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Derivation of high-resolution orthophoto map from multirotor drone survey for application in infrastructure management

Derivation of high-resolution orthophoto map from multirotor drone survey for application in infrastructure management

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Abstract. An orthophoto is a geometrically corrected aerial image that can be used in the same approach as map. It provides various geospatial information and therefore plays an important role in infrastructure management. This paper describes the methodology of an aerial survey using a multirotor drone and the processing of aerial images acquired from the survey to produce an orthophoto map. The survey work was carried out using Zenmuse X4S photogrammetric camera controlled by an autopilot multirotor drone at 200m above the ground. Optimal flight path for the autonomous mission was created and organized using the Map Pilot software. Five ground control points were laid within the survey area and their locations were determined using a real-time kinematic global navigation satellite system. Aerial images acquired from the survey were processed with the Pix4Dmapper photogrammetry software. The photogrammetric processing generated a 6 cm-resolution orthophoto map. The presented work demonstrates the practicality of multirotor drone survey and intelligent image processing for non-professionals in deriving high-resolution orthophoto map for application in infrastructure management.

Keywords: drone, unmanned aerial system, orthophoto, photogrammetry, infrastructure management

1. Introduction

Civil infrastructures such as public building, road, highway, pipeline and drainage network are valuable assets that serve our society and economy. They are usually designed to have long life cycle and are expected to perform at their best within the life cycle. Therefore, efficient management of these infrastructures are important. Typical management practices include scheduled monitoring to assess the condition of these infrastructures over their life cycle, projection of future maintenance especially major maintenance work and estimation of the cost for the maintenance work. Moreover, civil infrastructures are spatially distributed and interact with complex environment. Their condition and functionality depends heavily on the surrounding environment and therefore management of these infrastructures require integration of various spatial data. Managing various spatial data related to infrastructure could be done more efficiently with the establishment of digital database system. This is in line with the fourth industrial revolution (IR 4.0) which focuses on digitalization that promotes modern techniques supporting every component within industry [1]. The establishment of digital database will facilitate asset managers in planning, operation and analysis for decision making. In addition, a comprehensive data will guide the performance evaluation and risk assessment due to natural and human-induced hazards [2]. Furthermore, the digitalization can also tackle the issues of missing data as normally happened to the conventional paper-based record keeping method.

In practice, spatially distributed data are normally stored and analysed in computer aided design (CAD) software. Spatial data are represented in vector data model, stored in three-dimensional coordinate system. The software allows the attachment of images to enhance the representation of the data. Over the years, the technology has been improved. Geographic information system (GIS) softwares such as ArcGIS (commercial product by ESRI) and QGIS (open source platform) are becoming more common tool of storing and analysing spatial data. The GIS software has the ability to store, query, overlay and analyse various data layers in both vector and raster data model. Additionally, the software store supporting information associated to each spatial feature in an attribute table. Nowadays, the advancement in communication technology enables the web-based GIS. It is a geospatial application in an online environment. The web-based GIS application provide platform for data sharing and flexible access especially for large organization [3]. Regardless of the advancement of technology, the foundation of any development of digital database is the background map. One of the most effective way to develop a precise digital background map is by using aerial images acquired from unmanned aerial system survey [4]. The aerial images are then processed into an orthophoto which can be used in the same approach as map. It provides updated geospatial information in three-dimensional coordinates and therefore could be effectively used as a background map.

Multirotor drone has been widely used for many applications especially monitoring and mapping. Many studies found that drone surveys are reliable and effective for geomorphological and environmental monitoring [5]–[7]. The fine spatial resolution and accurately geolocated images are highly suitable to detect small scale changes of the monitored features [8], [9]. Over the years, technology and creativity has led to the unlimited exploration of drone use. A recent study in agricultural technology introduced an interesting concept of using drones integrated with bird psychology to control bird damage for high value crops [10]. The concept was proven effective to protect vineyards from the small and large pest birds. Additionally, the concept of utilizing drone in delivery and construction management were also explored [11], [12]. Note that drone surveys are the platform for data collection. Meanwhile, the aerial images must be geometrically rectified to produce a high quality orthophoto. Pix4D is a widely used commercial photogrammetry software package [13] that incorporates advance computer vision technology in the image processing. The application of structure from motion (SfM) and multi-view stereo (MVS) algorithm generate high precision orthophoto map, digital surface model, and digital terrain model [14]–[16].

