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Integration of Lidar system, mobile laser scanning (MLS) and unmanned aerial vehicle system for generation of 3d building model application: A review

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Abstract. Nowadays, 3D modelling has become very important because real information can be extracted from the model. UAV is system that was used for developing the 3D model and has proven capable to produce good results. However, the exploration of the integration of UAV with other technology like LiDAR and MLS to develop a more accurate and detailed model is still lacking. This study reviews the aptitudes of the UAV integrated with LiDAR and MLS for developing the 3D building model in Malaysia. Several issues, like type of platform, quality of 3D model and others to review the capabilities of the UAV used for producing very accurate 3D model were critically analysed. Previous research suggests that integration of Lidar with multi-rotor platform fusing with MLS could be used to construct an accurate 3D model. A dense point cloud of the whole building can be obtained from the fusion between Lidar and MLS. Moreover, an accurate 3D model can be generated from this process as the point-cloud from LiDAR and MLS has positional accuracy in centimetre level compared to a non-metric camera integrated with a UAV. This study finds the UAV has the potential to use to produce a quality 3D model.

1. Introduction
Over the recent decade, the usage of UAV photogrammetry for geographic data collecting has increased dramatically. Indeed, advancements in artificial intelligence and robotics are aspects that are expanding the use of the UAV system in a variety of applications, including three-modelling [1] [2]. In addition, the advancement of computer vision algorithms and new calculation techniques has reduced processing time, and the process is now mostly automated [3]. Previously, producing photogrammetric items took longer and often required a human process. Because a 3D model can extract genuine information in a 3D image, 3D modelling has become more significant in mapping applications. The 3D model is critical because it can provide information on the ground in a real-world situation that a 2D map cannot [4]. In many nations around the world, including Malaysia, the 3D model is in high demand. For the creation of the 3D model, a variety of techniques have been applied, including TLS and Lidar. However, these methods are prohibitively expensive [5,6]. As a result, the UAV system can be employed as a backup strategy. The development of the UAV system has improved photogrammetry's capabilities. The development of a 3D model, for example, may be done quickly and accurately. As previously stated, the UAV system has numerous advantages over other systems. One of these benefits is that the aerial images of the object can be completed quickly, especially for a small area.

Nowadays, 3D modelling has become very important in mapping application because the 3D model can be used for extraction of real information in 3D view. 3D model is very important because it can give the information on the ground in a real situation where the 2D map unable to do so. 3D model is a current demand in many countries around the world including Malaysia. There are many techniques that can be used for the generation of the 3D model such as TLS and Lidar. However, these techniques are very expensive. Therefore, the UAV system can be used as an alternative technique. The development of the UAV system has enhanced the ability of photogrammetry. For example, the creation of the 3D model can be done in short time and accurate model. As mentioned before, the UAV system offers many advantages compared to other technique. Among these advantages is the aerial images of the object can be completed within a short period for the small area and large area. Additionally, the 3D model can provide a visualization of the whole object. 3D modelling techniques can be used in Smart City, cadastral, hydrographic, strata, mapping and others [7]. Therefore, this article examines the capabilities of the UAV system for modelling the 3D building model in Malaysia examining numerous problems such as the type of platform, the quality of the 3D model, the type of sensor, and the system's limitations.

2. Unmanned aerial vehicle system (UAVS)

Drone is the common name for an unmanned aerial vehicle (UAV). It's a type of plane that doesn't require the presence of a pilot in the cockpit. The UAV is available in two versions: one that can be controlled remotely and the other that can be flown automatically based on flight plans that have been pre-programmed utilizing a tough dynamic automation system [8]. According to [9], a UAV is an aircraft that does not have a pilot on board and may be controlled autonomously, semi-autonomously, manually, or in a combination of these modes [10]. These modes allowed the pilot to control the UAV from the ground station. Because it was developed and programmed using a dynamic and automated system, the UAV may operate in a variety of modes. To allow the UAV to fly in autonomous mode at a set altitude, special software is needed to construct the flight path, which must be completed before the flying mission begins. This program is available as open source or as a commercial product. Mission Planner, ArduPilot, OpenDroneMap, Flone, DronePan, LibrePilot, Dronecode, Paparazzi UAV, Drone Harmony and many others are examples of open-source software. Commercial software examples include DroneDeploy, DJI Go, Map Pilot, and PIX4D Capture.

