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Application Point cloud data of Terrestrial Laser Scan (TLS) and Unmanned Aerial Vehicle (UAV) in establishing a 3D model (case study at Dieu Son Pagoda, Bac Ninh province)

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ABSTRACT

The architectural heritages are symbols of culture, social, historical, and religion and the exciting points of every city or country, especially for tourism development. In the world, thousands of architectural heritages are preserved and protected. UNESCO and many international organizations work together with all governments and local people to keep the heritages. Their efforts are great, but sometimes, the heritages are damaged and destroyed by a natural disaster and human activities. In Vietnam, many architectural heritages are in danger. Therefore, preservation of these architectural heritages is essential with all efforts from the government and scientists. This paper presents the results of applying UAV and Terrestrial laser scanners to model the architectural heritage in 3D with high quality for the purpose of preserving and protecting these works. The study was done by modeling the Dieu Son Pagoda in Bac Ninh Province. The result shows that the model is very detailed and precise enough to retain the building's main architectural characteristics.

1. Introduction

The establishment of 3D models has been studied for modeling the earth's surface and applications in the fields of Planning, Military, navigation systems, and especially in building

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models. 3D city, smart city, etc. In practical, there are many different methods are for 3D modeling such as direct measurement, using 3D Scan technology, UAV images from topographic map data, etc. (Bui Ngoc Quy, 2015; Bui Ngoc Quy, Pham Van Hiep, 2017; Bui Ngoc Quy et al., 2020). In Vietnam, in recent years, there have also been some research and application of modern technologies in 3D modeling (Le Dai Ngoc, 2010; Dao Ngoc Long, 2011; Bui Ngoc Quy, 2015; Bui Ngoc Quy, Pham Van Hiep, 2017; Bui Ngoc Quy et al, 2021). However, most of these studies are based on direct measurement methods, 3D Scan methods, and independent UAVimagess. Still, they have not paid attention to the combined data processing obtained from the systems to create 3D models. UAV image data is perfect for exterior features modeling but limited use for interior features, especially celling decorating, which is very important in heritages by terrain due to the airborne method's specificity. In contrast, the ground laser scanning (TLS) method can obtain data below in detail but cannot capture data above the top of features such as roofs and roofs of objects. Therefore, the study of combining point cloud data obtained from ground laser scanning methods and UAVs in 3D modeling will overcome the disadvantages of each of these methods.

2. Materials and research methods

2.1. TLS's technology

Terrestrial Laser Scanning (TLS) technology is a modern technology for collecting field data for building 3D (3D) applications. TLS technology is used to acquire topographic and geologic surface data with a dense measuring point density by laser light rays. The obtained point data is a collection of millions of points – Point clouds. The acquired point cloud carries all the X, Y, and Z parameters because the meter emits a laser pulse towards these points and measures the distance from the device to the target to depict the 3-D model of the object accurately. Topographical objects.

With the development of science and technology, manufacturers have launched many different types of ground laser scanning equipment. TLS devices are generally divided into three categories based on the distance the laser light can work (typically from a few hundred meters to several kilometers): short-range, mid-range, and long-range scanners. Long-range scanners are often used for measuring large areas (Abellán et al., 2006), while short-range scanners are more suitable for measuring small areas (from tens to several hundred meters) with a higher level of detail and precision (George L. Heritage and Andrew R.G. Larger, 2009).

Many manufacturers of ground-based 3D laser scanning equipment have many different devices such as Trimble TX6, TX7, TX8 of Trimble; Faro Focus X130, 150, 150 Plus, 350 of Farro; Leica Scan Station P50/P40/P30, Leica RTC360 of Leica, etc. Most of these scanning devices have advantages such as Large scanning speed (from 10,000 to 1,000,000 points/sec), fast scanning time; Large scanning point density; Flexibility in different types of terrain such as indoor and outdoor, underground, etc. Compact device size, etc., will be the primary type of data acquisition device in the measurement and establishment work. Current 3D modeling, especially when combined with other measurement systems such as UAVs, will bring great potential and efficiency in data acquisition to establish 3D models (Nguyen Viet Nghia, 2020).

2.2. UAV's Technology

In Vietnam, unmanned aerial vehicles (UAVs) have been researched by the Mapping Department - General Staff for military purposes in recent years. Up to now, UAV devices have been studied and expanded at many agencies and units such as the Vietnam Institute of Geodesy and Cartography, training and scientific research institutions in the field of Geodetic – Cartography (Le Dai Ngoc, 2010; Dao Ngoc Long, 2011; Phan Van Lam, Hoang Manh Hung, 2014).