This paper describes the methodology of an aerial survey using a multirotor drone and the processing of aerial images acquired from the survey to produce an orthophoto map for application in infrastructure management. The presented methods highlight that the advancement of technology has enabled non-professionals to conduct automated mapping and intelligent image processing for high-precision data. Therefore, the development of digital database could be initiated internally. Moreover, this study also proposes a simple overlay of the background map on an open access application such as google earth in the case of limited resources available in the organization.

2. Methods

2.1. Drone survey and the measurement of ground control points

Figure 1 shows the workflow of the overall methodology as proposed by this study. The survey work started with the preparation of the drone and other equipment including a tablet, RTK GNSS receiver, and marker. DJI Inspire 2 (Figure 2a) mounted with Zenmuse X4S photogrammetric camera was used for the survey work. The drone condition was checked using DJI GO 4 application to make sure it is in good condition before the mission. The firmware updates, drone calibration status, drone battery, telemetry, and other parameters were examined using the application. After that, the flight boundary, waypoints, and autonomous mission were specified using Map Pilot software.

Five ground control points (GCP) were laid out within the study area to increase the accuracy of the data acquired from the survey [17]. GCP locations were measured with a real-time kinematic global navigation satellite system (GNSS) receiver as listed in Table 1. The first GCP was made of a red marker whereas the other GCPs used color contrast features such as yellow line observed within the study area as shown in Figure 2b and 2c. The survey work was carried out by an autopilot drone at 200m above the ground. The aerial survey was extended to the north and south of the study area to ensure that sufficient overlapping images acquired for this study. During the flight, 97 images were taken covering an area of 36 ha (Figure 3).

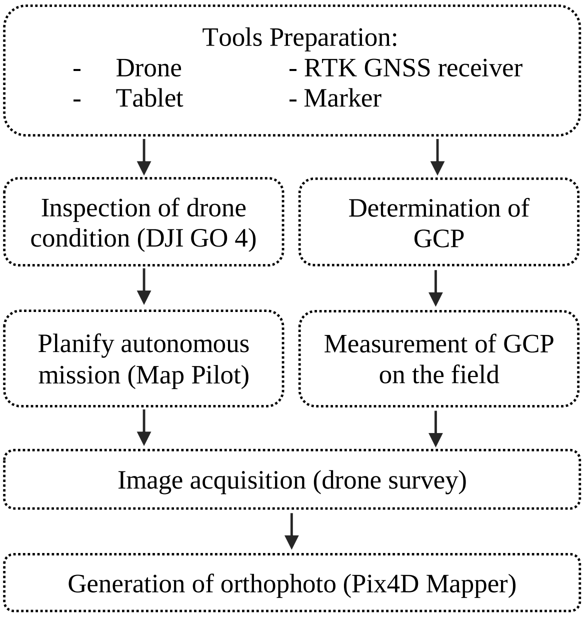

Figure 1. Workflow of the overall methodology

(c)

Figure 2. The photo of (a) multirotor drone (b) GCP marker (c) GCP measurement using GNSS receiver.

Table 1. Ground Control Points Coordinate System

Ground Control Points	WGS84 / UTM zone 48N		
	X (m)	Y (m)	Z (m)
GCP 1	291534.1241	411708.8784	52.7761
GCP 2	291444.5905	411716.4334	54.4521
GCP 3	291297.7485	411732.1002	53.5911
GCP 4	291296.7882	411876.4526	53.5471
GCP 5	291571.4775	411877.7470	52.6561

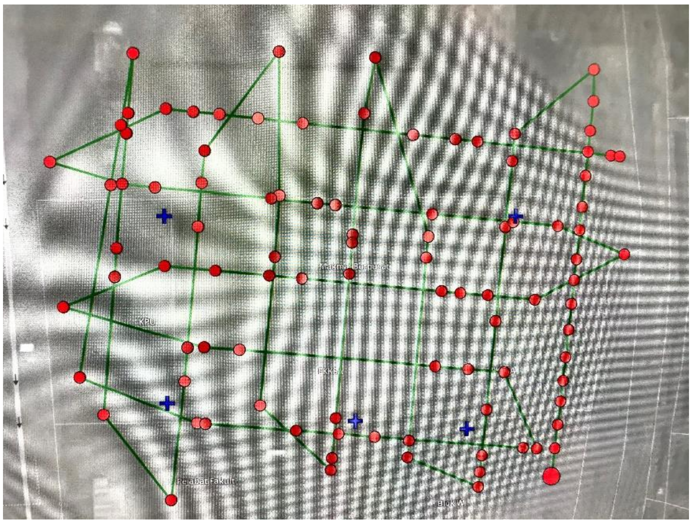

Figure 3. Flight path (green line) and the location of the image acquired during the survey (red dots)

