Analysis of the Forests Spatial Structure using SAR and Ikonos Data

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ABSTRACT

During the 1996 INDonesian Radar EXperiment (INDREX) campaign several types of high-resolution (1.5 meter) Dornier Synthetic Aperture Radar (DO-SAR) images, such as intensity, coherence, and interferometric images, were acquired. The campaign was sponsored by the European Space Agency (ESA) and facilitated by the Indonesian Ministry of Forestry and Wageningen University. The campaign was directed to develop a "Remote Sensing Monitoring System for Forest Management and Land Cover Change in Indonesia". The measurements taken through radar imaging data and the spatial information from multispectral data allow defining spatial structure in a quantitative way. Single tree-crown shape as well as tree distribution defines the spatial structure of the forest. Tree objects could be quantitatively clumped in various degrees and different hierarchy levels using several parameters, e.g. distance to the closest neighbour tree(s), tree height, and canopy structure. Starting with a tree-crown classification, the higher scale levels in forest structure (tree-groups) can be constructed with a set of spatial decision rules. This implies a hierarchical classification, integrating different scale levels in the classification process. Trees can be grouped in a quantitatively way without loosing individual tree information to be integrated into the smaller scale geo-database, e.g. forest density cover type. The natural tendency of tropical lowland forest is to develop a 'clumped' distribution of mature trees. The 'natural' mature tree-crown as well as their natural neighborhood has a unique spatial structure. Deviations from the crown structure as well as the 'natural' distribution might indicate forest function loss, degradation or recovering stages in the forest development. Therefore, the reconstruction of the forest spatial structure should allow making estimation up to what extend the forest can be considered 'intact'.

***Keywords and phrases*:** Tree Mapping, Synthetic Aperture Radar (SAR), Interferometric, Spatial Decision Rule

1.0 INTRODUCTION

1.1. Background

Aerial Photograph (AP) has been used to support forest inventory in Indonesia. The use of AP (scale of 1:25,000) is to estimate timber volume using the relationship among Crown Density, Tree Height, and Crown Diameter before the harvest. In addition, AP could produce contour lines to assist the logging road planning; however AP has limitation because of cloud coverage.

The Indonesian Ministry of Forestry (MoF) has decided to evaluate the use of alternative sensors to complement AP in the case of cloud cover problems. The suitable sensor to be evaluated is the Synthetic Aperture Radar (SAR). Therefore, during the 1996 INDonesian Radar EXperiment (INDREX) campaign several types of high-resolution (1.5 meter) Dornier Synthetic Aperture Radar (DO-SAR) images, such as intensity, coherence, and interferometric images, were acquired. The campaign was sponsored by the European Space Agency (ESA) and facilitated by the Indonesian Ministry of Forestry and Wageningen University. The campaign was directed to develop a"Remote Sensing Monitoring System for Forest Management and Land Cover Change in Indonesia". Besides the campaign, MoF sent two officials to study about SAR in Wageningen University at the PhD level.

Recently, the commercial satellite remote sensing sensor has reached 1 meter resolution along with optical and near infrared wavelength (Ikonos). This development is promising for investigation even if limited by the same cloud problems as AP. The traditional paradigm of photogrammetric interpretation of remote sensing for the Indonesian forest inventory or tropical forest inventory activities could be changed or improved by investigating the use of digital image analysis of very high resolution images of SAR and/or Ikonos to complement AP. Efforts on digital mapping and analysis to map individual tree have been started since the nineties (Gougeon, 1995 and Koop, 1996).

The studies of forest structure are usually based on the ground survey and these are related to the forest inventory (Loetsch *et al*., 1973). Indonesia is third country that has the largest tropical forests after Brazil and Zaire and its MoF has done the first National Forest Inventory (NFI) collaborated with Food and Agriculture Organisation (FAO). MoF has established about 3000 Temporary and Permanent Sample Plots with a grid distance of 20x20 Km throughout Indonesia and has built geo-database of 1:250,000 scale derived from Landsat (30m resolution) and existing forest land-use planning data (Anonymous, 1996). The outcome of NFI would be outdated if MoF would not do a massive ground survey activities in order to update its geo-database in a regular way and to predict the timber volume at the national level. Therefore, the ground survey activities could be supported by the use of very high-resolution remote sensing data. Koop (1989) has showed that the use of AP could produce such an analysis for the forest structure. Several parameters (e.g. Crown Density, Tree Height) could be extracted from AP and they could be used for further prediction and modelling of future forest structure.