Image data obtained from UAV devices are now used for various purposes, both military and civilian. In these applications, UAV image data is used primarily for the establishment of maps such as topographic maps and cadastral maps (Dao Ngoc Long, 2011); For monitoring and gathering geospatial information (Le Dai Ngoc, 2010; Phan Van Lam, Hoang Manh Hung, 2014; Bui Ngoc Quy, Pham Van Hiep, 2017), some 3D models have also been built from UAVs image data sources such as the 3D model of the Hai stream dam area (Bui

Ngoc Quy, Pham Van Hiep, 2017); a 3D model of 220 KV Me Linh - Ba Thien high voltage power line (Bui Ngoc Quy, Pham Van Hiep, 2018), etc.

3. Results and discussion

3.1. Case study

The experimental area is the campus of Dieu Son Pagoda, Thi Cau ward, Bac Ninh city (Figure 1).

3.2. Methods and Technological process to create 3D models from Point cloud data of TLS and UAV

How to register the scattered point cloud of these large-scale data quickly and accurately is a research hotspot of researchers at present. The most prominent contribution is the Iterative ClosestPoints (ICP) algorithm proposed by Besl (Besl, Mckay, 1992). In this method, the transformation parameters of two-point sets are calculated through the relationship between the corresponding matching points of two-point sets to satisfy the given convergence precision, and finally, the translation and rotation parameters between the two points are obtained to complete the registration process.

Figure 1. Construction location of Dieu Son pagoda 3D model.

Iterative closest point (ICP) registration is an accurate and reliable method for the registration of free-form surfaces (Besl, Mckay, 1992). ICP algorithm is used to find the rigid transformation T between the target point set S and the reference point set M. The two matching data satisfy the optimal match under some kind of metric criterion. Assuming that the coordinates of the target point set S are $\{S_i | S_i \in R^3, i = 1,2,\ldots,N_s\}$, the coordinates of the reference point set M are $\{M_i | M_i \in R^3, i = 1,2,\ldots,N_M\}$, in the k-th iteration, the coordinates of the corresponding point corresponding to the coordinates of the point set S are $\{M_i^k | M_i^k \in R^3, i = 1,2,\ldots,N_M\}$. The transformation matrix between S and M^k is calculated and the original transform is updated until the distance between the data is less than the given threshold τ. The ICP algorithm steps are as follows:

(1) Calculate the corresponding point $M_i^k \in M^k$ in the reference set M so that $\|M_i^k - S_i^k\|$=min;

(2) Calculate the rotation matrix R^k and the translation vector T^k so that

$$\sum_{i=1}^{N} \left\| R^k S_i^k + T^k - M_i^k \right\|^2 = \min;$$

(3) Calculate

$$S^{k+1} = \{S_i^{k+1} | S_i^{k+1} = R^k S_i^k + T^k, S_i^k \in S\};$$

(4) Calculate $d^{k+1} = \sum_{i=1}^{N} \left\| S_i^{k+1} - M_i^k \right\|^2$;

(5) If d^{k+1} is not less than the given τ value, return (1) until $d^{k+1} < \tau$ or iterations k is greater than the preset maximum number of iterations.

The average complexity of the ICP algorithm is O(n log n) (where n is the number of point cloud points), and it can be effectively converged to a local minimum. The estimation of a proper initial transformation is necessary, and the ICP algorithm assumes that all points of the target point set correspond to the set of reference points.

In this study, the ICP algorithm is selected to combine UAV and TLS cluster data. Before concatenation, the UAV and TLS point clouds are filtered to remove noise. Because the TLS point cloud has higher density and accuracy, it is used as the base point cloud and the UAV point cloud is