2.2. Processing of aerial images

Image processing was carried out using the Pix4D Mapper. The detail processing flow within the Pix4D Mapper is illustrated in Figure 4. All images collected during the survey were added into the software and the image coordinate system was by default set as WGS84. The metadata of the image stored in exchangeable image file (EXIF) format containing the image geolocation, orientation and camera model were loaded automatically. All added images and their properties such as position, position accuracy and orientation were listed in an image table. Only enabled images were taken into account for processing. In this study, all 97 images added into the software were taken into account for processing. The output coordinate system was by default, auto detected based on the image geolocation and in this study, the output coordinate system displayed was WGS84.

Pix4D Mapper offers several processing option templates that generate various outputs of different resolutions for various applications. A standard 3D Maps processing template was selected for this image processing task to produce a high resolution orthophoto. Ground control points were first imported without marking and the initial processing was carried out using the default setting in the 3D Map template. During the initial processing, the software computes keypoints on the images and uses these keypoints to find matches between the images. The quality report was generated after the completion of the initial processing and this quality report was carefully analyzed to verify all significant information as recommended by the user manual. The verification includes the number of images calibrated, camera optimization, distortions and orientations of the orthophoto, initial image positions, computed image geolocation, absolute camera position uncertainties, and 2D keypoint matches. In this study, all information displayed in the quality report comply with the recommended quality or parameter stated in the user manual.

Five GCPs were marked using the rayCloud interface in the Pix4D Mapper and the processing task was reoptimized for reconstruction of 3D points using the GCPs. Marking the GCPs on the images using the rayCloud interface after the initial processing was completed requires less manual intervention because automatic marking can be done based on color correlation of the images. Finally, the point cloud and mesh processing were carried out simultaneously with the DSM, orthomosiac and index processing. This photogrammetric processing results in a set of 6 cm resolution digital surface model and orthophoto. The vector and the orthophoto could be exported to other format such as CAD and GIS formats.

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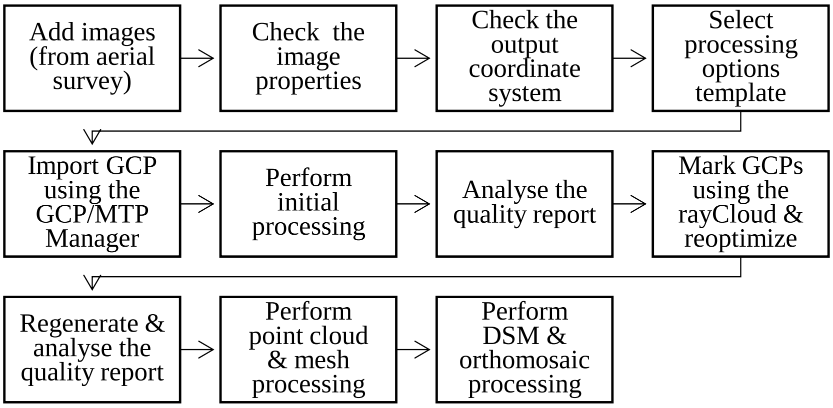

Figure 4. Workflow of image processing within the Pix4D Mapper

3. Results and discussion

Figure 5 shows the orthophoto and the corresponding digital surface model produced from the photogrammetric processing using the Pix4D Mapper. The 6 cm resolution orthophoto presented here is in the form of google tiles which can be overlaid on the google earth application. The output generated from the photogrammetric processing are also available in other format such as shapefile and CAD data format which can be overlaid on any supported GIS and CAD softwares, respectively. An orthophoto is a geometrically corrected aerial image that can be used in the same approach as a map. All objects presented in the orthophoto are accurately georeferenced to a coordinate system. Direct measurements of features can be carried on the orthophoto and therefore, it is suitable to be used as a background map. On the other hand, a digital surface model is a three-dimensional representation of all objects located on the ground to more accurately express the geographic information. It represents the land cover surface height information which can be further processed into a digital terrain model. The digital terrain model can be included in the civil infrastructure database to present the ground surface elevation of the surrounding environment.

