Application of unmanned aerial vehicle measurement to estimate quantity of forest biomass

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ABSTRACT**:** Recently, energy problem is deeply related with global warming or climate change. The use of forest biomass is one of the solutions for the energy problem. Remote sensing is a cost-effective technique for forest inventory and it is suitable for periodic monitoring of the forest biomass. The UAV measurement has the advantage that it can acquire the high-resolution digital imagery at reasonable cost and can measure same area with high accuracy and at regular intervals. The purpose of this study is to estimate the amount of forest biomass by using orthogonal image and digital surface model (DSM), which are derived from UAV measurement data. The heights of trees and the diameter of breast height (DBH) were derived from orthogonal image and DSM of UAV measurement data, and then the amount of biomass was calculated. The heights of trees derived from UAV data were lower than that of the field survey by approximately 2m, while DBH did not show the big difference between UAV measurement and filed survey. As a result, the amount of forest biomass was underestimated by approximately 20%. In order to improve the estimation accuracy of forest biomass amount, the accuracy of the extraction of trees must be improved, and also we need to verify the accuracy of DSM and DEM derived from UAV measurement data.

KEYWORDS: local maximum filter method, digital surface model, periodic monitoring

1. INTRODUCTION

Recently, energy problem is deeply related with global warming or climate change. The use of forest biomass is one of the solutions for the energy problem. In order to ensure the sustainable use of forest biomass in the region, forest management is important. The foundation of forest management is acquiring detailed forest inventory information. Conventional forest inventory involves periodic field survey, but it is labor and cost intensive (Ke and Quackenbush, 2011). Remote sensing is a cost-effective technique for forest inventory and it is suitable for periodic monitoring of the forest biomass. In estimating the amount of forest biomass by remote sensing technique, the digital surface model (DSM) is an important input data. DSM can be made from high-resolution digital imageries and LiDAR (Light Detection and Ranging) data. An unmanned aerial vehicle (UAV) measurement can acquire the high-resolution digital imagery and it has some merits in generating DSM because the cost of UAV measurement is cheaper than that of general air vehicle with LiDAR measurement. In addition, UAV can measure same area with high accuracy and at regular intervals. The purpose of this study is to estimate the amount of forest biomass by using orthogonal image and DSM, which are derived from UAV measurement data.

2. METHODOLOGY

2.1 Test area

The test are of this study is a cedar forest adjacent to Kochi University of Technology (KUT) in Japan.

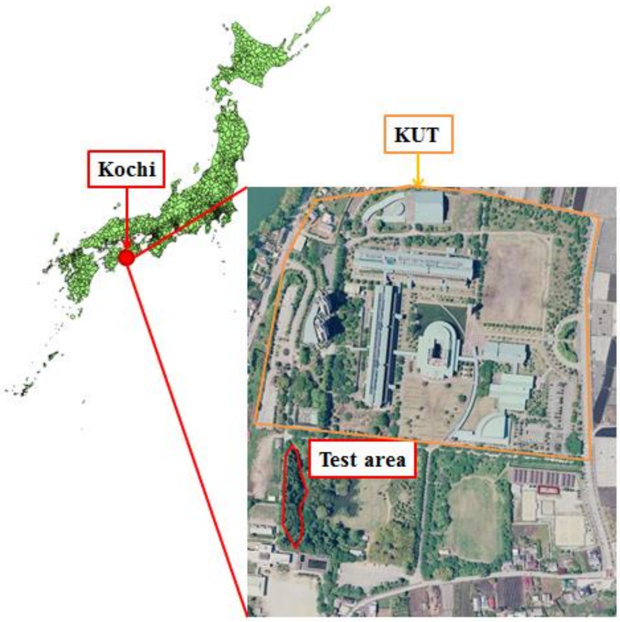

Figure 2.1 Test area

2.2 UAV data acquisition

2.2.1 Used UAV

In this study, Trimble UX-5 was used for measurement. UX-5 is taking off by the catapult. UX-5 makes DSM by using digital photogrammetry. It is a basic method to make DSM by the stereo image from plural viewpoints. Figure 2.2 shows appearance of UX-5. Table 2.1 shows specification of UX-5.

