THREE-DIMENSIONAL MODELLING OF BUILDING BASED ON THE COMBINATION BETWEEN UNMANNED AERIAL VEHICLE AND LASER SCANNING DATA

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DEDICATION

This thesis is dedicated to

To my parents, Mr Adnan and Madam Shahrizad,

To my forever life partner, Muhammad Aiman

To my siblings and to my family,

Who stayed throughout the journey.

For their love and endless support,

For always believing in me.

For always loving me.

For the constant encouragement and love.

I will always remember all of you in my heart.

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ABSTRACT

Unmanned Aerial Vehicle (UAV) is frequently used for obtaining two-dimensional (2D) or three-dimensional (3D) data acquisition. Meanwhile, Terrestrial Laser Scanner (TLS) is used for obtaining only 3D data acquisition. However, if both are combined, they are able to produce a more accurate data. The purpose of this study is to investigate the possible combination of point clouds obtained through the acquisition of data from UAV and TLS at two buildings in Universiti Teknologi Malaysia (UTM), Skudai, Johor which are T06 and T05 buildings. The aim is to generate 3D model of those two buildings. The objectives of this study are; (i) to combine the data through the aerial survey and ground survey by merging their point clouds and develop 3D model from the combination, and (ii) to evaluate the results and the accuracy of the combination process. These objectives were achieved by appropriately merging data from UAV DJI Phantom 4 and TLS Topcon GLS2000 throughout the survey of the roof and facades. The aerial data were processed using Pix4D software and ground data were processed using Scanmaster software. The data combination process was done by converting both point clouds into the same coordinate system and then by aligning the same points of both points clouds in Cloud Compare software. The results were presented in the form of orthophoto, point clouds and 3D model of both buildings. For verification purposes, dimensional survey was done and there were several distances taken from the man-made features of the study area to validate the accuracy assessment. The results of residuals between the dimension survey and combination were measured using the Root Mean Square Error (RMSE) method. Both T06 and T05 buildings were presented as a 3D model based on the point cloud accuracy in cm level. To conclude, the combination between these both UAV and TLS can be implemented to produce 3D model of a building.

ABSTRAK

Kenderaan Udara Tanpa Pemandu (UAV) kerap digunakan untuk memperoleh data dua dimensi (2D) atau tiga dimensi (3D). Manakala, Pengimbas Laser Terrestrial (TLS) digunakan untuk memperoleh data 3D sahaja. Namun, jika kedua- duanya digabungkan, ia mampu menghasilkan data yang lebih tepat. Tujuan kajian ini adalah untuk menyiasat kemungkinan gabungan data titik awan yang diperoleh melalui UAV dan TLS di bangunan Universiti Teknologi Malaysia (UTM) Skudai, Johor iaitu bangunan T06 dan T05. Matlamatnya adalah untuk menghasilkan model 3D bagi kedua- dua bangunan tersebut. Manakala, objektif kajian ini adalah; (i) untuk menggabungkan data melalui tinjauan udara dan tanah dengan menggabungkan titik awan mereka dan membangunkan model 3D daripada gabungan tersebut, dan (ii) untuk menilai keputusan dan ketepatan hasil daripada proses gabungan. Objektif-objektif ini dicapai dengan menggabungkan data daripada UAV *DJI Phantom 4* dan TLS *Topcon GLS2000* melalui tinjauan bumbung dan fasad. Data udara diproses menggunakan perisian *Pix4D* dan data pada bumi menggunakan perisian *Scanmaster*. Proses gabungan data dilakukan dengan menukar titik awan ke dalam sistem koordinat yang sama dan kemudian dengan menjajarkan titik yang sama bagi kedua-dua titik awan dalam perisian *CloudCompare*. Hasilnya dipersembahkan dalam bentuk ortofoto, titik awan dan model 3D kedua-dua bangunan. Untuk tujuan pengesahan, tinjauan dimensi telah dilakukan dan terdapat beberapa jarak telah diambil daripada ciri buatan manusia di kawasan kajian untuk mengesahkan penilaian ketepatan. Keputusan antara tinjauan dimensi dan gabungan diukur menggunakan kaedah *Root Mean Square Error* (RMSE). Kedua-dua bangunan T06 dan T05 dipersembahkan sebagai model 3D berdasarkan ketepatan titik awan dalam aras sentimeter. Sebagai kesimpulan, gabungan antara UAV dan TLS ini boleh dilaksanakan untuk menghasilkan model 3D bangunan.

