points were used, and the transformation's error was 0.0018 m. The specification of MLS LiDAR points cloud data is shown in Table 1.

Table 1 **Specification of MLS LiDAR Point Cloud**

Specification	Description
System	MLS LiDAR
Total Points	234,699,568
Standard Deviation of Height	8.493m
Standard Deviation of Intensity	4413.447

Figure 10 depicts the 3D point cloud of the UAV LiDAR system covering the building's roof structure. During data collection, a LiDAR sensor was placed on an octocopter platform with its sensor pointing to the nadir. It scanned the study area features from an aerial perspective. The specification of the UAV LiDAR point cloud is shown in Table 2.

Table 2 Specification of UAV LiDAR Point Cloud

Specification	Description
System	UAV LiDAR
Total Points	61,923,198
Standard Deviation of Height	10.745m
Standard Deviation of Intensity	4654.287

In this case study, two types of systems were used for constructing a 3D building model due to the limitations of the systems. As shown in Figure 11, each system cannot scan a whole building's point cloud due to obstacles. Therefore, both point cloud needs to fuse to obtain the complete structure of the building. Some of the results are shown in Figure 12, while Figure 13 shows the fusion point cloud of UAV and MLS for the whole area.

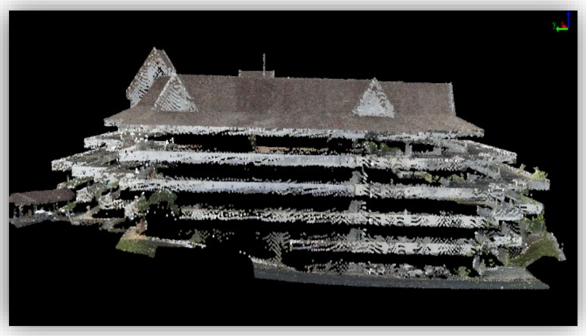

Figure 11 UAV LiDAR Point Cloud of Library

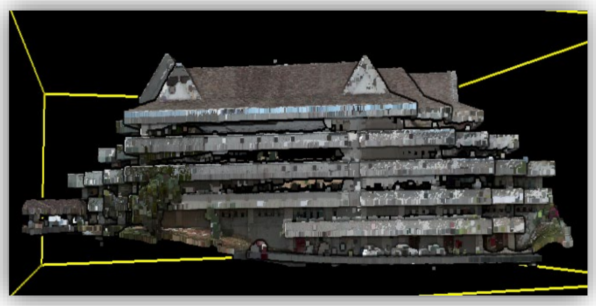

Figure 13 UAV-MLS Point Cloud of Library

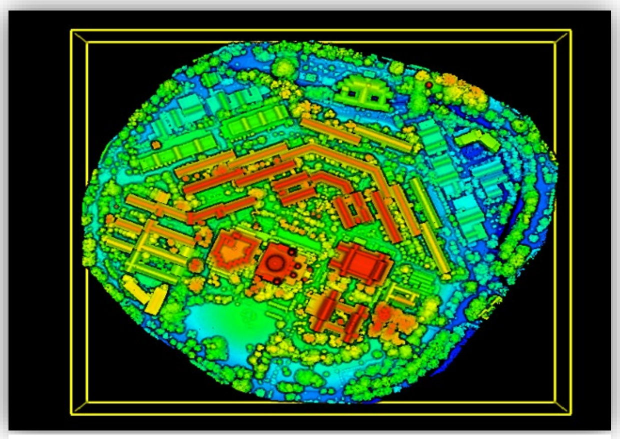

Figure 12 UAV-MLS LiDAR Point Cloud

Accuracy assessment is carried out by comparing between planimetry coordinate on the ground and the planimetry coordinate on the model. Besides that, the model's height was also analysed by comparing the height value on the ground and the height value on the image. The RMSE of planimetry and height is calculated using equations 1 and 2. Orthophoto and DRM were used to extract the information on planimetry and height coordinates of the model. The RMSE value is shown in Table 3. Based on Table 3, the RMSE value of planimetry is ±0.015 metres, while the RMSE value of Z/height is ±0.009 metres. This result shows that the 3D building model developed from the UAV-MLS LiDAR system is accurate in quantitative assessment. The reason is LiDAR system has advantages compared to other methods for acquiring point cloud data with high accuracy.

Table 3 RMSE Value

	Different (m)		
CP	**Delta X**	**Delta Y**	**Delta Z**
CP1	0.015	0.006	0.016
CP2	0.006	-0.004	0.011
CP3	0.009	0.002	-0.005
CP4	0.002	-0.008	0.009
CP5	-0.012	0.012	0.012
CP6	-0.005	-0.003	-0.008
CP9	0.008	-0.004	0.008
CP10	-0.007	-0.004	-0.004
RMSE	Planimetry = ±0.015		Z = ±0.009

4. CONCLUSION

An approach that fuses point cloud data from multiple sensors can develop a complete 3D building model, especially in an area with numerous objects nearby. In this case study, the aim is to construct a complete 3D building model was achieved. The 3D model has high accuracy at the centimetre level. However, the building model is not 100 per cent complete since some structures are still not fully covered. Therefore, it is proposed to create a 3D building model using three lidar systems, namely the LiDAR Backpack. Using this system can overcome the problem of obtaining cloud points in certain parts that are difficult to scan by the UAV LiDAR and MLS LiDAR systems.

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