Application of UAV (Unmanned Aerial Vehicle) Photogrammetry for Forest Fire Early Detection System

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Abstract. Indonesia has 15 big potential forest fires locations which destroyed twice the area annually. Moreover, there are almost 20 fire points for each location which increase gradually according to the satellite images of LAPAN (Lembaga Penerbangan dan Antariksa Nasional - National Institute of Aeronautics and Space of Indonesia). Therefore, some monitoring and early warning system for this disaster are needed to minimize the loss and damage of forest ecosystem, smoke exposure to human respiratory system, aviation business, and some forest related industries. Unmanned Aerial Vehicle (UAV) technology could be proposed as the alternative to solve this problem. The forest is monitored by an UAV, in other hand it could be used for image data acquisition to construct 2D and 3D maps for further analysis of the early warning system. The images of sampling location had been taken by an UAV - DJI Phantom 4 Pro which automatically controlled by a flight plan using Pix4D Capture and processed by Pix4D Mapper. The sampling location took place in different areas: near a building, few km squares of campus area consists of building-vegetation combination, and three forest locations in two active volcanoes. The maps with Ground Sample Distance (GSD) under 3 cm/pixel result in under 1\% error for X, Y and Z of 2D and 3D constructed maps. The maps also show an important finding where the movement object could be detected, which potential to be applied for fire evolution detection of a forest fire early warning system.

Keywords: forest, early warning system, fire, UAV, photogrammetry

1. Introduction

Forest fire is a disaster frequently happen in Indonesia [1]. In September 2020, there were 21 areas with hotspots widely spread in Indonesian provinces potent to cause the forest fire. Statistically, the burned land area increased twofold annually in average [1]. In 2015, the burned land area was 2,611,411.44 Ha, then in the next year decreased until 2019 mounted up to 1,649,258 Ha. Moreover, according to LAPAN satellite data, the hotspot in each area tend to increase, peaked in dry season around August and September. Therefore, it is needed a forest fire monitoring and early warning system, smoke hazard for human respiratory system and losses in forestry industry could be minimized.

This area with hotspots tend to increase in a relative short time needs a real-time forest fire monitoring system, which still impossible to be performed by satellite. Furthermore, although satellite could monitor wider area, it lacks in operation and cost [2]. UAV technology offers promising solution for this problems [3-7]. Not only for defining a real-time evolution and fire front shape using multiple UAV [3,7], this technology could also be used for defining location, diameter and hotspot height using UAV equipped with temperature sensor and air sensor [4], with image processing ability in the images produced. Hereinafter, forest fire detection and false alarm could be more accurate to be applied [5].
On the other side, image data processing technique of UAV to generate an orthophoto has been applied for map generation, morphology reconstruction and etc. [8-10]. UAV mapping is a mobile mapping where spatial data acquisition held in the same time using moving instrument to collect data such as images, locations, height and other data for raw data processing into desired product [11].

2. Methodology

Generally, the forest fire early warning system we will develop is presented in Figure 1.

Periodically, a UAV always connected with the base station/control station which equipped with camera, GPS, IMU (Inertial Measurement Unit) and thermal sensor flies at certain height to capture a wide forest images (e.g 150 ha). After it is analyzed to get the hotspots (red circle in Figure 1), this vehicle will fly to this hotspots area to captured more detail images (with suitable flight plan) to be processed and analyzed to get the evolution of these hotspots, hence the forest fire detection and its area can be predicted. The fire alarm will ring and the firefighter unit will get the notification through internet connection. However, this research only focuses on photogrammetry process for detail images data indicated by the blue dashed line in Figure 1 without hotspot indication which will be obtained in our next research.

2.1 Data acquisition by UAV

Quadcopter DJI Phantom 4 Pro was used to capture images in this research. Not only equipped with 20 megapixel camera, this vehicle also has 3 axial gimbal for the best quality images and a GPS system to get the position for automatic flight. However, an optimum flight plan should be designed previously. Some parameter related to this plan also should be set properly, including geometry parameter such as GSD (Ground Sample Distance) as the key to a map accuracy as desired, overlap and camera precision; flight parameter including velocity, takeoff and landing spot; and also image acquisition parameter. These parameters should be combined with the plan parameter including the area of interest, flight direction, coordinate system, camera and DEM (Digital Elevation Model).
Furthermore, a software (Pix4D Capture) for double-grid (suitable for various characteristics of the area) flight-plan design and flight control (geo-referencing control, block control, image deviation control, scale control and overlap control) were used in this research. However, the environment factor should also be considered, including wind velocity, flight restricted area and remote control-UAV connection.