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LIST OF ABBREVIATIONS

3D	-	Three-dimensional
UAV	-	Unmanned Aerial Vehicle
TLS	-	Terrestrial Laser Scanner
GCP	-	Ground Control Point
CP	-	Control Point
GPS	-	Global Positioning System
DTM	-	Digital Terrain Model
DSM	-	Digital Surface Model
AGL	-	Above Ground Level
LOD	-	Level of Detail
GDTS	-	Geodetic Datum Transformation System
GLS	-	Ground Laser Scanner
RTK	-	Real Time Kinematic
TOF	-	Time of Flight
LiDAR	-	Light Detection and Ranging
CAD	-	Computer Aided Design and Drafting

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Rapid development in the city has produced lots of buildings and skyscrapers with unique architecture. They grow like mushrooms after the rain in line with the time. With a high population density and limited land space, better technology is required for future management and building. As the time passed, technology also grows over the past years.

Three-dimensional (3D) model or representation is often associated to the future as it is the current growing technology used (Gruen et al., 2013; Hashim, Hassan, & Rahman, 2019; Nex, 2011). It has the potential to deliver several benefits to the general public and municipal governments because people can have a better understanding of the visual representations. 3D mapping helps to facilitate in desired developments and also vastly improve transportation and utility networks. Because 3D models can imitate realistic impacts, they are useful in disaster management. Even so, 2D representation is still greatly used despite the growing technology of 3D.

3D mapping and modelling has also grown in popularity, particularly in surveying and engineering work. The act of mapping an object, structure, or area and describing it in the form of x, y, and z coordinates — a format known as a "point cloud" - is known as 3D scanning. A point cloud is a set of data points specified by a specific coordinate system (Mader, Blaskow, Westfeld, & Weller, 2016). Point clouds are used to generate 3D meshes, which characterise the geometry of a real item or research area. Terrestrial Laser Scanner (TLS) are the most often utilised platforms for 3D mapping operations presently. TLS technology is a well-known way for acquiring three-dimensional data in a short period of time. It reconstructs the scanned object and generates 3D point clouds with excellent accuracy and precision. TLS technology is

currently widely employed in a variety of applications, including building modelling and building information modelling (R. Akmalia, H. Setan, Z. Majid, D. Suwardhi, & A. Chong, 2014; Huber et al., 2010; López, Lerones, Llamas, Gómez-García-Bermejo, & Zalama, 2018)

Recently, Unmanned Aerial Vehicle (UAV) techniques have also received a lot of interest in 3D mapping and modelling (Nex & Remondino, 2014). The primary reason for the increased usage of UAVs in surveying operations is their light weight and low cost. UAVs are inhabited, reusable motorised vehicles that typically fly vertically above objects at a few metres in altitude (Tong et al., 2015). Furthermore, by adopting the UAV photogrammetric approach, UAV can collect data quickly and provide high resolution aerial photos. The data can then be utilised to reconstruct the surface of a model of the research region and produce extremely comprehensive 3D mapping and modelling by taking image overlapping, scale factors, and flight altitude into account (Sanz-Ablanedo, Chandler, Rodríguez-Pérez, & Ordóñez, 2018). Survey through scanning can be a bonus as it can save up a lot of time since it is robotic and many details can be collected in one scan, so there is no possibility of a detail being left out.

The demand for 3D city models is increasing and developing rapidly across a wide range of industries (Aicardi, Dabove, Lingua, & Piras, 2016; Gruen et al., 2013; Huber et al., 2010; López et al., 2018). Everyone is working with the most up-to-date information at all times. Because of that, it can become a limitation to surveying industry to collect data using TLS owing to the fact that TLS has a limited working range. Most land surveyors in Malaysia still use the common brand for laser scanners such as Topcon and Leica to collect point clouds for 3D applications such as building information modelling for indoor application and building modelling for outdoor application. However, these laser scanners usually used for high-resolution mapping of terrains and other landscape features over limited distance in the range 50-300m (Šašak, Gallay, Kaňuk, Hofierka, & Minár, 2019), which means the scanner emits laser ranging from about 0m to 300m from the instrument. This issue means they are limited to survey until certain floors whereby they cannot perform a full survey for high-rise buildings.

With the introduction of new technologies like TLS and UAV, it may be possible to create accurate and precise 3D models of complex things for mapping applications. According to Xu et al. (2014), even if numerous multi-surveys are being used, no single sensor can obtain complete information on an object.

Data combination is the process of combining data from diverse sources in order to present users with a uniform view of data (Jo & Hong, 2019; Li et al., 2019). According to J. Zhang (2010), data combination is the process of merging interdisciplinary data from many sources to obtain high-quality data. Data combination from different sources can improve information and make data processing easier (Gruen et al., 2013). Thus, the possibility of data combination technology is being applied in the measurement to generate 3D model.