Figure 2.2 Appearance of UX-5

Table 2.1 Specifications of UX-5

Products of UAV	UX-5
Length of a wing	1m
Duration of flight	50minutes
Range of flight	60km
Flying speed	80km/h
Ground Sample Distance	2.4cm~24cm
Flight altitude	75m~750m

2.2.2 Operation of UAV

In this study, measurement by UX-5 was carried out once per month from October, 2014 to August, 2015. Table 2.2 shows observation date of UX-5.

Table 2.2 Observation date of UX-5

Observation date
October 9, 2014
January 24, 2015
March 6, 2015
April 17, 2015
August 5, 2015

Flight area is over the KUT. Taking off and landing point is Monobegawa riverbed. Figure 2.3 shows the taking off and landing point of UAV. Flight altitude is 150m and flight time was approximately 30minutes. Orthogonal image and DSM were made using software called Aerial Imaging. In this study, Ground Sample Distance (GSD) of orthogonal image is 15cm and DSM GSD is 25cm. Figure 2.4 and 2.5 shows the orthogonal image and DSM on October 9, 2014, respectively.

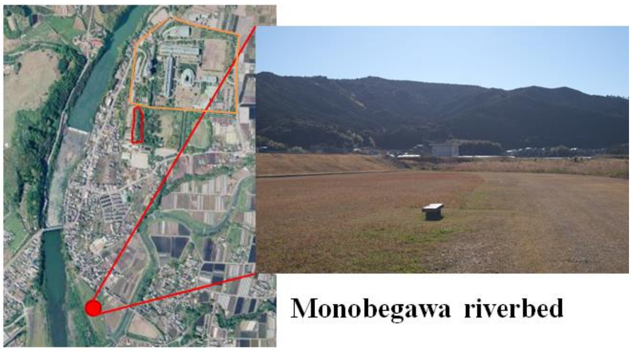

Figure 2.3 Taking off and landing point of UAV

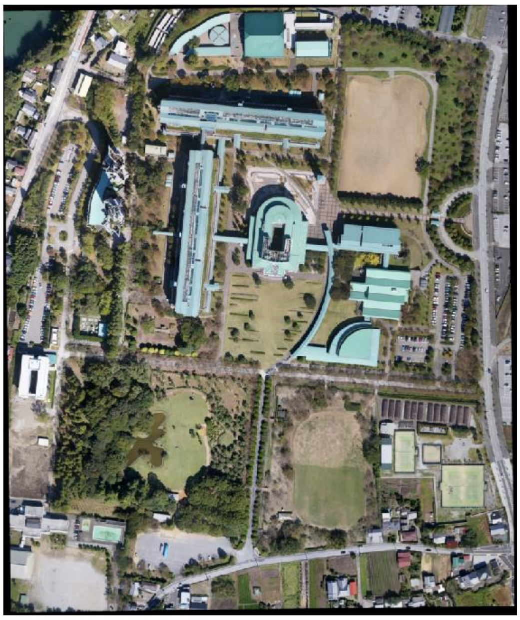

Figure 2.4 Orthogonal image of October 9, 2014

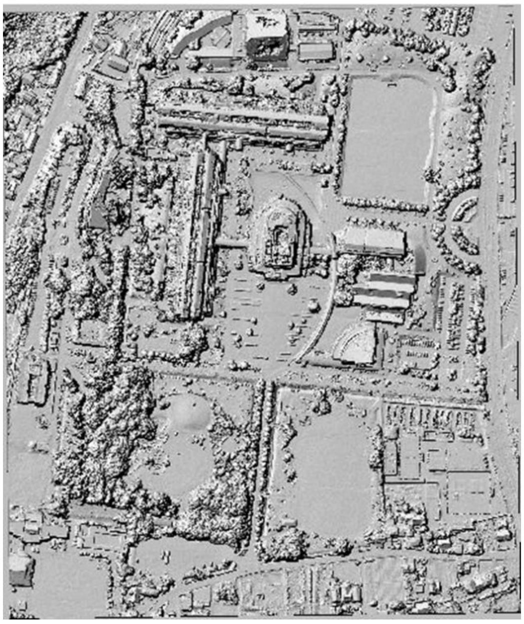

Figure 2.5 Digital Surface Model of October 9, 2014

2.3 Extraction of the tree position

2.3.1 The local maximum filter method

In this study, the extraction of tree means identifying the number of trees in test area and the height of each tree. The number of trees in the test area is counted by using the projected position of treetop on the ground. The local maximum filter (LMF) method was used for the extraction of treetop position (Wulder, 2000). In this method, a window (i.e. 3×3 pixels) is passed over all pixels in DSM image to determine if the given pixel, which is the center pixel of window, is of higher pixel value than all other pixels within the window. Pixels identified as the largest pixel value within the