Besides that, it can be considered a flying robot that can fly thousands of kilometers from the earth's surface to record all the information on the earth or capture aerial images from the sky. Nowadays, many sensors have been integrated with UAV systems such as Lidar, thermal, hyperspectral, multispectral, digital compact camera, digital single-lens reflex camera and many more [11]. At present, many manufacturers designed the sensor based on the UAV design and specification to make this sensor easily integrated with the UAV system. Indirectly, this development made UAV technology very useful and can be used in various applications. Photogrammetry has seen a significant increase in its applications for acquiring digital 3D models over the last decade. Factors that were once considered weak points of the technique, such as photogrammetric image processing, now take less time and are largely automated due to the advancement of algorithms from computer vision and modern computing techniques [12].

When searching for related articles on the internet, the term UAV is currently the most popular. This is the name given to a flying object that is used for both recreational and professional civilian purposes. Even though an online agreement appears to have been reached, many aviation agencies have chosen a term other than UAV. Remotely Piloted Aircraft (RPA), Remotely Operated Aircraft (ROA), Unmanned Aircraft (UMA), Automatically Piloted Vehicle (APV), Remotely Piloted Vehicle (RPV), Re-motely Operated Aircraft (ROA), Remotely Piloted Aircraft (RPA) and Unmanned Vehicle Systems (UVS) are some examples of UAV terminology [13,14] Each of these terminologies has a different definition and explanation. For example, the terminology of RPV refers to an electronic aircraft operated by a pilot at a ground station, and the US Department of Defense commonly uses it. While the terms ROA and RPA were popularized by the US National Aeronautics and Space Administration (NASA) and the US Federal Aviation Administration (FAA).

UAVs come in many different shapes, sizes, configurations, and features. Developed during and after World War I (WW1), the Hewitt-Sperry Automatic Airplane was the first UAV. Later, several advances in remote-controlled aero plane technology were made during World War II. Anti-aircraft gunners were trained on these, and attack missions were flown with them. UAVs' interest in the military as applicable technologies matured and highly advanced, as seen in the 1980s and 1990s. UAVs were seen to create less expensive, more capable machines that could be used without endangering the pilots. The early generation of aircraft was primarily surveillance planes, but some were equipped with weapons [9].

Today, UAV has been used in various applications. Remote sensing is one of the applications that has benefited from the use of UAV technology. This was due to the mission expense, the need for quick response, the information in real-time and re-quired to observe the hazardous area or unsafe to the human. The use of UAV in agriculture application is a significant increase. Information extracted from aerial imagery taken from the sensor attached under UAV can be used for classification, study phenological behavior, yield estimation, crop monitoring, crop height estimation, pesticide spraying, soil and field analysis, monitoring and management [2][15][16][17][18][19]. Among the models of UAV agriculture are AeroVironment, X-Copter, VIPtero, Fieldcopter, Yamaha RMAX, DJI Phantom quadcopter and Sensefly eBee [20][21][22][23][24][25]. In geomatic application, UAV was used for 3D building modelling, slope mapping, river stream mapping, updating the topographic map, monitoring coastal erosion line and many more [9]. DJI Phantom, DJI Matrice 100, Skywalker, and hexacopter are examples of UAV used in geomatics applications [26][27][28][29].

3. Three-dimensional modelling

A 3D modelling is a process of representing any kind of object or surface into three-dimensional form through manipulating the polygon, edges and nodes of the object. Basically, transformation from two-dimensional into three-dimensional can be done either in manual or automatic process. On the manual processing, a specified software was used for creating or modify the polygon, edges and nodes or scanning the object by using a special equipment to transform it into digital form. There are many types of three-dimensional software are available on the markets such as AutoCAD 3D, ZBursh, 3DS Max, SketchUp, Blender and many more. Now, this discipline has been used in the various fields like engineering, architecture, entertainment, urban planning, film, special effect, medical, game development, 3D mapping, commercial, building inspection and many more. Viewing the object in the three-dimensional representation, it will allow the users to extract all kind of the information in the real situation. A 3D building or city modelling is one application in this field.

