Review

Information Acquisition of Forest Resources Using Photographing from UAV: Case Study in the Mie University Forest, Hirakura†

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ABSTRACT

In recent years, unmanned aerial vehicles (UAVs), which have been internationally developed and utilized in many fields, has also attracted people’s attention in the forestry service. Using UAV systems as a data acquisition instrument and a monitoring tool, it can be expected to solve some issues in conventional forest resource inventories and enabling more efficient research. This study was conducted using structure from motion (SfM), which is a photogrammetric range imaging technique. This is accomplished using aerial photography with a UAV in the University forest and consists of: 1) generation of a 3D model of photographed objects, 2) estimation of tree height and DBH, 3) evaluation of the estimation accuracy, and 4) comparisons to measurement errors between two aerial photography sets. The result showed that root mean squared error (RMSE) in the estimated tree height was 1.58 m and RMSE in the estimated DBH from a relational expression between tree height and DBH was 3.88 cm, and RMSE in the estimated tree height between the first and second photography was 0.21 m.

Keyword: forest monitoring, GIS, remote sensing, SfM, UAV

INTRODUCTION

In recent years, unmanned aerial vehicles (UAVs), which have been internationally developed and utilized in many fields, has also attracted people’s attention in the forestry field. Using UAV systems as a data acquisition instrument and a monitoring tool can be expected to solve some issues in conventional forest resource inventories such as ground survey and remote sensing methods and to enable more efficient research at a low cost. Moreover, it was developed as a photogrammetric range imaging technique, structure from motion (SfM), which reconstructs camera positions, orientations, and a three-dimensional scene structure model from a set of overlapping photographs (Obanawa et al., 2014), the possibility of the UAV systems with SfM has been greatly increasing. However, there are still few reports on research results for the systems and basic data required for their practical use (e.g. measurement accuracy, flight range) is insufficient at present. In 2015, the Civil Aeronautics Law was revised due to a rapid diffusion and expansion of UAVs in Japan, which were obliged to comply with regulations for flying UAVs. Thus, it is necessary to develop utilization of the UAV systems from not only the technical aspects but also the flight rules.

In this study, using digital photogrammetry software employing the SfM technique from aerial photography with a UAV in the University forest, tree height and diameter at breast height (DBH), which is basic forest resources information, are estimated and the estimation accuracy is evaluated. Measurement errors between first and second aerial photography are compared in anticipation of continuous use of the UAV systems. Finally, the possibility of the UAV systems as a forest monitoring tool and concrete directions of their use in the future are discussed.

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MATERIALS

UAV and Camera

The UAV used in this study is Spreading Wing S900 (DJI, China) (Fig. 1). S900 is a kind of multicopter with six rotors, which has a high flight stability and controllability, is used for mainly aerial photography such as film making and photogrammetry (DJI, 2018). In this study, it photographed from above a forest. This was done because it doesn’t have automatic tracking or an obstacle avoidance system and it is difficult to fly inside the forest.

The UAV body is equipped with devices relating to attitude control (e.g. GPS, IMU, Gyroscope sensor) and to management and transmission of real-time flight data (e.g. Datalink, iOsd), and is attached to a camera and battery.

The camera is a mirrorless single-lens reflex camera, Canon EOS M2 (Canon, Japan) with approximately 18 million valid pixels and an image sensor of 22.3 x 14.9 mm. The focal length of a lens is 22 mm. The inclination of the camera stays in a fixed range by the attitude control system and a 3-axis motorized gimbal stabilizer for the camera.

Flight Rules

In 2015, a revision of the Civil Aeronautics Law was carried out in the background of a rapid diffusion and expansion of UAVs in Japan, and fundamental rules involving UAV flight was determined (Ministry of Land, Infrastructure, Transport and Tourism, 2017). This law requires permission or approval from the Ministry of Land, Infrastructure, Transport and Tourism when a UAV flies above a certain airspace (e.g. densely inhabited district, around an airport, a ground altitude over 150 m), or in some flight conditions (e.g. Outside of visual range, within 30 m from an above-ground construction or a person, or night flight).

OUTLINE OF AERIAL PHOTOGRAPHY

This UAV photography was conducted at Ro sub-compartment, No.10 compartment, a permanent plot, and around forests (Altitude: 550–620 m) in the Mie University Forest, Hirakura of Misugi Town, Mie Prefecture, Japan (Fig. 2). In the estimation of tree height and DBH, the area was limited to A, B at the sub-compartment (Area: 0.05 ha). This forest has a plantation of 46 sugi (Cryptomeria japonica) trees at the age of 59 (Average tree height: 22.5 m, Average DBH: 30.1 cm, Relative spacing index: 14.3% by measured result using Vertex IV (Haglöf, Sweden) and measuring tape on November, 2013). This area requires no permission from the Ministry of Land, Infrastructure, Transport and Tourism.

