DEVELOPMENT AND APPLICATION OF THREE DIMENSIONAL MEASUREMENT SYSTEM FOR TOROPICAL RAINFOREST CANOPY

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ABSTRACT:

As the most basic knowledge of remote sensing, spectral radiances that are reflected from the surface and received by the sensor are under the influence of various physical factors. One of the most important factors is the reflectance properties of the surface such as spatial, spectral and biophysical conditions. On the other hand, Tropical Rainforest is known as the most important for us to sustain the global earth environment. However it is impossible to reach its canopy top because of their tall height. Recent years some of canopy access systems such as walk way and crane appeared in the world. This kind of canopy crane can provide use good opportunities to know the mechanisms of atmosphere-ecosphere interaction.

From the above background, we used the tropical canopy crane system with 80m height and 75m arm length as our measurement platform, and developed the three-dimensional canopy structure measurement system by laser scanning system. One of main purposes of this study is to identify three dimensional canopy surface structures. Our used laser scanning system, which we developed, is integrated system with Global Positioning System, non-prism   based laser scanning system and related technologies instead of traditional photogrammetric techniques. The laser scanning system, which is loaded on the gondola of crane, is introduced to the every measurement point by the manipulation of the arm swing and gondola moving. Both of monitoring system of the crane and Global Positioning System (GPS) estimate each measurement point where we are. Furthermore the Digital Surface Model (DSM) for tropical canopy was generated from the obtained three-dimensional data. This kind of information could provide the most common and important knowledge for multi-disciplinary scientists in order to know the tropical canopy.

1. INTRODUCTION

Our research site is the tropical rainforest in Lambir hills national park and the western part of Sarawak state, Borneo Island, Malaysia. Figure 1 shows the location of our research site in Southeast Asia. This region is known as the typical tropical weather region without seasonal change. The tropical rainforest also is known as the lug of the earth or the treasury of biodiversity. Most of important processes of a tropical rainforest are taking place at canopy layer. Canopy is the place that trees make photosynthesis and transpiration, thus gas exchange between ecosystem and atmosphere could not be detected without studying the process in/on the canopy. At the same time, the canopy is the place of interaction among many organisms. And the canopy surface is the observation target of remote sensing. However we do not know much about their nature yet.

On the other hand, in order to estimate the surface physical properties by remote sensing, it is necessary to gather the atmospheric, climate, sun conditions and reflectance characteristics at the target area as the basic information in the same time as the satellite over passing. The authors have been conducting the scaling up research of physical properties related to forest ecosystem functions based on the ground based measurements. At the beginning of our research, we only wanted to know the spectral radiances that are reflected from the surface and received by the sensor at tropical rainforest canopy as the basic knowledge of remote sensing. Actually an incident solar irradiance, atmospheric, meteorological, sensor viewing conditions and reflectance properties are the basic

information not only for our own research but also for multi-disciplinary researches related to ecology and meteorology.

From the above background, we had developed the laser scanner based measurement system for identifying the three dimensional tropical rainforest canopy structures and applied the measurement results in order to generate canopy DSM and re-construct the virtual tropical rainforest. One of most important purposes is to provide an actual canopy structure as common data for multi-disciplinary usages.
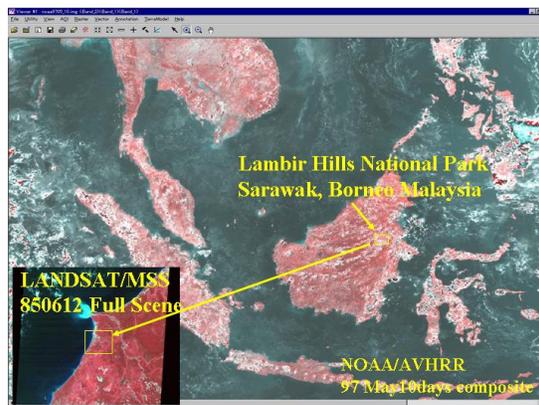
Figure 1. Lambir Hills National Park as Our Research Site

2. DEVELOPMENT OF THREE DIMENSIONAL CANOPY STRUCTURE MEASUREMENT SYSTEM

2.1 Canopy Crane as Measurement Platform

The canopy crane as our research platform was established on March 2000 as a JST CREST Project entitled 'Mechanisms of Atmosphere-Ecosphere Interaction in Tropical Forest Canopy' (Nakashizuka et al., 2001) in cooperation with Forest Department, Srawak. Figure 2 is the canopy crane.

Figure 2. Canopy Crane as Our Platform

This crane is about 80m tall height with 75m arm length. It is equipped with observation stages at 4 levels (24, 43, 58 and 75m above the ground) and elevator to reach the control cabin. Using the gondola of this canopy crane, it can make us possible to access the canopy three-dimensionally.