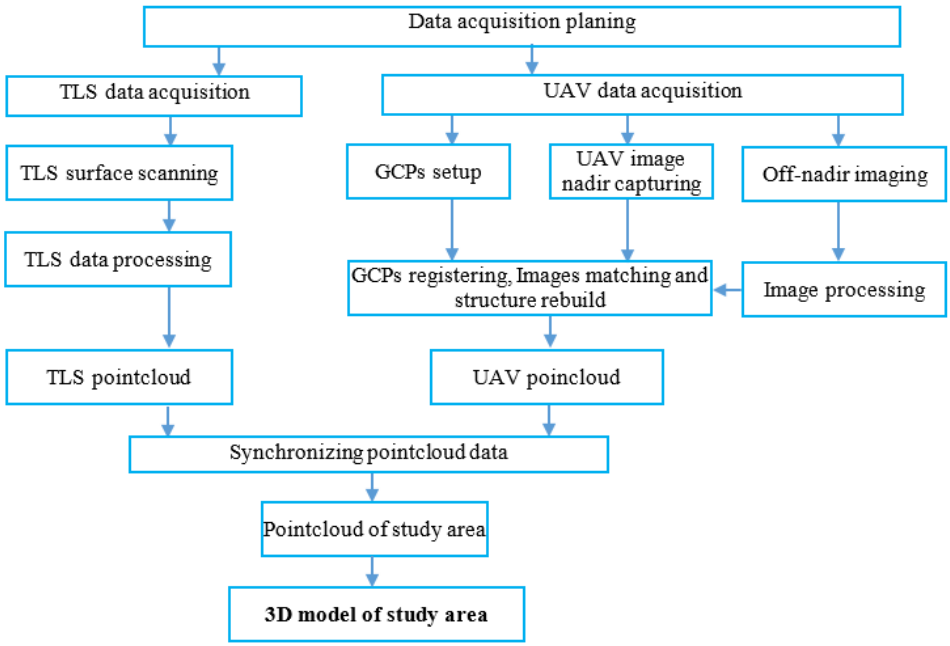


Figure 2. Technological process diagram for creating 3D models from TLS and UAV point cloud data.

the compound point cloud. The data concatenation process consists of two steps: Coarse Alignment and Fine Alignment. In which, the raw coupling step, it is necessary to select at least 4 duplicate points on both point clouds data (This can be a focal point, a control point, or a sharp feature on two-point clouds). In the exact match step, the number of points participating in the matching process increases significantly, so the data matching accuracy also increases, however, the processing time will be longer. As a result, we get a paired point cloud from UAV and TLS point cloud data. This point cloud will be used to create a 3D model. The 3D models of the study area from LTS and UAV point cloud data are created according to the technological process (Figure 2).

3.3. Data acquisition

3.3.1. UAV data capture and acquisition flight design

To ensure that the experimental area is photographed at all angles from above (Figure 3), the UAV collection plan is designed with the following parameters:

- First flight: vertical angle photography, flight altitude 50 m, coverage 80/80.

- Second flight: take photos at four perpendicular angles, 30 m high, 80/80 coverage.

3.3.2. Design a plan to receive TLS data

The TLS data acquisition plan is designed so that the scanning stations are located at locations that can scan the entire wall of the pagodas. A total of 08 stations were observed (Figure 4).

3.4. Data processing work

3.4.1. UAV data processing

Processing UAV data from the input image creates a georeferenced point cloud that is interpolated from the UAV image to proceed to the next step, integrating with the point cloud data from the TLS scanner (Figure 5).

3.4.2. TLS data processing

TLS data, after being collected from scanning stations in the field, is internally coupled to each other by points of the same name or through shadows placed in the experimental area. After each pairing, an assessment of the internal error between the scanning stations is carried out. At the end of this concatenation process, we obtain a TLS point cloud of the entire experimental area without geographical parameters (Figure 6).

