Reconstruction of 3D Building Model Using Point of Interest Technique at Different Altitude and Range

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Abstract. The essential techniques used in 3D model reconstruction are LIDAR scanning, close-range photogrammetry, and aerial photogrammetry. The aim of this study is to investigate 3D building model results using a UAV platform using different altitudes and ranges. The methodology was divided into four phases. Phase one was a preliminary study and phase two was the data acquisition phase which included flight planning, camera calibration, and image acquisition at three different altitudes; 150m, 170m, and 190m and at different ranges; 180m, 190m, and 200m, respectively. Phase three was data processing whereby the resulting 3D models were generated using five steps which are image masking, image aligning, image dense clouding, image meshing, and image texturing. Phase four contained analyses on the 3D model such as accuracy assessment of the 3D model and analysis on the different altitudes and ranges employed. This study stated that the maximum accuracy was 0.195m without a control point, while the minimum accuracy was 0.123m with a control point. It shows that the 3D model with a control point produced measurements that were 37% more accurate than the 3D model without a control point. In the final analysis, the results showed that the built 3D model resulting from the UAV platform can provide an accuracy of less than 0.200m with or without control points. These findings can be applied to many fields, such as heritage and conservation in the efforts to preserve the 3D model of heritage objects.

1. Introduction
The demand for 3D models over the past few years has significantly increased, more so for cultural heritage applications. The techniques applied have progressed from surveying and CAD tools or traditional photogrammetry to laser scanning and more automated image-based techniques. 3D modelling of heritage buildings and monuments are a source of accurate documentation for reconstruction in case they are destroyed, and for creating educational resources to cater to history and cultural students and researchers [6]. The latest digital 3D scanning device has assembled new means to preserve a site and its historic trace digitally using photorealistic 3D models and building geometry. Even though the quickest and most adequate way of generating a 3D model is by using laser scanning, usage of the instrument is quite costly today [1]. LIDAR is a very expensive means of acquiring more detailed information, while close-range photogrammetry reconstructs a 3D model.
using images from a calibrated digital camera. The traditional approach used to construct a 3D building model in urban planning and design involves one person operating a computer to display the digital building on the planned location after designing and space planning [4]. A 3D model is an object that has height, width and depth like any object in the real world. In the past, the techniques generally used to build 3D models include terrestrial close-range photogrammetry based on engineering plans which were further generated into 3D models using certain processing software [2]. The essential techniques used for 3D model reconstruction are LIDAR scanning, close-range photogrammetry, and aerial photogrammetry. LIDAR is a powerful system and an appropriate source of high-accuracy 3D point cloud data [5]. The process of reconstructing 3D building models using LIDAR and Ultra Cam is costly and has a limitation in terms of the location suitable to place the camera in order to obtain accurate photos, especially those that capture the height of the building. Another drawback of this method is the comprehensive task of determining and adjusting control points that may limit image-taking and the obtaining of 3D reconstructed images of acceptable accuracy [3].

The accuracy of a 3D building model can be diversified using different ranges, altitudes, focal lengths and number of photographs taken which will result in various levels of accuracy. However, if the photographs are taken at low altitude but are far from the object or building, it will result in either low accuracy, and vice versa. So far, many studies have been conducted on the assessment of accuracy between measured and actual measurements of reconstructed 3D building models and the evaluation of 3D building models using different software. Sensor quality and stability may influence the geometric precision of the 3D models attained. Furthermore, the number of images needed must be considered using a processing strategy which economises the available computing resources [6]. The novelty of this study is to investigate the ideal altitude and range to capture 3D building models. Altitudes and ranges are very important during the image data acquisition to lessen the probability of the 3D building model’s resulting quality to be questioned. Therefore, this study aims to assess the accuracy of a 3D building model from a UAV platform based on different altitudes and ranges.