The crane stands at the center of 4ha plot where all individual trees (DBH: Diameter Blest Height > 10cm) have been mapped on DEM which generated by ground survey, measured and identified. This facility can solve the difficulty to reach the forest canopy and prevent our studies.

2.2 Laser Profiler Based Measurement System and its Configuration

Our developed laser profiler based measurement system mainly consists of system operation PC, laser profiler, its mount system, digital camera, and power supply equipments. PC is equipped the specified software in order to control all of instruments operations, measurement and data recording. The laser Profiler mount system is used for fixing the laser profiler on the crane gondola and operating laser beam in the perpendicular axis with 0.25 degree. Power supply equipments enable use to provide stable and continuous electricity at any time.

3. MEASUREMENT AND DATA PROCESSING FOR VIRTUAL FOREST RE-CONSTRUCTION

As the results of brief investigation of 4ha plot canopy structure, the maximum, minimum and average distances from the crane arm to the top of canopy surface had already obtained and they are 58m, 27m and 45m respectively. Also this measurement system confirmed to have a good enough performance under the condition of less than 50m distance from scanner to the target through our laser profiler capability examination.

3.1 Measurement Concept

Figure 3 is illustrated how the laser beam irradiates to the canopy surface and measures the distance to the target canopy. Here measurement system is introduced to one measurement point by the crane arm swing and both forward-backward and upper-lower moving of gondola (refer yellow lines). Blue rectangle area in this figure corresponds to the area where the developed system can observe at one time. In this case, the laser beam is irradiating from -30 to +30 degree with 0.25 degree resolution in both X, Y axes.
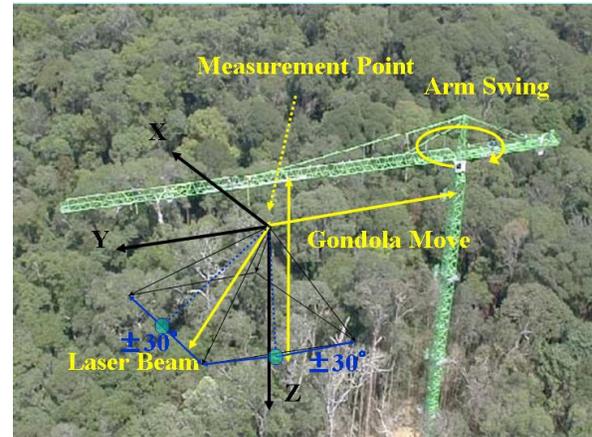
Figure 3. Concept of 3D Measurement using Canopy Crane

3.2 Measurement Geometry and Axes Adjustments

Figure 4 is illustrated the measurement geometry and its overlook. (Point-i,i=1, 4) is a measurement point. The blue dotted line is the global coordinate system and its coordinate expressed by F(X, Y, Z). The black solid line at (point-i,i=1,4) is an obtained scanner coordinate system $(F(X_i,Y_i,Z_i),i=1,4)$. In order to integrate all independent measured coordinate systems, the difference between global coordinate system F(X,Y,Z) and each different coordinate systems $(F(X_i,Y_i,Z_i),i=1,4)$ has to be adjusted as the pre-processing of scenes mosaic.
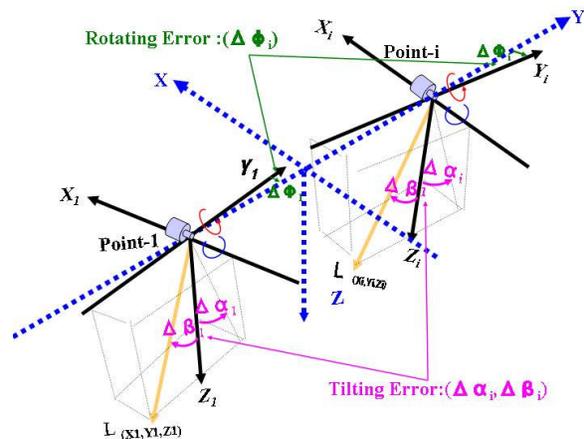
Figure 4. Measurement Geometry

Here all errors have to be corrected by using the differences between F(X, Y, Z) and F(X_i, Yi, Zi) in X, Y, Z axes. And they can be classified into two kinds of errors. One of errors is a rotating error. It is defined by an angle $(\Delta\Phi_i)$ in Z axis. The

other is tilting error and also defined by angles $(\Delta\alpha_i, \Delta\beta_i)$ in X, Y axis respectively. In order to correct the above errors, two kinds of correction targets were adopted in the actual measurement. One is a vertical target and used for adjusting the vertical, i.e. Z axis. The other is a direction target and for adjusting scene rotation with the vertical point as its central position. This process is to adjustment axes.