2.2 Data processing

After images, GCPs (Ground Control Points) and geolocations data [12] have been collected, these data was imported to Pix4D mapper (suitable for this research according to its documentation, result reporting, parameter control, result variation, memory optimization and appropriate time for the mission [13]) to get a digital model of the area. Previously, an initial processing should be, where each coordinate of the spots in the images collected, saved and compared for image compatibility. Hereinafter, an orthopoto of a model has been generated after point cloud and mesh steps was analyzed for its application.

The most important part of the model was classification. This process should be conducted by the expert. Nevertheless, this process could follow some references to for model validation by standard method of ASPRS (The American Society for Photogrammetry and Remote Sensing) for geospatial data.

2.3 Testing for a building

A preliminary testing for a building (CIBE - Center for Infrastructure and Built Environment of ITB) has been conducted with a flight plan at 50 m of height and 55 x 57 m² of area within 7 minutes and 30 second (Figure 2). GSD was set for 1.45 cm/px where 1 pixel of image shows 1.45 cm of real world.

![Figure 2. Flight plan for CIBE building](image)

2.4 Testing for a wider area

To follow up the preliminary testing, it has been conducted a wider area testing project for ITB Ganesha campus filled with build-vegetation combination at 838 m of height above sea level (Figure 3). The data was collected 13 times (17 minutes for each flight) for 15 days at 80 m of height and 2.32 cm/px GSD.
2.5 Testing for forest areas

Testing have been conducted in 3 different locations: Tangkuban Parahu, Bandung (1600 m and 1900 m of height above sea level (asl)) at 90 m of height data collection, and Kelud mountain (731 m (asl)) at 50 m of flight height (Figure 4).

Figure 3. Flight plan for wider area
3. Result and Discussion

3.1 Testing for a building

Full scale image keypoints was used for this medium-initial processing step. Two-dimension map (.tif) and 3D map (.obj) (Figure 5 with 1.64 cm/px GSD) was generated after point cloud and mesh step, with half image size option and point density optimal. From raw data, it could be collected 54,068 keypoints for image reference (Table I). This result could be chатегорized as “very good” criteria for reference minimum points (10,000 points) [14]. Sixty-nine raw images have been succesfully calibrated where these images palced in the position suitable with image coordinats. Moreover, camera optimization which shows disturbance while image collection process for both internal and external factors such as temperature and vibration, only about 1.03% can be chategorized as “good” (under 5%) [14]. Meanwhile, it has 21,962.7 match (“good” criteria = 1000 match minimum [14]) among reference points of overlap images (Figure 6) (Table I), the higher the match, the better the image quality. Furthermore, average error for the image was below 1% for X, Y and Z axis.
Figure 5. 2D map (left) and 3D map (right) of CIBE building

Table 1. Quality report of the CIBE map

| Parameter               | Value                                |
|-------------------------|--------------------------------------|
| Images                  | 54,068 keypoints for each image      |
| Dataset                 | 69 images, 100% calibrated           |
| Camera optimization     | 1.03 %                               |
| Matching                | 2,1962.7 match                        |
| Average error (X Axis)  | 0.000001 %                            |
| Average error (Y Axis)  | 0.000000 %                            |
| Average error (Z Axis)  | 0.000001 %                            |

Figure 6. Overlapping images of CIBE map
3.2 Testing for a wider area

Two-dimension map and 3D map of 0.545 km² ITB campus area with building-vegetation combination and 2.22 cm/px GSD has been successfully generated (Figure 7). There were 5,172 keypoints as the references which categorized as “good” (minimum 1000 points for a quarter of the first image size [14], because the original size was too big to be processed by the processor (Intel core i7, 12 GB RAM based Windows 10)). The resize image affects 5,053 of 99% image-calibration with 879,456 match which categorized as “good” (minimum 100 match [14]) (Table II). This match is supported by the overlapping (green area) images in Figure 8. The red area of Figure 8 shows only 1 overlapping images in the edge of the map where the data border taken by the UAV. Whereas, camera optimization is also in “good” category (under 5% [14]).