2. Material and Methods
In this study, the research methodology was divided into four phases. Phase one involved a preliminary study. Phase two consisted of data acquisition which included flight planning, camera calibration and image acquisition at three different altitudes which are 150m, 170m, and 190m at different ranges of 180m, 190m, and 200m respectively. The selection of altitudes and ranges was determined with respect to the surrounding environment where the building is located near other high-rise buildings and trees. The altitudes and ranges were also determined based on the size and height of the building. The size of the building is about 160m x 130m while the height is about 142m. The different altitudes and ranges can affect the angle of view between the camera and the object. This study focused on a 54° angle of view for the 150m altitude and 180m range, a 48° angle of view for the 170m altitude and 190m range, and a 43° angle of view for the 190m altitude and 200m range. Range is defined as the distance between aircraft and building, while altitude is the height of aircraft from the hover point. Phase three consisted of data processing and the generation of a 3D model using five steps which are image masking, image aligning, image dense clouding, image meshing and image texturing. Phase four consisted of the analysis on the 3D model which included assessments on the accuracy of the 3D model and analysis on different altitudes and ranges. Figure 1 shows the research methodology of this study.

2.1 Preliminary Study
The site selected is located at latitude 3° 04’ 43” and longitude 101° 31’ 15”. The study area is a state mosque which is the Sultan Salahuddin Abdul Aziz Mosque situated in Shah Alam, Selangor, Malaysia. This study area was chosen because it has a large open space and fewer obstacles for the UAV’s flight mission. The location of the study area is suitable because the site needs to be free from any obstacles at a range of further than 180m from the building. As mentioned before, the
ranges were determined based on the environment surrounding the building. Additionally, the height of obstacles near the site must be below than 150m. This will ensure the smoothness of the flight mission and avoid any unexpected disturbance. This location is also suitable for UAV studies because it has sufficient space for the UAV’s launching and landing. The maximum flying height altitude was set based on the limit imposed on the DJI Phantom 3 Pro UAV which is 190m above surface level. This altitude was also chosen to adhere to local flight regulations. The minimum flying altitude was set based on the selected building’s condition where the altitude of 150m above surface level was deemed the safe minimum flying height for DJI Phantom 3 Pro due to the building and facilities’ height.

Figure 1. Research Methodology on 3D building model using a UAV platform from different altitudes and ranges

2.2 Data Acquisition
In this study, data acquisition for the 3D model was conducted using the Phantom 3 Professional software. Before the commencement of work, information on the camera’s calibration was processed
in the Agisoft software to obtain the internal camera parameters. Data acquisition was acquired from several flight missions at different altitudes and ranges. There were three altitudes, i.e. 150m, 170m and 190m with ranges of 180m, 190m and 200m, respectively. The type of UAV used in this study was the DJI Phantom 3 Professional set. Data on both categories were obtained using the DJI GO. The DJI GO app was also used to plan the flight lines for image acquisition. The DJI GO app provides UAV users with a platform to operate the system. This app includes features such as intelligence flight mode and options such as follow me, waypoints, home lock and points. For the construction of the 3D building model, the project used the intelligence flight mode on a point of interest to obtain images. This mode enables the system to focus on a point of interest and fly in a circular path in order to acquire images. Multiple overlapping photos with 80% to 90% overlap were taken using the autonomous programmed flight path. In this study, the conditions of the study area were explored before the flight mission was conducted in order to find the best location for the hovering and landing of the UAV during the flight mission. The DJI GO app generated waypoints for the UAV during the flight mission. All waypoints were sent to the UAV’s navigation control via a radio modem. Data was collected in the form of images captured at different altitudes and ranges using the point of interest technique. The distance between the aircraft and the building had to be continuously monitored to avoid the aircraft from deviating from the given trajectory.

2.3 Establishment of Control Points
The establishment of a control point which is the Sultan Salahuddin Abdul Aziz Mosque was conducted using the survey technique. Ground control points were established around the building as reference stations for the establishment of control points on the building. The ground control points were located on the ground, while the control points were located on the building’s surfaces such as walls, windows, and other geometric structures on the building. All of the ground control points were established using the Global Positioning System (GPS) method with MyRTK (Malaysia Real-Time Kinematic) Network. The purpose of this survey is to acquire the position of northing, easting and heighting for all ground control points. At an early stage in the study, reconnaissance was conducted. The step was followed by GPS observation to acquire the positions of all selected ground control points based on Malaysia’s MyRTK network coordinate system with geodetic datum GDM2000. Then, the coordinates of the ground control points were transferred to the control points at the building. The selected control points for the Sultan Salahuddin Abdul Aziz Mosque were the dome of the mosque, edge of the roof and design shape below the dome. Furthermore, the target points of the building must be seen from at least three control stations. The intersection method was used to transfer the coordinates from the ground control points to the control point on the building. The intersection method is one of the surveying methods used to establish coordinates on a building’s wall or structure. This method records the angle and distance to calculate the coordinates of control points (building structure) from the reference station (ground control points). Data needed at this step included back bearing, horizontal angles on the left and right faces, vertical angles on the left and right faces, and the height of the instrument. About 16 control points were established around the building (Figure 2).