window are noted as treetop location (Wulder, 2000). If the window size is too small, commission errors occur through selection of nonexistent trees. If the window size is too large, omission errors increase (Wulder, 2000). The suitable window size will be determined by the relationship between image resolution and the crown size of trees. Therefore, in this study, the window size was varied from 3×3 to 13×13 pixels. The 9×9 window size was most suitable for extracting treetop position in the 25 cm resolution DSM image, which is determined by reference to previous study (Wada et al., 2014). Figure 2.6 shows conceptual diagram of LMF method.

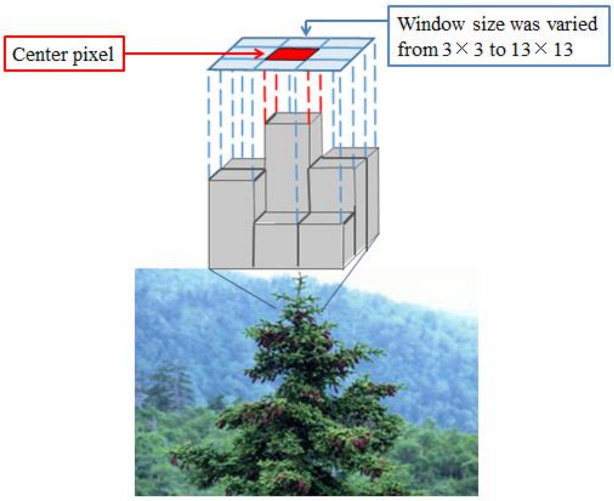

Figure 2.6 Conceptual diagram of local maximum filter method

2.3.2 Discriminating method of tree using color of the image

The extraction of tree position only by LMF method may produce over-extraction, because this method cannot discriminate trees from artificial objects. Therefore, the band operation of orthogonal image was used to reduce over-extracted tree position. Band operation was using the value of Red, Green and Blue bands of the orthogonal image by UAV. Generally, the tree has highest value of Green band, and both Red and Blue band are lower value. Band operation was computed as shown in equation (1) by using Green band and Blue band.

$$Band\ \ Operation = \frac{Green - Blue}{Green + Blue} \qquad (1)$$

The band operation is conducted by using orthogonal image. Then, the band operation values of the pixels corresponding to treetop location, which is determined by the LMF method, are extracted. If the value of band operation was higher than 0.15, the pixel was judged as a treetop pixel. If the value of band operation was between 0.05 and 0.15, and if all the values of Red, Green and Blue were less than 100, the pixel was also judged as a treetop pixel. Figure 2.7 showed flowchart of discriminating tree by LMF and band operation.