![Figure 7. 2D map (left) and 3D map (right) of ITB campus](image)

| Parameter            | Value                        |
|----------------------|------------------------------|
| Images               | 5,172 keypoints for each image |
| Dataset              | 5,053 images, 99% calibrated  |
| Camera optimization  | 1.36 %                       |
| Matching             | 879,456 match                |
| Everage error (X Axis)| 0.000000 %                  |
| Everage error (Y Axis)| 0.000000 %                  |
| Everage error (Z Axis)| 0.000000 %                  |
From the map of Figure 7, there is an anomaly from a moving object at latitude 6°53’24.56 and longitude 107°36’45.15. This anomaly forms a paler color of the object in more than 1 points/location compared to other objects on the map (Figure 9). This anomaly is potential to be applied for detection of fire evolution for forest fire early warning system. For more detail, this anomaly could be seen in Figure 10 where there was no the object (an orange car) on that location (left of Figure 10), then appeared (right of Figure 10).
3.3 Testing for forest areas

Two-dimension maps of a forest areas of Tangkuban Parahu 1600 m asl, 1900 asl, and Kelud mountain 731 asl with 2.61 cm/px, 2.59 cm/px and 1.61 cm/px GSD respectively can be seen in Figure 11, while the 3D maps can be seen in Figure 12. These maps were generated by “very good” references (more than 10,000 keypoints [14]) (Table III) (supported by the overlapping (green area) images in Figure 13) with different error for the first map (0.01% of x axis, 0.01% of Y axis and 0.02% of Z axis) because of its 97% image calibration, while the other two maps have 0% error for the 3 axis. This percentage of image calibration was affected by the wind speed (almost 4 m/s²) at this area when the data were collected (Figure 14). However, this error was low enough because the wind speed had no significant effect to camera optimization (under 5%) as well as the second and third maps.

Figure 11. 2D map of forest areas: Tangkuban Parahu 1600 asl (left), 1900 asl (middle) and Kelud 731 asl (right)
Figure 12. 3D map of forest areas: Tangkuban Parahu 1600 asl (top), 1900 asl (middle) and Kelud 731 asl (bottom)

Table 3. Quality report of the forest areas: Tangkuban Parahu 1600 asl, 1900 asl and Kelud 731 asl

| Parameter          | Tangkuban Parahu 1600 asl | Tangkuban Parahu 1900 asl | Kelud 731 asl |
|--------------------|---------------------------|---------------------------|---------------|
| Images             | 72,921 keypoints for each image | 71,212 keypoints for each image | 71,494 keypoints for each image |
| Dataset            | 270 images, 97% calibrated | 271 image, 100% calibrated | 375 image, 100% calibrated |
| Camera optimization| 0.78 %                    | 0.93%                    | 0.97%          |
| Matching           | 9,976.88 match            | 22,884.5 match           | 17,129.9 match |
| Average error (X Axis) | 0.019707 % | 0.000001 % | 0.000000 % |
|------------------------|------------|------------|------------|
| Average error (Y Axis) | 0.014968 % | 0.000001 % | 0.000000 % |
| Average error (Z Axis) | 0.017153 % | 0.000001 % | 0.000000 % |

Figure 13. Overlapping images of forest areas: Tangkuban Parahu 1600 asl (left), 1900 asl (middle) and Kelud 731 asl (right)

Figure 14. Wind speed (blue graph) and air temperature of forest area at Tangkuban Parahu 1600 asl

4. Conclusion

A UAV has been tested for acquiring the data (images) from different locations consisting of buildings, vegetation-building combinations, and forests. All the orthophotos and 3D models of the locations show that the data has been well processed, indicated by an under 1% average error.

For wider areas with large images, they could be resized until the quarter of the original, however they still could be very well processed. The orthophoto and 3D model could be used to detect some movement inside this map which has a great potential to be applied for defining hotspots and fire evolution of the forest fire. Moreover, external factors (such as wind speed) should be considered for data acquisition using UAV. In the near future, we would apply the UAV for hotspot detection in fire forest simulation.

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