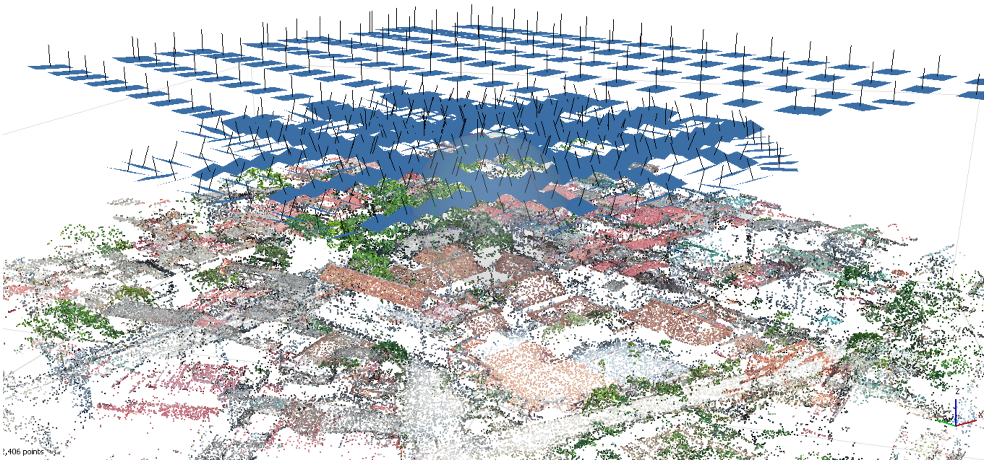
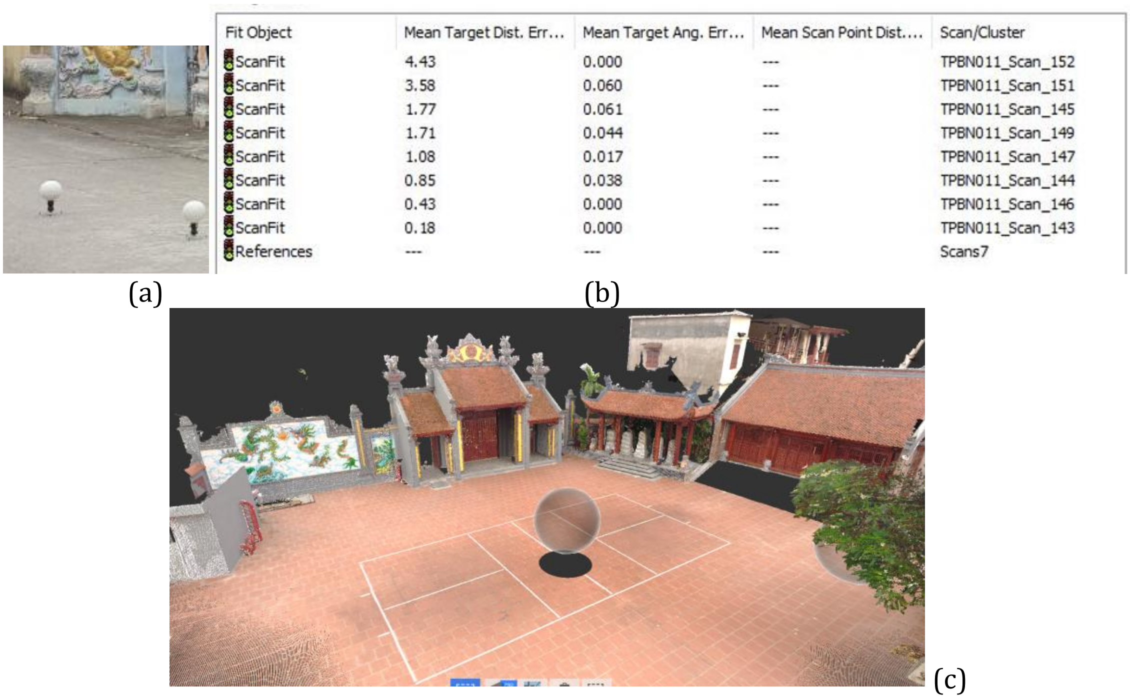


Figure 3. Plan of flight design for capturing UAV.

Figure 4. Location of TLS scanner stations.

Figure 5. Point cloud interpolated from UAV image.



Fit Object	Mean Target Dist. Err...	Mean Target Ang. Err...	Mean Scan Point Dist....	Scan/Cluster
ScanFit	4.43	0.000	---	TPBN011_Scan_152
ScanFit	3.58	0.060	---	TPBN011_Scan_151
ScanFit	1.77	0.061	---	TPBN011_Scan_145
ScanFit	1.71	0.044	---	TPBN011_Scan_149
ScanFit	1.08	0.017	---	TPBN011_Scan_147
ScanFit	0.85	0.038	---	TPBN011_Scan_144
ScanFit	0.43	0.000	---	TPBN011_Scan_146
ScanFit	0.18	0.000	---	TPBN011_Scan_143
References	---	---	---	Scans7

Figure 6. Shadows for station coupling (a), local station coupling error reporting (b), coupled TLS point cloud (c).

3.5. Combine Point cloud data from UAV and TLS to create 3D models

Because the TLS data is not georeferenced yet, the TLS point cloud data and the UAV point cloud data are temporarily located in different locations. So, to combine these two types of data, we select points of the same name from UAV data and TLS data so that points of the same name in TLS data will be assigned geographic coordinates from the UAV point cloud (Figure 7). The product of this process is the TLS point cloud and the UAV that is located in the exact location and are integrated (Figure 8).