Recently, an increasing number of cities and organizations have developed three-dimensional city models for a variety of purposes, including 3D cadaster, city information, tourism, urban planning, architecture, disaster management and many more. 3D city models are used to depict buildings, city quarters, urban districts, cities, and regions, as well as other elements such as structures, trees, man-made features, infrastructure, vegetation, and topography. Various levels of data quality are attained or required depending on the data gathering procedures, data processing, and planned use of the city model. The level of detail reflects the degree of data quality. There are numerous techniques for creating a virtual three-dimensional city model, including high-resolution satellite photography, laser scanning, and aerial photogrammetry. Among these approaches, aerial photogrammetry is the one that is most frequently employed to construct three-dimensional city models. It has the advantage of requiring only a few photos. Because the texture, footprints, and root of buildings are retrieved from the same image, the photos' color balances do not need to be adjusted. Additionally, this technology is capable of providing information about the three-dimensional geometry and texture of the ground. Additionally, it is capable of obtaining information on vertical elements through the use of oblique photogrammetry.

4. Previous study related of UAV in 3D modelling application

There are many studies have been conducted which involves the use of UAV technology for the three-dimensional modelling application around the world including in Malaysia. These articles are reviewed not only focused on modelling involving the object such as building, but it also involves other object like trees and highways. Over the past few years, the use of UAV technology in this application has significant in-creases. This is due to the ability of UAV technology capable to accelerating the pro-cess of producing 3D object besides the costs of data acquisition is lower compared to others techniques.

Isa et al. [30] have studied the use of UAV photogrammetry survey for 3D modelling of archaeological site in Italy. The factors such as flight configuration and the georeferencing technique have been take account in order to analyzed the effects of these factors towards the final product. In this study, the hexacopter UAV and 24-megapixel compact digital camera have been used for captured the aerial image of object from two different angle which are nadir and oblique. From the data acquisition, two sets of aerial images have been taken in which the first set are captured from nadir view while the second set are captured from nadir and oblique views. Ac-cording to [19], it is more appropriate to acquire an oblique aerial image in order to obtain more detail data and create a more accurate 3D model. Rapid static and Real Time Kinematic (RTK) GPS were used to established ground control points (GCPs) in the study area. GCPs rapid static was used to evaluate the accuracy of GCPs RTK. As a result, the Root Mean Squared (RMS) is 9 mm of planimetry and 12 mm of altimetry. Additionally, the oblique aerial imagery is capable for minimize the shadow effect. When both nadir and oblique aerial imagery were used for production of 3D model, the residuals on the GCPs are more dispersed. While, the residual on the GCPs is less dispersed but the value of RMS is higher, when only nadir aerial imagery is used.

Mohd Noor et al. [31] was used UAV-based Lidar system for modelling the riverscape topography and vegetation. The Lidar points cloud were classified into two classes which are vegetation and ground, also were used to produce the digital terrain model and canopy height model. Result was compared with the point cloud acquired from airborne LiDAR System. In this case study, the UAV technology was used because it is capable for scanner the object at lower altitude. As a result, a denser points cloud is ac-quired, which improves the object's detail, especially vertical elements like vertical streambanks, rock, vegetation or built environment [23] [24]. Because of these bene-fits, UAV-based Lidar is more suitable for used in areas with complex topography. Apart from that, the accuracy of points cloud from UAV-based Lidar are more accurate than points cloud obtained from airborne Lidar with relative error of 0.93 percent.

Halim and Chan [32] was combined UAV, terrestrial photogrammetry and laser scanning for 3D modelling of Historic Churches in Georgia. The main reason of integrating these three types of data is to construct an accurate and comprehensive 3D model of the monument. The aerial images of the monument were taken with a quadcopter UAV from two different angles: nadir and oblique. During data collection, the pilot operated the UAV in the manual mode. While, the 24.2-megapixel SLR camera was used for captured the terrestrial images of the monument. The camera's lens was fixed with adhesive tape, and the autofocus and sensor cleaning functions were disabled. The points cloud of the monument was captured by using geodetic laser scanner with maximum range of 330 meter. As a results, Photogrammetry using UAVs allows for the calculation of roof and tower areas that are not visible in TLS or terrestrial images. Even a basic, low-cost drone has been shown to be useful in this situation. If a significant overlap (approximately 80–90 percent) is ensured, the terrestrial images can be analyzed without difficulty. Individual terrestrial images were difficult to process, but almost all images could be focused when combined with UAV images. The overall accuracy is equivalent to laser scanning at around 5 into10 mm.