The aerial photograph data acquisition flight mission was conducted at 1 p.m. on October 10, 2016, the weather was sunny with a light breeze. Flight supporting software, PC Ground Station 4.0.11 (DJI, Chain; hereinafter referred to as “GS”) was used for carrying out the flight mission. GS enables autonomous generation of an optimal flight route under predefined algorithms by setting photography conditions such as flight height, photographing overlap ratio, and range. Communication between the GS and the UAV body enables it to autonomously conduct a takeoff and a flight on the determined mission route, and to confirm real-time flight information such as the body location, direction, and altitude. Moreover, continuous aerial photography on the same route is possible and expected to be used for fixed-point observations and time-series monitoring because files of route mission can be saved and exported to a PC. Table I shows the photography conditions in detail.

Table 1  Photography conditions

| PC Ground Station | Camera |
|-------------------|--------|
| Overlap ratio     | 90%    |
| Sidelap ratio     | 60%    |
| Flight height above the take-off position | 100–175 m |
| Flight height above the ground | 100 m |
| Photographing area | 0.9 ha |
| Flight velocity | 3 m/s  |
| Shutter speed priority | 1/1600 seconds |
| F-number | 8 |
| ISO speed | Auto (2500–6400) |
| Format | JPEG |
| Photographing interval | 2 seconds |
**METHODS**

**UAV Photo Processing**

The aerial photographs were processed using digital photogrammetry software, SfM software, PhotoScan Professional 1.2.6 (Agisoft, Russia). First PhotoScan estimates the camera positions and orientations, and generates basic point clouds for a three-dimensional scene structure model from the photos using the SfM technique (Uchiyama et al., 2014). Then, it applies the point clouds to densification processing. A three-dimensional model, RGB orthomosaic image and digital surface models (DSM) are generated based on the dense point clouds.

It is necessary to place some ground control points (GCPs) in order to define the geographic space coordinates in the generation of orthomosaic image and DSM. With more than three GCPs, a three-dimensional space location can be generally reconstructed (Yamamura, 2015). This study placed four GCPs.

**Tree Height Estimation**

Digital canopy height model (DCHM) was computed, subtracting the DSM generated by PhotoScan from digital elevation model (DEM) of a 10 m grid mesh from the web site of the Ministry of Land, Infrastructure and Transport. Then, neighborhood statistical analysis and basin analysis function of ArcGIS (ESRI, USA) smoothed the DCHM cell and semi-automatically extracted tree crown canopy areas (individual trees). The maximum DCHM cell value of the canopy area is the point of the tree peak and estimated tree height, UAV-tree height ($H'$).

**DBH Estimation**

Estimated DBH, UAV-DBH ($D'$) is derived by substituting UAV-tree height ($H'$) in the preceding section for $H$ in a relational expression ($D = 0.3914H^{1.407}$) between tree height and DBH proposed in long-observation of sugi plantation in Mie Prefecture (Shimada, 2010).

**Accuracy Evaluation**

In the accuracy evaluation, there was a comparison between 1) the result of individual tree extraction and measured data in 2013, 2) the two results of UAV-tree height ($H'$), UAV-DBH ($D'$) and measured data ($H$, $D$). $H$, $D$ was calculated by the sum of the measured data in 2013 and the predicted amount using a Mitscherlich growth curve acquired by the result of a stem analysis conducted for development of growth model for the sugi plantation in the same forest on November, 2015 (Tobita, 2016). For the accuracy evaluation of 2), root mean squared error (RMSE) and relative RMSE divided RMSE by average measured data ($H$, $D$) were used. The overall data processing and analysis of the workflow is summarized in Fig. 3.