Figure 7. Selecting points of the same name between TLS and UAV data.

Figure 8. TLS and UAV point cloud data stitched together.

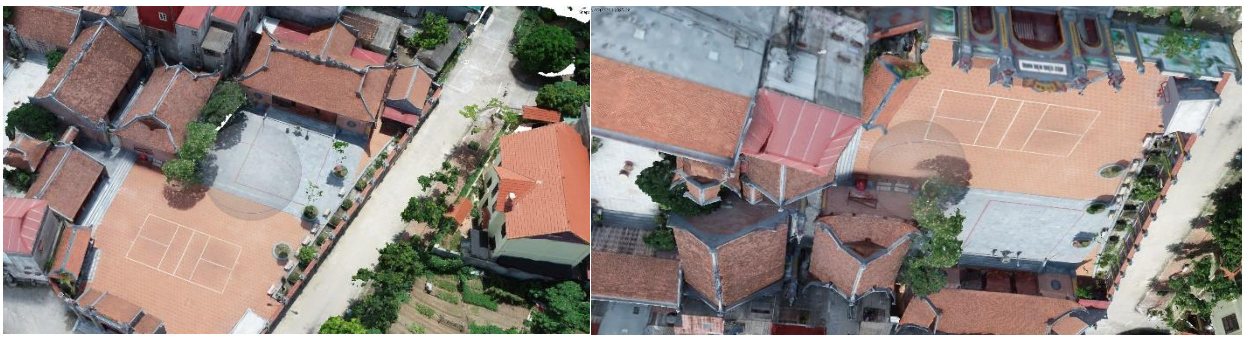


Figure 9. Creating a 3D Mesh model from an integrated point cloud between a TLS scanner and a UAV.

To prepare the point cloud data for the 3D modeling process, manual data editing was carried out, and the noisy, bad, and replaceable points were filtered out. Then, the point cloud data will be automatically modeled mesh. This mesh model will be manually edited before automatically pasting the image from the UAV image (Figure 9).

3.6. Evaluation of the accuracy of experimental 3D model construction results

3.6.1. Results of building 3D models

As a result of combining UAV and TLS point

Figure 10. 3D model of Dieu Son pagoda area.

clouds, we obtain a 3D model of the experimental area (Figure 10).

3.6.2. Evaluation of 3D model results

In order to evaluate the accuracy of the 3D model, we measured the test points by the total station in the experimental area. The test results show that the 3D model built from the integrated point cloud data has relatively high accuracy, with a mean square error for the plane of 3.55 cm and an elevation of 5.16 cm. The measurement points on the wall and the roof have higher altitude errors than those measured at the ground (Table 1).

Table 1. Error checking results of 3D model of Dieu Son pagoda.

Points	Horizontal error (cm)	Vertical error (cm)	Point type
S1	1.45	3.65	Ground
S2	1.98	2.14	Ground
M3	2.45	4.15	Roof
M4	3.74	6.19	Roof
M5	1.93	4.98	Roof
C6	4.18	3.67	Door
C7	6.62	5.73	Door
CS8	3.17	6.73	Window
T9	4.18	7.38	Wall
T10	2.83	4.67	Wall
RMS(cm)	3.55	5.16	

4. Conclusion

Building an experimental 3D model of the area of Dieu Son pagoda shows that the 3D modeling process from the combination of 2 sources of UAV and TLS point cloud data can achieve a high level of detail and fullness. This is more than sufficient because the UAV devices have added data sources above the structures. At the same time, the TLS data ensures reception for the areas below, where the UAV equipment is limited.

The data processing process is highly automated and does not require much effort in drawing and modeling. The generated 3D model has a relatively high geographic accuracy with 3 cm RMS. Building 3D models from UAV and TLS point cloud data shows that it is very suitable for 3D modelings single and small-scale objects such as cultural works and architectural heritage. However, a large area such as the whole city, it is costly and time consuming.

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Contribution of authors

Quy Ngoc Bui contributes to the idea, data acquisition, and analysis, and writes the manuscript; Hien Dinh Le contributes to editing the writing; Quan Anh Duong, Hiep Van Pham, and Chinh Cong Thi Vo contribute to collecting the data.

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