Therefore, the focus of this research is on the data combination of TLS and UAV for a building. According to previous research conducted by other researchers, TLS is used to obtain building facades, while UAV is used to capture the rest of the building (Alshawabkeh & Haala, 2004; Masiero & Costantino, 2019a). Their study utilizes the usage of point clouds from UAVs and TLS for modelling and surface reconstruction. It is predicted that a 3D model of a building can be developed as a result of this study, with the final findings of a complete point cloud and the orthophoto of the study area.

1.2 Problem Statement

In recent years, the importance for applications of the 3D modelling has evolved from measurements to digital representation of physical and functional characteristics of places. The information that 3D maps or models can provide a lot to problems solving and give benefits to many applications such as topographic mapping and city modelling. One of the most significant advantages of 3D mapping is that it provides the most up-to-date technical ways for visualization and data collection.

When a 3D map of the object or area under research is accessible, knowledge visualisation and science mapping become easier. A 3D map provides a realistic image of a location that local governments and planners can use. A 3D map is just as useful as a blueprint in the construction industry. It is quite simple to visualise floor layouts on a 3D map and detect potential building obstacles. They also improve transportation as well as utility networks and helpful for disaster management as 3D data can simulate realistic effects. 3D mapping can improve city environments by allowing urban planners a more effective and efficient way to analyse proposed development.

If an area is filled with high density of building or we called high-dense area, it will be very difficult to map a 3D model because 3D mapping using only UAV would not be very accurate as the UAV needs to fly multiple times at different altitude. Some of commonly used laser scanners have limitations and cannot reach higher level of a high rise building since its maximum range from instrument to building is approximately 200m to 350m for a common laser scanner. Due to this uncertainty, this study investigated and searched the possibility of laser scanner combined with UAV to map a 3D model of a building. The investigation can help to clarify the probability of TLS range vs accuracy; of how far can a TLS scan a building façade (Blais, Picard, & Godin, 2004). A study by Sanz-Ablanedo et al. (2018) was made on a group of trees, they proposed the same thing that any taller trees, it is most likely that TLS would not capture the top of it. Through few processes, TLS is able to acquire a complete coverage spatially complex object like building and objects from different viewpoints (Alshawabkeh & Haala, 2004). With the aid of TLS collecting building's façade data, UAV focused more on the top of a building which will be explained more on the latter part of this thesis. Moreover, with the recent developments in technology, UAVs have been widely used to complement the limitations of TLS (Son, Kim, Sung, & Yu, 2020).

One of the technologies used in creating a detailed 3D model necessitates a high degree of technology, such as Light Detection and Ranging (LiDAR). As a benefit of adopting LiDAR technology, data may be obtained fast and with high precision. According to Slob and Hack (2004), the most important advantage of this method is that a very high point density can be achieved, in the order of 5 to 10 mm resolution. LiDAR, on the other hand, has substantial running costs in some applications.

Although LiDAR is inexpensive when used in large applications, it can be prohibitively expensive when utilised to collect data in tiny locations. As technology advances, 3D mapping can also be accomplished by utilising an Unmanned Aerial Vehicle (UAV) or a Terrestrial Laser Scanner (TLS).

Data acquisition using UAV by flying vertically above object covered the roof of an area and UAV captured the aerial images. The aerial images were used to generate point cloud and subsequently a 3D model was formed. However, 3D mapping and modelling using UAV would not be very accurate if UAV only flies vertically and the flying height used is consistent because the model would not be formed completely. It will be distorted. Therefore, to generate a better 3D model using only UAV needs a lot of flying from oblique angle and lower altitude (Manajitprasert, Tripathi, & Arunplod, 2019).

Meanwhile, 3D modelling using Terrestrial Laser Scanner (TLS) is commonly used and considered the best for 3D model production nowadays due to its complete point clouds generation. TLS is able to obtain rich 3D coordinate information over the complete objects or surface through the technique of reflection of laser pulses on the surface of objects and reception of reflected laser signals (Zang, Yang, Li, & Guan, 2019). Regardless of how advanced a laser scanner can be, there are still flaws depicted from this instrument. A study by Sadikin, Hernandi, Saptari, and Puspa (2015), even in superhigh mode, there is a corruption in the cube's point cloud data among the 3D point data gathered by scanning.

There were many studies of UAV integrating with TLS in producing 3D model (Alshawabkeh & Haala, 2004; Fassi, 2007; Guarnieri, Remondino, & Vettore, 2006; Masiero & Costantino, 2019b) but many of them are focusing on cultural heritage, suburban mapping and agriculture monitoring. Because, in most circumstances, problems can arise as a result of the time required to set up and remove the entire laser system. There were also studies in producing 3D building model using only UAV but the images are taken from top and oblique angle and from certain altitudes (Manajitprasert et al., 2019).

