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SUMMARY OF DOCTORAL THESIS

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Title: Synthetic Aperture Radar Application for Agricultural Land Use Classification in Java Island, Indonesia

（インドネシア、ジャワ島における農業的土地利用分類のための合成開口レーダ画像の応用）

According to the statistics of Indonesia Statistics Bureau in 2010-2014, the ratio of agriculture, forestry and fisheries sector to gross domestic product shows high value (13.38%). Despite its small area, Java Island in Indonesia plays a central role in agriculture. Rural areas are widely distributed in Central Java province and Eastern Java province. The traditional rural landscapes can be seen at the foot of Merapi volcano in Central Java province. Majority of people living in these traditional rural areas are working as small-scale farmers which cultivate various crops and cultivation types, including paddy. In these small-scale farming systems, the area under management per household is generally as small as 0.3 hectares, and they are irregularly dispersed in more complex terrain shapes. Due to these conditions, it is extremely difficult to map detailed agricultural land use patterns and to grasp the spatial and spatial changes.

Currently, the population of Java is still increasing. The population growth is directly related to the need to increase food production; however, agricultural fields are decreasing due to the expansion of land used for infrastructure purposes. The reduction of agricultural fields could result in less agricultural production. Thus, accurate and updated information on land use and land cover mapping in agricultural areas has become a crucial issue for decision-making on agricultural policy. However, the mapping of agricultural land use and land cover is difficult due to the complexity of farming systems, the diversity of natural conditions, and the rapid development taking place on Java Island. In fact, agricultural statistics are still based on direct surveys of fields, despite the highly time consuming nature of these surveys. In this regard, there are extremely high expectations for geo-spatial technology, such as GIS and remote sensing to obtain information about agricultural croplands. In particular, synthetic aperture radar (SAR) satellite imagery is now being increasingly utilized based on its convenience and utility in overcoming cloud cover in tropical regions.

In this study, the available imagery from L-band SAR systems, such as ALOS/PALSAR, ALOS2/PALSAR2, and C-band SAR named Sentinel-1 was used to classify the land use and land cover of complex agricultural areas in Java Island as well as for discussing methods of classification. There are six objectives that must be met in order to achieve this purpose: (1) to examine the characteristics of complex agricultural cropland that can be identified by using active remote sensing data; (2) to explore the full polarization ability of ALOS/PALSAR; (3) to investigate the efficacy of temporal ALOS-2/PALSAR-2 in identifying and classifying croplands, (4) to analyze the influence of sample point selection based on the backscatter value characteristics for the classification process; (5) to understand the backscatter value characteristics of paddy field cropping patterns; and (6) to test the most effective backscatter value parameters for classifying areas of complex agricultural croplands

In brief, main component of the SAR image is the transmitted and received waves in horizontal (H) and vertical (V) directions. There are four polarizations that can be generated from these two directions, namely HH, HV, VH, and VV. The two letters in each abbreviation indicate transmission direction and receive direction. The classification of agricultural land use and land cover type using four polarization

mode of L-band SAR, the ALOS/PALSAR, taken in April 2010. The target area covered around 50 km2 in Central Java province. The four polarizations were processed into two types of decomposition type namely the Freeman and Durden and Yamaguchi 4-component. There are also 33 parameters extracted from these polarization by using the arithmetic calculation, such as add, subtract, multiply and division. The classification of full polarization achieved 67.09% and 0.523 for overall classification and kappa respectively. Meanwhile, the integration between backscatter intensities (HH, HV, VH, VV, and HH+HV) and the three components of the Freeman and Durden decomposition significantly improved the overall accuracy and kappa coefficient (74.11% and 0.6247). This fact implies that the integration of the full polarization and polarimetric decomposition of Freeman and Durden methods was able to compensate for the weakness of each component in discriminating complex agricultural croplands. The dry fields and paddy fields become bare land before the cultivation or after the harvest. These stages lead to the misclassification between both classes. On the other hand, mixed garden crop was surrounding with tree canopy that produced unique backscatter. Consequently, the mixed garden crop could be distinguished from other croplands class. The settlement class is recognized from the building structures that reflect stronger backscatter compared to other classes.

The second research focuses on classifying agricultural land using the time series imageries from the L-band SAR, ALOS2/PALSAR2. The study area covers around 112 km2 and consists of several land use and land cover types such as woodlands, paddy fields, upland fields, tobacco fields, settlement and mixed garden crops. There are three of dual polarizations imageries (HH, HV) and one full polarization imagery (HH, HV, VH, and VV). Similar to the previous study, the maximum likelihood classification method was also applied in this study. However, the temporal of ALOS2/PALSAR2 and field survey conducted in this area present there are two types of paddy field cultivation, paddy I for irrigated paddy field and paddy II for rain-fed paddy field. The significant size of tobacco fields which planted during the dry season increases the difficulty of the classification process. Therefore, the temporal of Landsat-8 imageries were also applied to assist the sample point selection, especially for the tobacco fields. The RGB composite of HH, HV and HV-HH polarizations was used for the separation of these paddy fields' cropping patterns. Sample points were selected based on the characteristic of the RGB composite. The low backscatter coefficient areas, which appeared as dark blue, were categorized as paddy-I. Meanwhile, the paddy fields in a late growing stage showed more roughness and a higher backscatter coefficient and categorized as paddy-II. This method gave higher classification result compared to the first study. The overall accuracy of 85.02% and a kappa coefficient of 0.824 were achieved by using the multi-temporal combination of HH and HV polarization from four temporal data taken between January and September 2015.

In the third study, the multi-temporal imageries of C-band SAR, the Sentinel-1, taken on 2017 were applied in the similar study to the second research. The Sentinel-1 data assisted with Sentinel-2 were successfully classified for the complex agricultural area in GEE platform. The threshold of backscatter coefficient less than -17.4852 dB and greater than -31 dB generated a paddy fields area. The detail cropping pattern of paddy fields became possible with the high multi-temporal of Sentinel-1 and the optical of Sentinel-2. A comparison of the backscatter coefficient and NDVI value derived from the Sentinel-2 of these paddy fields classes shows the backscatter coefficient was more sensitive to the surface structure, which led to the shifting time between the backscatter coefficient and NDVI. The combination band of VH, VV, and the subtraction of VH and VV polarization classified with the random forest with 50 number of trees obtained the highest overall accuracy and kappa value as 76.88% and 0.728, respectively.

In summary, this study presented the capability of SAR imageries for identifying and mapping the complex agricultural croplands in tropical area. This study explored the best parameters generated by using the combination of full polarizations from L-band, the benefit of sample points collection based on the backscatter coefficient of multi-temporal from L-band SAR and the methodology for sample point collection in cloud based system classification for multi-temporal C-band SAR. The results and finding exposed that the characteristic of the cropland derived from the backscatter coefficient is beneficial for classifying the complex agricultural croplands. The multi-temporal polarizations and the optical imageries assistance were also highly affected the accuracy of classification. The cloud based processing is highly favorable to maintain and process big amount of temporal data. Lastly, this study aimed to enhance more knowledge for faster identifying and mapping complex agricultural lands in tropical regions by using C-band and/or the L-band SAR.