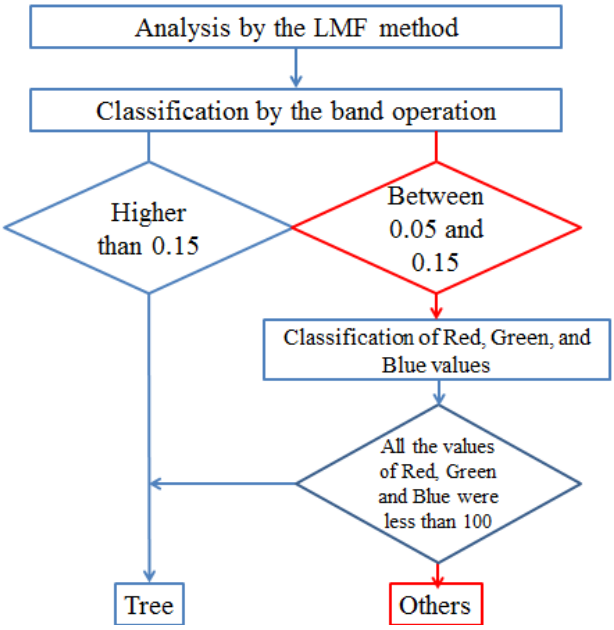

Figure 2.7 Flowchart of discriminating tree by LMF and band operation

2.4 Extraction of the tree height

The height of the tree was calculated by subtracting numerical value of Digital Elevation Model (DEM) from numerical value of the DSM. DEM is produced by Triangulated Irregular Network (TIN). TIN represents the ground surface in creating triangles by tying the points, which were judged to be a ground surface from DSM by visual interpretation. Figure 2.8 shows conceptual diagram of the height of the calculation using DSM and DEM.

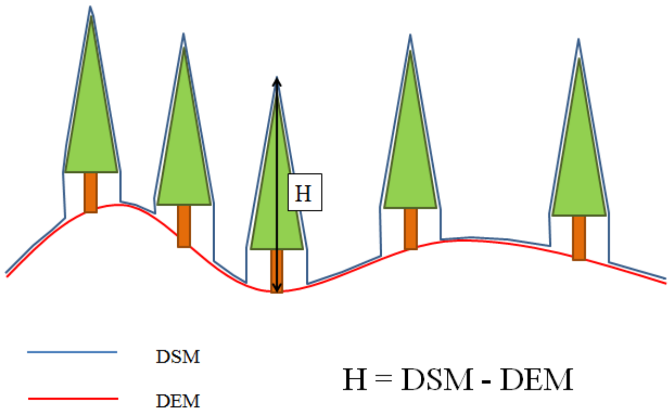

Figure 2.8 Conceptual diagram of the height of the tree calculation using DSM and DEM

2.5 Forest biomass estimation

The amount of forest biomass can be estimated using following equations (Kitagawa, 2011).

$$V = H \times DBH \qquad (2)$$

$$Bi = V \times I \times Bd \qquad (3)$$

V=Volume of trunk (m^3)

H=Tree height (m)

DBH=Diameter of breast height (m)

Bi=Biomass (t)

I=Intensity factor (=1.57)

Bd=Bulk density (=0.314 t/m^3)

Accrding to equation (2) and (3), the tree height and diameter of breast height (DBH) are nesesary to estimate the amount of forest biomass. We used the values of intensity factor and bulk density, which are shown in National Greehouse Gas Inventry Report of Japan (Greenhouse Gas Inventory Office of Japan, 2008). The number of trees in test area and the height of each tree can be calculated by UAV data. However, the DBH cannot be directly derived from UAV measurement data. Therefore, we used the following equation to calculate the DBH using a diameter of tree crown(Kajiwara and Shigematsu, 2008)

$$DBH = 9.366\times C - 0.007\times H + 8.052 \quad (4)$$

DBH=Diameter of breast height (m)

C=Diameter at crown (m)

H=Tree height (m)

The diameter of crown of the tree is estemated using the orthogonal image by UAV measurement. A polygon of each tree was made using an orthogonal image by visual interpretation, and a diameter of crown was gotton by measuring the diameter of a polygon on the orthogonal image.