Therefore, in this study, the combination of UAV and TLS was studied to increase the effectiveness and accuracy of 3D modelling a building with appropriate criteria such as scan and spatial resolution for laser scanning and image resolution for imaging in order to get high quality of end product. Also, appropriate methods will be used to integrate those data and certain parameters in refining methods were considered. Therefore, there are several research questions were queried in this study as follows:

a) How the combination between UAV and TLS will be conducted?
b) What is the innovative method can be produced by combining both data?
c) What is the accuracy of 3D mapping obtained from both UAV and TLS?

1.3 Aim and Objectives of Study

The aim of this study is to produce 3D model of building through the combination of UAV and TLS. Hence, the objectives of the study can be defined as follows:

(a) To combine the data between UAV and TLS by merging their point clouds and develop 3D model of building.

(b) To evaluate the results and the accuracy of the combination process.

1.4 Scopes of Study

Before starting the project, several steps had been planned to ensure that the project objectives can be achieved. Therefore, it is essential to understand the basic theory of UAV, TLS, combination between those two data and 3D modelling. Also, it

is important to recognize the equipment and tools that were used for data processing in this study.

1.4.1 Study Area

This study was conducted at two UTM buildings which are T05 UTM Space building and T06 Fakulti Alam Bina dan Ukur (FABU) building using UAV and Terrestrial Laser Scanner approach. The criteria of the study area are a building with at least more than two-storey. Figure 1.1 and Figure 1.2 show the study area at both buildings respectively.

Figure 1.1 T05 UTM Space building

Figure 1.2 T06 UTM Fakulti Alam Bina dan Ukur building (formerly FGHT)

1.4.2 Image and point cloud acquisition

For data acquisition, the primary data that was involved in this study are the images from UAV and the point clouds obtained from TLS. Flight planning was discussed in advance to ensure that the collected data will cover the whole study area. Ground Control Points (GCPs) and Check Points (CPs) were considered non-primary data in this study. GCPs are the point that were used for image processing meanwhile CPs were used for accuracy assessment. In this study, GPS Real Time Kinematic technique was chosen to establish several ground control points (GCPs) and check points (CPs). Subsequently, TLS was used to acquire the facade of the building from the ground. TLS produced point clouds that were used further in data processing.

1.4.3 Image and ground data processing

Meanwhile, the data processing was divided into two parts which were aerial images and ground data processing like the following:

1. In aerial images processing, the images from the UAV was used to generate texture mapping by utilizing GCPs for this study.

2. Simultaneously, GCP involved in the georeferenced process was used to synchronize the point clouds from TLS in actual position for the ground data processing.

1.4.4 Combination of UAV & TLS and accuracy assessment

The combination process of the point clouds from both façades and roof models was carried out in this study to generate a complete geometry model. In order for the combination process to be successful, it is important for both of the point cloud to be in the same coordinate system. These data were used to evaluate and analyse based on the outcome of results by using root mean square error (RMSE) from comparing the distance measured from the study with the distance from the actual building.

1.5 Significance of Study

This study focused on the combination of data between UAV and TLS to produce 3D model of building. Following are the significance of this study:

1. Facilitate in visualization for public and local government – allow urban planners to analyse proposed developments effectively and people can actually participate in providing ideas for urban development.
2. Understanding the procedure of combination of point clouds from UAV and TLS whereby a lot of integration methods are already on market but this thesis is to focus on how UAV is used to collect the rooftop and TLS is used to collect facades of building.

1.6 Thesis Organization

Chapter 1 is an introduction of study. This chapter consists of background of study, problem statement, objective of study, scope of study, significance of study and research methodology.

Chapter 2 describes the fundamental of this study which provides appropriate knowledge including the theories, definition and applications employed in this study. This chapter reviews the existing research related to this study and some useful references on TLS and UAV.

Chapter 3 consists of research methodology which covers the preliminary study, data acquisition and processing, result and analysis as well as conclusion and recommendation for this study.

Chapter 4 presents the result and analysis of this study. This chapter discusses on the accuracy assessment which consists of accuracy and precision assessment for each result, orthophoto, the point clouds and the 3D model. The results and relevant analysis is illustrated and elaborated in various forms such as table, graphic presentation, tabular form and graph presentation.

Finally, Chapter 5 delivers the concluding remarks and recommendations which are drawn from the study that has been carried out. This chapter concludes the finding of this study and achievement of study objectives. Then, this chapter discusses the suggestions or recommendations that can be used for future work.

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