**RESULTS AND DISCUSSION**

**UAV Photo Processing**

This flight produced 150 photos (Photo size: 8.5–12.0 MB) in about 8 minutes. The photo processing with PhotoScan generated a three-dimensional model, RGB orthomosaic image, and DSM based on dense clouds of approximately 77 million points (Fig. 4). The model showed the detailed shape of the tree canopy and forest structure, enabled us to understand the current situation of the forest, especially

![Fig. 3 Workflow.](image)

![Fig. 4 Result of UAV photo processing.](image)
the tree canopy. The spatial resolution of the orthomosaic image was 1.5 cm, which can read the shape of the sugi’s leaf. Judging from this result, it is presumed that we can identify other tree species as well. The DSM resolution was also as high as 3.0 cm, although it was lower than that of the orthomosaic image. Since above resolutions depend on the resolution of the aerial photographs, it seems that changes in various settings of the photography lead to a higher resolution image (the resolution of the aerial photographs was 72 dpi in both the horizontal and the vertical direction).

Tree Height Estimation and Accuracy Evaluation

Individual tree extraction resulted in the extraction of 44 trees and the extraction accuracy was about 96% calculated by 46 measured trees (no over extraction). UAV-tree Height ($H'$) was calculated from DCHM for the peaks of 44 extracted trees (Fig. 5 left). Comparing to the measured tree height ($H$) and UAV-tree height ($H'$), the UAV-tree height ($H'$) proved to tend to be higher than the measured tree height ($H$) (Fig. 5 right). The result of the accuracy evaluation showed that the Root Mean Squared Error (RMSE) was 1.58 m, and relative RMSE was 6.7%.

The DEM data of 10 m grid mesh was used for the calculation for DCHM in this study. The DEM data was produced by using contour lines on a topographical map in this area, its altitude accuracy is 5 m (Geospatial Information Authority of Japan). In other words, an improvement of the altitude accuracy can lead to an improvement in the accuracy of tree height estimation. In the case of government data that is publicly available in Japan for instance, in addition to that of 10 m grid mesh, there is DEM data of 5 m grid mesh produced by using aerial laser measurement or aerial photographic measurement in limited areas, its altitude accuracy is 1 m. Therefore, using the DEM data of 5 m grid mesh for the tree height estimation seems to improve the accuracy.

DBH Estimation and Accuracy Evaluation

DBH estimation was conducted for 44 extracted trees in the same way as the tree height estimation. Comparing to the measured DBH ($D$) and UAV-DBH ($D'$), the distribution had less over/underestimation than that of tree height, but the accuracy evaluation results showed that the RMSE was 3.88 cm, relative RMSE was 11.3%, and the accuracy was lower than that of tree height (Fig. 6). The reason appears to be that UAV-tree height ($H'$) was substituted for the expression of which only tree height was the predictor variable, and the error of the UAV-tree height ($H'$) was directly reflected in the accuracy; in addition, the inherent error of the relational expression affected it. As stem parts cannot be photographed directly in the UAV survey unlike tree height, it is most likely difficult to have a high accuracy equivalent to the tree height estimation. However, using some factors such as size, shape, and density of the tree canopy possibly enables us to estimate the DBH more precisely.

Comparisons to Errors between Aerial Photography

Comparisons to DSM between aerial photography resulted in that a DSM error that was large in the shaded areas of the lower tree canopy in contrast to the upper tree canopy with less shade (Fig. 7 upper). In the SfM technique, it is difficult to extract precise feature points in the shaded areas, the point clouds would be rough even if possible. Therefore, three-dimensional locations weren’t reconstructed properly, the errors became lager in the lower tree canopy as a result (Robert et al., 2016). The cloud cover during the second aerial photography was smaller than during the first one, that is, solar radiation intensity was different, which appears to have made the error larger. In the case of aerial photography in the
forests, we can use UAVs further in not only forest measurement, but also nationwide forest management in Japan.

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CONCLUSIONS

The results of this study revealed that the UAV systems enabled us to understand the current situation of the forest, especially tree canopy from the three-dimensional model, and to evaluate tree species with high resolution orthomosaic images. Moreover, using DSM data and the basin analysis function by GIS, basic data of the UAV systems in the forest monitoring were acquired from the results of individual tree extraction, estimation and accuracy evaluation of tree height and DBH, and comparisons to measurement errors between the repeated aerial photography sessions. Some issues involving the estimation accuracy are predicted to improve based on the efforts presented in this study.

Recently, UAV capability has dramatically increased, and products with excellent safe performance ratings, flight time and management cost have released one after another. Furthermore, in Japan the fourth Quasi-Zenith Satellite was launched in 2017 for the Japanese version of a global positioning system, and GPS accuracy in Japan is expected to improve to a large extent. With the improvement in GPS reception in forests, we can use UAVs further in not only forest measurement, but also nationwide forest management in Japan.

Fig. 7 DSM error and UAV photo (upper) and comparison of UAV-tree height values (lower).