![Some example of control points at the target building](image-url)
2.4 Data Processing and Analysis

In this study, a commercial software, Agisoft Photoscan was used to process the images produced by the Phantom 3 Pro UAV. The Phantom 3 Pro UAV was used to capture images from the altitudes of 150m, 170m, and 190m and at the ranges of 180m, 190m, and 200m respectively. In addition, the capturing of images can also be done at both high altitude and low altitude. The resulting images were then combined through image processing. As a result, the images also covered the lower part of the building; this served as an alternative way to enhance the accuracy of the 3D model. An oblique image acquisition procedure using Phantom 3 Pro was also conducted. Three different processes were conducted for the different altitudes and ranges. The UAV raw images were downloaded into a computer after the flight mission was completed. Each image was saved as a JPEG file. As a result, 80 images from the 150m altitude and 180m range, 119 images from the 170m altitude and 190m range, and 153 images from the 190m altitude and 200m range were processed to generate a 3D model of the building. The quality of images was checked before they were used in the processing stage. The quality of images is based on the sharpness of the images. Blurred images were not considered for image processing as it might affect the accuracy of the 3D building model results. After checking the quality of all images, the images were imported into the software. Next, the masking process was conducted. This process is very important to enhance the quality of the 3D model results. The masking of an image depends on the purpose of the study conducted. If a user needs to create a single 3D model without surrounding features, the image mask must be applied to remove all unnecessary elements on the source image such as background, accidental foreground, surrounding buildings or roads. The masking of image also contributes to more accurate results, especially for 3D building model generation. This is because the tie point of all the surrounding areas that generate the whole area will affect the 3D model generation itself. The masking of images began with the use of tools from the toolbar such as the rectangular selection, intelligent scissors, intelligent paint and magic wand. All of these functions have their own use; for example, the rectangular selection can be used to mask rectangular irrelevant elements, the intelligent scissors can be employed to cut irregular shaped areas, and the intelligent paint can paint over unwanted images. The magic wand button can be used to mask the background of the image used. After masking all the images, the photos were then aligned. Photo alignment is important in order to estimate the camera position for each photo as well as find the matching points in overlapping images to generate a sparse point cloud. In this study, the parameters used were high in terms of accuracy but generic for pair preselection. The markers (control points on the building) were paired to the selected images. The use of markers is meant to optimize the camera’s position and orientation data which allows for improved model referencing results. Then, the coordinates of the control points for every marker were inserted.

3. Result and Analysis

In this study, the 3D model acquired was developed based on three different altitudes and ranges. There were many uncovered areas for images taken at the altitudes of 150m and 180m. This was because the images were captured closer to the building and thus did not cover the details below the roof. Therefore, usage of high altitudes during image capturing is required in order to obtain highly detailed data on the selected building. Furthermore, the façade of the 3D model for altitudes 150m and 170m and ranges 180m and 190m were not fully generated and suffered from some distortion because the POI technique did not fully cover the area as it was based from the centre of the dome. Hence, the 3D models for altitudes 190m and 200m produced better results compared to the other models as the mentioned ranges were sufficiently spaced from the centre of the dome. Moreover, the quality of texture depends on the quality of the camera itself. The 3D models for all attitudes and ranges are as illustrated in Figure 3.
Figure 3. 3D Model Results; (a) Altitude 150 Meter and Range 180 Meter, (b) Altitude 170 Meter and Range 190 Meter, (c) Altitude 190 Meter and Range 200 Meter