2.6 Filed survey

The data acquisition by filed survey was carried out for the validation of tree extraction by UAV measurement. The number of trees was counted in the filed on August 27, 2015.The diameter of breast height was measured by electronic caliper on August 28, 2015. The height of the trees was measured by using Total Station (TS) and prism on August 31, 2015. TS can measure distance and the vertical angle to a target. If we can get the distance to an object, the vertical angle, and the height of prism, the height of the tree can be calculated using equation (5). Figure 2.7 shows conceptual diagram of the tree height measurement using a TS and a prism. Figure 2.8 shows state of the tree height measurement using a TS and prism.

$$H = HD\times \tan(90°-ZA_1)-HD\times \tan(90°-ZA_2)+h \quad (5)$$

H=Tree height (m)

HD=Horizontal distance (m)

ZA1=Vertical angle of the top of the tree (°)

ZA2=Vertical angle of the prism (°)

h=Prism height (m)

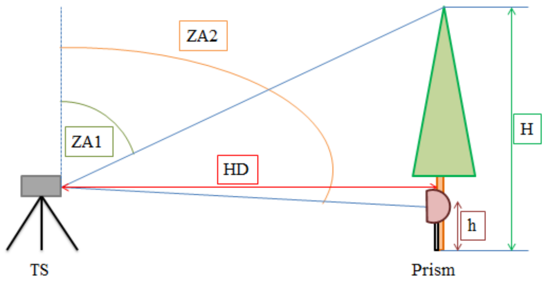

Figure 2.7 Conceptual diagram of the tree height measurement using a TS and a prism

Figure 2.8 State of the tree height measurement using a TS and prism

3 RESULTS AND DISSCUSION

3.1 **Extraction of the tree**

Figure 3.1 shows the result of the extraction of tree position by LMF method. Figure 3.2 shows the result of the extraction of tree position by LMF method and band operation of color information. Red dots in both figures mean the projected position of treetop on the ground. It was find that the over-extraction of tree position around the artificial objects, such as buildings, could be reduced by band operation of orthogonal image following a LMF method.

Figure 3.3 shows the result of the extraction of tree height by subtracting numerical value of DEM from that of the DSM at the projected position of treetop on October 9, 2014. Figure 3.4 shows the result of the extraction of tree height on August 5, 2015.

Figure 3.1 Result of the extraction of tree position by LMF method

Figure 3.3 Extraction result of the tree height October 9, 2014

Figure 3.2 Result of the extraction of tree position by LMF method and band operation of color information

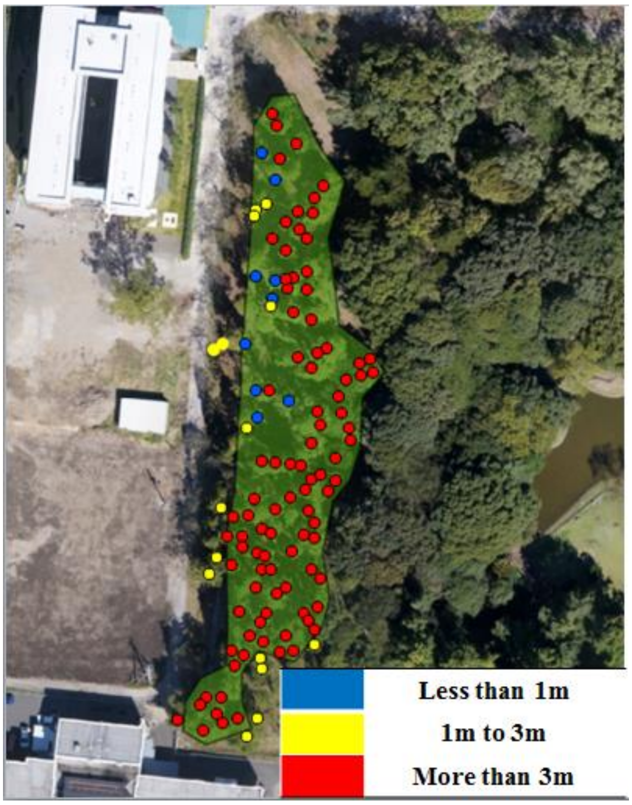

Figure 3.4 Extraction result of the tree height August 5, 2015

3.2 Validation of tree extraction

3.2.1 The number of the trees

The total number of trees in the test area, which is acquired by field survey, was 101. Table 3.1 shows the total number of trees and the extraction rates of the cedars by UAV measurements from October 2014 to August 2015. The extraction rate varied in each month. As a result, the extraction of cedars was relatively precise in October, January and August.