Huang et al. [33] was integrated the UAV system and mobile laser scanning (MLS) for produce of high-resolution 3D model. the objective of this study is to proposed the standard operational procedure for the use of UAV system and MLS for 3D model reconstruction in Finland. This studied have been implemented in Sandburg, Finland where this area covers dense building and middle height trees. The Microdrone UAV was used in this study to acquire the points cloud of the building roofs, while MLS was used to acquire the points cloud of the building wall. Both sets of data were combined using the iWitness software to form a complete dense point cloud of the building. Huang et al. [34] also investigate the potential of UAV system fused with MLS for generate high resolution of 3D city model. UAV was used to construct very high-resolution 3D model of roof landscape, while 3D models of façade or wall produced from the MLS. The increasing availability of multiple data sources acquired by various sensor platforms has given significant benefits in achieving desired results. Therefore, both technologies are complementary.

Zheng et al. [35] was used multi-UAV to construct 3D model of building for route planning especially in emergency case. Aerial imagery of the building was taken from nadir and oblique angle. There are three data collection were used which are manual operation, single UAV route planning and multi-UAV route planning. The results show manual operation successful acquired more than 1000 aerial images while the both rest of method acquired 500 aerial images. The quality of 3D model construct from UAV with error less than 20 cm and 11 cm of standard deviation. The points cloud from the UAV was evaluated and analyzed for construct the 3D model of building with Level of Detail 2 (LOD2) in semi-urban area [36]. Finding of this research shows the data process model developed allows the developer to easily monitor and manipulate each processing phase, making spatial ETL solutions useful for 3D building modelling from UAV data. Wroc and Sciences [37] investigated the possibility of using UAV aerial photos as an information source for automated 3D building modelling.at LOD2. The accuracy of the building models acquired using the UAV-photogrammetry is less than 18 cm for the planimetric and around 15 cm for the height. The 3D model constructed from UAV photogrammetry have high correlation with the 3D model constructed from ALS. However, UAV photogrammetry have advantages for produce higher density of points cloud compared to ALS.

5. Analysis

This article provides an overview of the areas of 3D building model from aerial photo, airborne LiDAR, terrestrial LiDAR and their integration. The primary objective of this research is to assess the UAV system's aptitudes to develop a 3D building model when combined with LiDAR technology. According to the articles reviewed, UAV systems have been extensively used for generate a 3D building models around the world. This fact demonstrates that the UAV system is capable of being used in 3D model applications. However, the majority of researchers have combined the UAV system with LiDAR technology to create a high accurate and detail a 3D model. The primary reason why both photogrammetric and LiDAR methods are required for fusion because the LiDAR sensor are specifically designed for producing a high accurate point cloud with high density. With recent developments in photogrammetric software, the point cloud can also be derived directly from the aerial photo taken with a digital camera or a non-metric camera. However, the quality of the data is highly dependent on the global positioning system have been used during data acquisition. Navigation GPS and Real-Time Kinematics (RTK) GPS are the two common systems that are frequently used in UAV photogrammetry methods but the point cloud's accuracy is lower than LiDAR. Additionally, LiDAR sensors have advantage over non-metric cameras in terms of producing a high-density point cloud. Indeed, from higher density points, a highly accurate and detailed 3D building model can be generated. Some of the building is located in the compact and crowed place like city therefore the space between adjacent building is narrow. Thus, the UAV system will have difficulty for capture the aerial photo of vertical structure of building like the wall. A fusion UAV system and LiDAR technology such as ALS, MLS, or TLS can be used to acquire the entire structure of the building. According to the majority of case studies, UAV systems are best suited for modelling buildings in open areas rather than compact areas. Previous research has shown that multi-rotor platforms are widely used because they are more stable than fixed wing platforms due to their gimbal system. The gimbal is capable of absorbing wind resistance, preventing the sensor's angle from becoming excessively tilted. it is more convenient to operate, even in confined spaces. Additionally, the point cloud can be acquired from multiple perspectives in order to produce the complete model, as the sensor's angle can be adjusted.

6. Conclusion

We can conclude that the combination of UAV photogrammetry and LiDAR technology has a lot of potential for 3D building modelling in Malaysia. The benefit of integrating both techniques is that a highly accurate and detailed 3D model can be produced in the short time and at the low cost compared to conventional techniques.

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