論文の内容の要旨

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論文題目　Optimizing digital aerial photogrammetry for forestry applications in tropical montane forest environment
(熱帯山地林環境における林業的利用のためのディジタル空中写真測量の最適化)

Remote sensing technology is a promising technology for many forestry applications such as aboveground biomass measurement, forest biophysical characteristics estimation, forest monitoring system and biodiversity assessment. Two major advantages of using remote sensing technology are the capability for large spatial and multi-temporal assessment. Generally, three dimensional dataset of the earth surface can be derived from three main types of remote sensing technology; i.e. airborne laser scanning (ALS) system, synthetic aperture radar (SAR) and stereo imageries, where each type of dataset provide different information and resolution depending on sensors' type and altitude. Aerial photogrammetry have the advantages on the low cost data acquisition, higher availability and unique reflectance information compared to ALS and SAR dataset, thus making photogrammetry to remain as important dataset in addressing global challenges such as forest carbon monitoring under the reducing emission from deforestation and forest degradation (REDD-plus) mechanism. In the monitoring, reporting and verification (MRV) of REDD-plus, a reliable and alternative method is needed. The main objective of this research study is to evaluate and demonstrate the capability of digital aerial photogrammetry for forestry applications in tropical montane forest environment. Analyses are divided into three main parts; performance of photogrammetric digital surface model (DSM), above ground biomass estimation, and forest biophysical characteristics estimation. Chapter 4 explains the dataset used in this research study. The study area is located in Ulu Padas forest area (approximately 4° 26' N, 115° 45' E) of Northern Borneo, Malaysia, inside the Heart of Borneo initiative area with elevation ranges from 900 m to 2,000 m and consists of several forest types with different forest degradation levels. The remote sensing dataset were acquired during a flight mission in October 2012 using Riegl LMS-Q560 for LiDAR data and Canon 1D-Mark III for aerial photographs attached to a helicopter platform. Field works were conducted between 2011 and 2014 using different plot sizes (30 m × 30 m; 20 m × 20 m; and 90 m × 90 m) and tree information of DBH, tree height, tree crown, and species were recorded for each plot. Processing of aerial photographs were performed using structure-from-motion (SfM) software, Agisoft PhotoScan Pro version 1.0.3 to produce photogrammetric point cloud. In addition, ortho-photo was generated using the same software and digital surface model was derived from the photogrammetric point cloud. Chapter 5 explains the evaluation performance of photogrammetric DSM (photo-DSM). Photo-DSM of 1 m resolution was derived from photogrammetric point cloud and its performance of DSM was assessed using ALS dataset as the reference. Image matching was successfully performed of which 86.1% of the aerial photographs used. The result demonstrated that different forest structures characterized by mean and standard deviation of ALS-CHM (ALS canopy height model) influenced the root-mean-square-error (RMSE) values (RMSE = 1.01 - 4.19 m) of photogrammetric DSM. Compared with other canopy surface area, RMSE values on steeper canopy slope and darker area were found higher with values of 8.6 m and 5.8 m, respectively. No-data constituted about 3.3% within the forest blocks. Chapter 6 explains the aboveground biomass (AGB) estimation using aerial photographs and ALS datasets. In this research component, photogrammetric and ALS point clouds were used to develop model for the AGB estimation. MRV (measurement, reporting and verification) under REDD-plus requires cost effectiveness with accurate result, and aerial photographs can potentially be an alternative for this purpose under the condition if country-wide aerial photography mapping program is available. AGB estimations were evaluated using different prediction methods (i.e. linear regression and random forest model), sets of ground sample plots, ALS and SfM datasets, and allometric equations. Chapter 7 explains the forest biophysical characteristics estimation where forest inventory information is important both for scientific and forest management purposes. The result of forest biophysical characteristics estimation using SfM is similar with the estimation from ALS (i.e. the difference of relative RMSE values were less than 2.6% when using Random Forest). The RMSE values for mean diameter, dominant tree height and Lorey's height are less than 15%, while basal area and tree density within 22-37%. The key points of this research study demonstrated the capability of aerial photogrammetry for forestry applications specifically on AGB estimation and forest biophysical characteristics estimation; (1) The performance on photogrammetric DSM analysis showed that accuracies were influenced by mean and standard deviation of ALS-CHM, dark area and steep slope. This suggests note must be taken when using photogrammetric DSM for certain applications such as monitoring forest dynamics especially on highly heterogeneous forest type, (2) AGB estimation result from aerial photogrammetry is potentially used for MRV in REDD-plus once a detailed digital terrain model is available from ALS, (3) forest biophysical characteristics can be estimated using SfM and the result are similar with estimation from ALS. There is a potential of its applications to forestry if a routine national aerial photography program is available and potential use with unmanned aerial system (UAS) for small scale project, and (4) the full applications of aerial photogrammetry in forest environment can be achieved once a high accurate digital terrain model from ALS is available.