Figure 5 illustrated the cross section of measurement and correction targets deployment. $(T_i, i=1,4)$ is a direction target. The vertical target is hanged from the scanner original position.
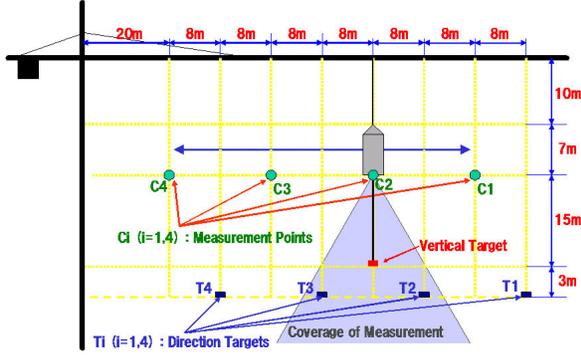
Figure 5. Measurement Coverage and Deployment of Correction Targets

Bright blue triangle corresponds to one measurement and its coverage. Consequently four measurements are necessary at one arm direction.

Within coverage of one measurement, at least two direction targets and one vertical target are included. One vertical target is identified in obtained data with specific distance and a tilting error angle is calculated by its position. According to the same process, a rotating error angle is introduced by the difference between line $((T_i)-(T_{i+1}))$ and Y axis with the vertical point as its central position.

3.3 Measurement
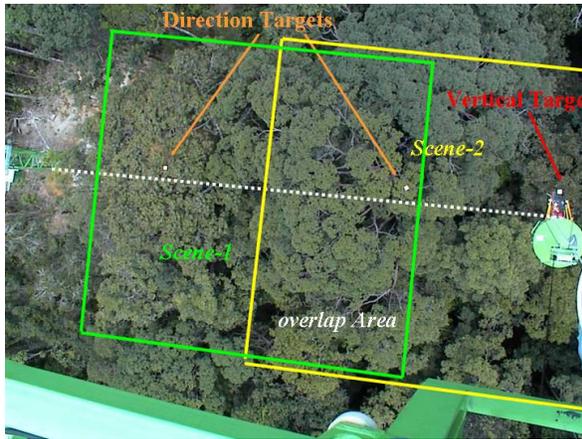
Figure 6. Actual Targets and Target Canopy

Figure 6 shows the picture which took from the crane arm in the actual measurement. The left edge of this picture is the central position of used crane. The green rectangle area is one measurement area (Scene-1). The continuous yellow rectangle is the next measurement area (Scene-2). On Scene-1, two direction targets can be seen. Around the right edge, gondola with circle shape and vertical target with white point can be also seen. Between Scene-1 and Scene-2, overlapped area is allocated by the consideration of scenes mosaic.

On the other hand, the crane stands at the center of 4ha plot where all individual trees (DBH: Diameter Blest Height > 10cm) have been investigated in every 10X10m patch area as minimum unit and identified to species. 400 patch areas had totally set up within 4ha plot using survey pins. Using these pins, the ground survey for identifying pins' location with geographic location (X, Y, Z) had been done.

3.4 Data Processing for DSM and DEM Generation

Data processing procedure for obtained measurement row data is illustrated in figure 7.
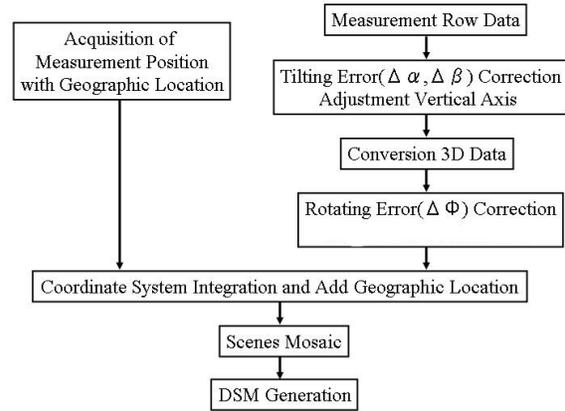
Figure 7. Data Processing Procedure

3.4.1 Data Acquisition and its Data: Acquired row data consists of the distance (L) from the laser beam original position to the target surface and angles in X, Y axes with 0.25 degree resolution. Also the location of measurement point is identified by both GPS and crane operating system.

3.4.2 Tilting Error Correction: The tilting errors $(\Delta\alpha, \Delta\beta)$ are calculated by identifying targets. Using these values $(\Delta\alpha, \Delta\beta)$, Z axis is adjusted to the vertical axis.

3.4.3 Conversion 3D Data: Equation (1) is the conversion from corrected row data to 3D data by considering tilting errors.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} L*\sin(\alpha i \quad \Delta\alpha_i) \cos(\beta i \quad \Delta\beta_i) \\ L*\cos(\alpha i \quad \Delta\alpha_i) \sin(\beta i \quad \Delta\beta_i) \\ L*\cos(\alpha i \quad \Delta\alpha_i) \cos(\beta i \quad \Delta\beta_i) \end{bmatrix} \quad \text{....... (1)}$$

Here, (X, Y, Z) is the converted 3D data. L is measured distance and i is the number of measurement point. Angles$(\Delta\alpha_i, \Delta\beta_i)$ are the tilting errors in X,Y axes at point-i. Angles$(\alpha i, \beta i)$ are the beam irradiating angles.