Based on the results, a comparison between the Sultan Salahuddin Abdul Aziz Mosque’s 3D building model and actual measurements was evaluated. The result was determined based on the 3D model developed in the Agisoft Photoscan software, multi-photograph images of the Sultan Salahuddin Abdul Aziz Mosque, and the actual measurements of the Sultan Salahuddin Abdul Aziz Mosque as shown in the mosque’s original plan. Figure 4 shows the error for all 3D models processed without control points. The errors were calculated based on actual (real building) length and the measured (3D model result) length of the 30 samples. Three types of 3D model had resulted from this study which were based on altitude 150m and range 180m (A150R180), altitude 170m and range 190m (A170R190) and altitude 190m and range 200m (A190R200). Based on Figure 4, the range of error for A150R180 is between -0.552m to 0.626m. The standard deviation for the A150R180 3D model is ±0.294m where 10 outliers or 33% of the data samples have been removed. The RMSE for the A150R180 3D model is 0.165m. The range of error for A170R190 is between -0.792m to 0.526m. The standard deviation for the A170R190 3D model is ±0.373m where about 43% or 13 outliers have been removed.
Figure 4. Error for all 3D Models without control points

The RMSE for the A179R190 3D model is 0.195m. The range of error for A190R200 is between -0.873m to 0.713m. The standard deviation for the A190R200 3D model is ±0.379m where about 11 outliers or 37% of data samples have been removed. The RMSE for the A190R200 3D model is 0.189m. Therefore, the most accurate model among these three 3D models is the A170R190; this means that low altitudes and ranges can provide good data for 3D models when the UAV images are processed without control points. Figure 5 shows the error for all 3D models processed with control points. As mentioned in the previous section, 16 control points were established around the building. Based on Figure 5, the range of error for the A150R180 3D model is between -0.353m to 0.328m. The standard deviation is ±0.186m where 11 outliers or 37% of data samples have been removed, and the RMSE for the A150R180 3D model is 0.151m. The range of error for the A170R190 3D model is -0.344m to 0.391m. The standard deviation is ±0.207m, where about 11 outliers or 37% of data samples have been removed. The RMSE for the A170R190 3D model is 0.123m. The range of error for the A190R200 3D model is between -0.300m to 0.322m. The standard deviation is ±0.210m where 33% or 10 outliers of data samples have been removed. The RMSE for the A190R200 3D model is 0.135m. Therefore, the most accurate model among these three 3D models is the A170R190; this means that medium altitudes and ranges can provide good 3D models when the UAV images are processed with control points.

Figure 5. Error for all 3D Models with control points
Based on these findings, it can be summarized that the 3D models processed without control points and with control points have differences within the centimetre level at about 1.4cm to 7.2cm. However, the accuracy of the 3D models without control points are also below 20cm for all altitudes and ranges. Figure 6 shows the RMSE for all 3D models, including those without and with control points.

![Figure 6. RMSE for all 3D models](image)

4. Conclusions
In conclusion, rotorcraft UAVs are able to develop very fine 3D building models with reliable accuracy. This study had investigated the flight mission using the POI technique at different altitudes and ranges. Altitude and range play an important role in producing good 3D models. For example, lower altitudes and short ranges produce more gaps or holes during the creation of a 3D model, thus a suitable altitude and range must be determined before the flight mission. This study has also investigated the use of control points during image processing. It is proved that control points can increase the accuracy of 3D models. In the construction or building industry, this value is very significant in order to get accurate and precise 3D models for further analysis. This study found that POI flight missions at different altitudes and ranges can gave different accuracies of not more than 0.030m. As mentioned before, the accuracy of 3D models processed both using control points and without control points could produce accuracies below 0.200m. This study implemented the automatic aerial triangulation method to process the UAV images. This method requires less human involvement but needs the use of high-end computers to process the UAV images. This method is faster than the conventional close range method which requires image matching to be done manually for every stereo model. This study is very useful for related agencies, for example those in the building maintenance, heritage conservation, architecture, archaeology and construction fields. It is recommended that future researchers should study the optimum number of control points needed to develop 3D models. This study only used 16 control points to develop a 3D model of the mosque. Future researchers can also study various kinds of altitudes and ranges to be used during flight missions. The effect of different focal length sensors can also be investigated in the future.

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