Table 3.1 Extraction rate of the cedars

Observation date	Number	%
October 9, 2014	108	106.9
January 24, 2015	105	104.0
March 6, 2015	133	131.7
April 17, 2015	152	150.5
August 5,2015	106	105.0

3.2.2 The height of the tree

Figure 3.5 shows validation results of tree height using field survey data in August 2015. In the field survey, the heights of all trees were more than 10m, but the heights of 20 trees derived from UAV data were less than 10 m. It means that commission errors may have occurred in extracting the heights of trees by using UAV data. The nonexistent tree pixels seemed to be extracted as the treetop pixels. In addition, heights of trees derived from UAV data were lower than that of the field survey by approximately 2m. This is because the height of tree derived from UAV data is mean value of a pixel, which includes treetop, even though the top of the tree was detected almost correctly by TS measurement. The average height of the trees measured in field survey was 19.0m, and that of the trees derived from UAV data was 14.3m. However, when the trees whose height is less than 8m were excluded, the average height of the tree was 17.9m

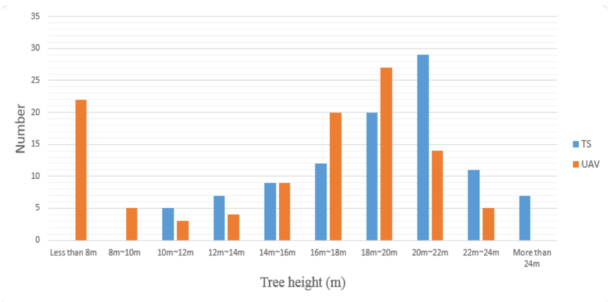

Figure 3.5 Validation results of tree height using August data

3.3 Validation of forest biomass

3.3.1 Validation of diameter at breast height

Figure 3.6 showed validation results of the DBH. The average of DBH, which is estemated using UAV data, was 35.1cm. In addition, the average of filed survey data was 35.8cm. In DBH estimation, the big difference between UAV measurement and filed survey was not shown.

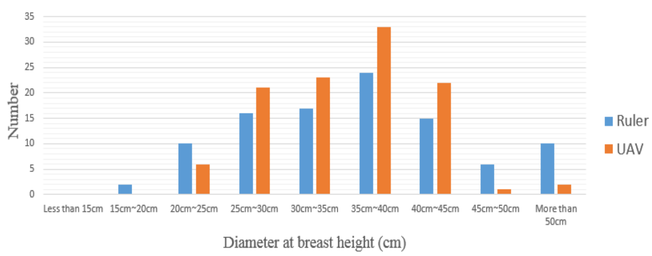

Figure 3.6 Validation results of DBH

3.3.2 Validation of the amount of forest biomass

Table 3.2 shows the estimation results of the amount of forest biomasss in test area. The amount of forest biomass was calculated by adding together biomass of each tree, which is calculated by equation (2) and (3). The amount of forest biomass estemated from filed survey data was 276.99t, and the amount of forest biomass estemated from UAV data was 225.57t. The main cause of difference between them is the difference of the tree height. The tree height derived from UAV measurement data was underestimated because the extraction of trees has not sufficient accuracy. In addition, the accuracy of

DSM and DEM, especially DEM, seem to be one of the causes of underestimation. DEM has possibility to be really the DSM of the understory vegetation, so the tree height may have been underestemated.

Table 3.2 Validation results of the cedar

	Filed survey	UAV
Average of tree height	19.0m	14.3m(More than 8m is 17.9m)
Average of DBH	35.8cm	35.1cm
Biomass	276.99t	225.57t

4 CONCLUSIONS

In this study, the estimation of forest biomass amount was carried out by using UAV measurement data. The height of tree and DBH were derived from orthogonal image and DSM of UAV measurement, and then the amount of biomass was calculated. The heights of trees derived from UAV data were lower than that of the field survey by approximately 2m, while DBH did not show the big difference between UAV measurement and filed survey. As a result, the amount of forest biomass was underestimated by approximately 20%. In order to improve the estimation accuracy of forest biomass amount, the accuracy of the extraction of trees must be improved, and also we need to verify the accuracy of DSM and DEM derived from UAV measurement data.

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