3.4.4 Rotating Error Correction: The angles organized by the line between two direction targets with the center of data as the central measurement point, decide the rotating errors. Through tilting and this corrections, all measured coordinate systems could be integrated to the same coordinate system.

3.4.5 Coordinate System Integration and Add Geographic Location: All measured data have their own coordinate system. Until the above mentioned processes, they are integrated into the same coordinate. However it's still local coordinate. Then UTM location is added to one of the point. In this study, it is one of measurement points.

3.4.6 Scenes Mosaic and DSM Generation: All of measured data after coordinate integration process are mosaicked and generated DSM.

3.5 Results

Figure 8 is the tree census GIS dataset with DEM at 4ha plot. This is one of the results in this study focused on the ground level surveys. The tree census data was obtained through all individual trees (DBH>10cm) investigation. The leaves pictures and explanations of trees are also recorded as attributes of tree location data. We can see this information on the screen by mouse designating the specific tree position on this kind of display under running GIS software. Through this study, GIS was confirmed to be powerful information tool for ecologists and other scientists.
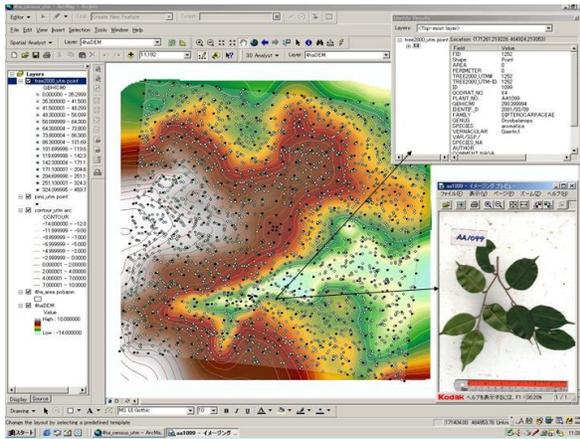
Figure 8. Tree Census GIS with DEM

Figure 9 is DSM and DEM composite 3D imagery as the other result of this study focused on the three dimensional measurement. From the canopy DSM, each crown can be identified. And various undulation of the forest floor can be seen from the DEM. Then this is the result of re-construction of virtual forest. By the comparison with DSM and DEM, the relationship between the growth and geographic conditions could be introduced (Yoshimura et al., 2001).
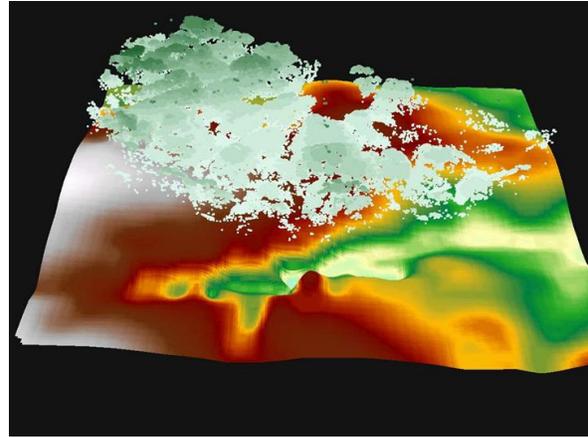
Figure 9. DSM and DEM Composite 3D Imagery

4. CONCLUSIONS

In this study, the authors used tropical canopy crane with 80m height and 75m arm length and developed three-dimensional canopy structure measurement system by laser scanning system. Furthermore DSM was generated and compared with DEM based on the ground survey as one of its applications. We define this kind of research is the re-construction the virtual tropical rainforest.

From the results of this study, our developed system was confirmed to have a satisfied performance and can provide an actual canopy structure as common data for multi-disciplinary usage.

We are still continuing to observe and measure various parameters related with photosynthesis and carbon exchange for tropical rain forest. In this kind of advanced research, three-dimensional data is also the most important for use to summarize various parameters.

REFERENCES

Nakashizuka T., Lee H. S., Chong L., 2001. Studies on canopy processes of a tropical rain forest in Lambir Hills National Park. Proceedings of the International Symposium, Canopy Process and Ecological Roles of Tropical Rain Forest, Miri, Malaysia, pp.2-7.

Yoshimura M., Yamashita M., 2001. Multi-scale approach for rainforest environment monitoring by remote sensing / GIS/ direct measurements - towards virtual field construction -. Proceedings of the International Symposium, Canopy Processes and Ecological Roles of Tropical Rain Forests, Miri, Malaysia, pp96-101.