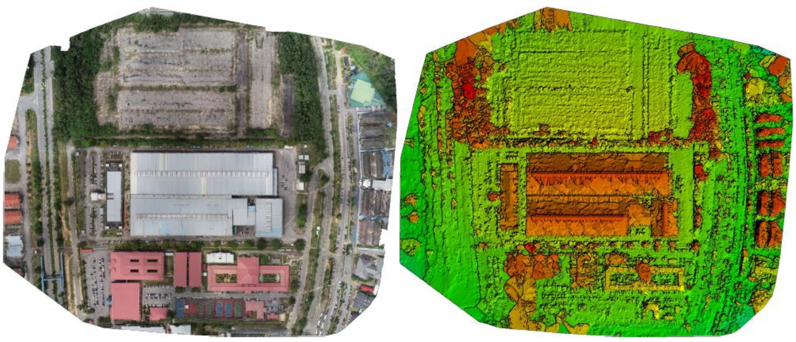

Figure 5. Orthophoto and the corresponding sparse Digital Surface Model (DSM)

Figure 6 compares quality of the aerial image obtained from the google earth application and the multirotor drone survey, respectively. It is observed that the drone-based image presents all features more clearly as compared to the image obtained from the google earth application due to different image resolution. It was long proven that the low altitude survey by drone will generate a higher resolution data as compared to the remote sensing method by satellite [18]. Besides posing as an excellent background map, the orthophoto also provides abundance of data [19]. The key features can be digitized manually or extracted automatically using the advanced computer vision algorithms [20]. The accuracy of the orthophoto depends greatly on the number of ground control points distributed over the study area and the accurate marking of the ground control points on the projected aerial images. Optimal accuracy is usually achieved with minimum five to ten ground control points and the georeferencing mean RMSE error of less than 3 times of the ground sampling distance. In addition, the accuracy of the orthophoto also depends heavily on the number of overlapped images acquired during the survey and an accurate classification of point clouds generated during the image processing [21]. Overlapping of over five images for every pixel will generate sufficient number of keypoint matches for the study area and manual classification of the point clouds are recommended for mixed land use land cover observed in the study area.

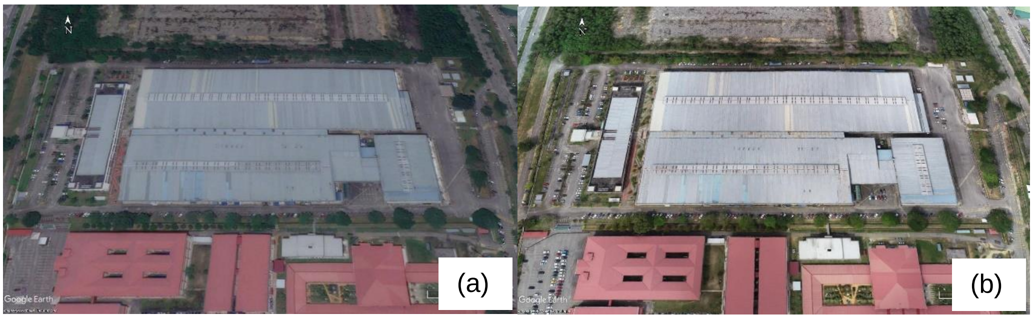

Figure 6. Comparison of the aerial images from (a) the google earth application and (b) the multirotor drone survey

4. Conclusion

Civil infrastructures are spatially distributed in complex environment and therefore, management of the infrastructures require integration of various spatial data. Managing various spatial data could be done more efficiently with the establishment of digital database system. The use of drone is increasing in all sectors including infrastructure management. Drone-based images provide updated high resolution geospatial information in three-dimensional coordinates, hence could be effectively used as background map. The presented methods of automated mapping and intelligent image processing highlight that the advancement of technology has enabled non-professional to collect and processed high-precision data. Therefore, the development of digital database for civil infrastructures can be initiated at a more affordable cost without the need to engage professional surveyor in the data collection process. Moreover, a simple overlay of the background map on an open access application such as google earth provide an alternative in the case of limited resources available in the organization.

Future study should explore the best practices to improve the accuracy of the data collection and image processing. This may include the investigation of the effect of ground control points distributed over the study area on the accuracy of the rectified images. Moreover, future study may also discuss the important parameters in the photogrammetric processing that will affect the accuracy of the final product. It is also recommended for technologist to explore and innovate different types of markers that can enhance the visibility of the ground control points in any site condition.

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