Conventional nomenclature for the forest structure has been summarised by Koop (1996). The common and simple nomenclature are Gap, Building, and Mature (Whitemore, 1990), but to implement this nomenclature of forest structure, it requires sound forest inventory or survey activities in situ. “For example, we may usefully compare richness within rain forests by counting tree species of *c*. 1 ha. This within–community diversity has been called alpha diversity.” Obviously, this simple nomenclature could become an input for the government to plan their action on forests, e.g. reforestation plan.

Forest survey measures a quantity of parameters as complete as possible to describe the forest structure in plot sizes of 1 – 6 ha (Oldeman, 1990, Koop, 1996, Prakoso and Suryokusumo, 2000). Prakoso and Suryokusumo (2000) established a 6 ha square plot of intact secondary forest to be used for DO-SAR image validation and this plot contained complete information, e.g. contour of the land, x,y,z coordinates of tree trunk, local-species-genus- family identification, tree height, diameter at breast height, height of first branch, height of periphery, canopy radii of 8 compass directions at periphery. Therefore, a good forest survey or forest plot could be used to simulate and evaluate potential parameters to be derived from SAR image.

In East Kalimantan, Dipterocarpaceae is the dominant family with a tendency for clumping (Smits, 1994). This clump symptom could be a nice indicator to judge the nomenclature of forests. This can be done because the tree trunk positions or 3D-coordinates including the form and height of tree canopy are measured (Prakoso and Suryokusumo, 2000). DO-SAR image after being processed in the algorithm of 3D Tree Mapping (Hoekman and Varekamp, 2001) can produce information on the volume of canopy, backscatter intensity of the tree canopy, and grouping trees using spatial decision rules, e.g. minimum 3D distance of trees and size of the canopy volume. On the other hand, Ikonos image using object segmentation can produce additional information of a tree, e.g. tree position, NDVI value, tree shadow. Therefore, all information of various sources, e.g. SAR, Ikonos, and forest survey could be used in a synergic way to map the 'clumped' distribution including mature trees. The ‘natural’ mature tree-crown as well as their natural neighbourhood has a unique spatial structure. Deviations from the crown structure as well as the 'natural' distribution might indicate forest function loss, degradation or recovering stages in the forest development.

1.2. Objective

The objective of this paper is to investigate the use very high-resolution SAR and Ikonos images along with the analysis of forest spatial structure.

1.3. Structure of the Paper

The structure of the paper consists of:
- Introduction
- Materials and Method
- Results and Discussions
- Conclusion and Recommendation

2.0. MATERIALS AND METHOD

2.1. Materials

This study uses data of Ikonos dated on December 17, 2001 and Airborne DOSAR of August 1996 and the study area is located in Samboja, East Kalimantan, Indonesia (Figure 1). One forest plot is used along with Ikonos data. The fieldwork has been done in the study area in July 2002 along with Global Positioning Systems (GPS) measurement.

Figure 1. The location of study area

1.2. Method

The object based segmentation in this study is applied on Ikonos imagery using eCognition software. The object based segmentation analyses several hierarchical layers of different size of segmentation scale (Baatz and Schäpe, 1999 in Strobl and Blaschke, 1999) and this technique requires interactive user input to achieve the best solution for assessing the clump behaviour or tree position and statistics, e.g. NDVI value (Figure 2). The point of departure is an individual tree level up to a group of trees or groups of trees. In addition, this study uses the 3D-tree-aggregation-mapping algorithm developed by Dr. Hoekman, Wageningen University.

The simple ordinary least square (OLS) regression in SPPS software is used to find relationship between the proposed index and different forests or lands cover types.

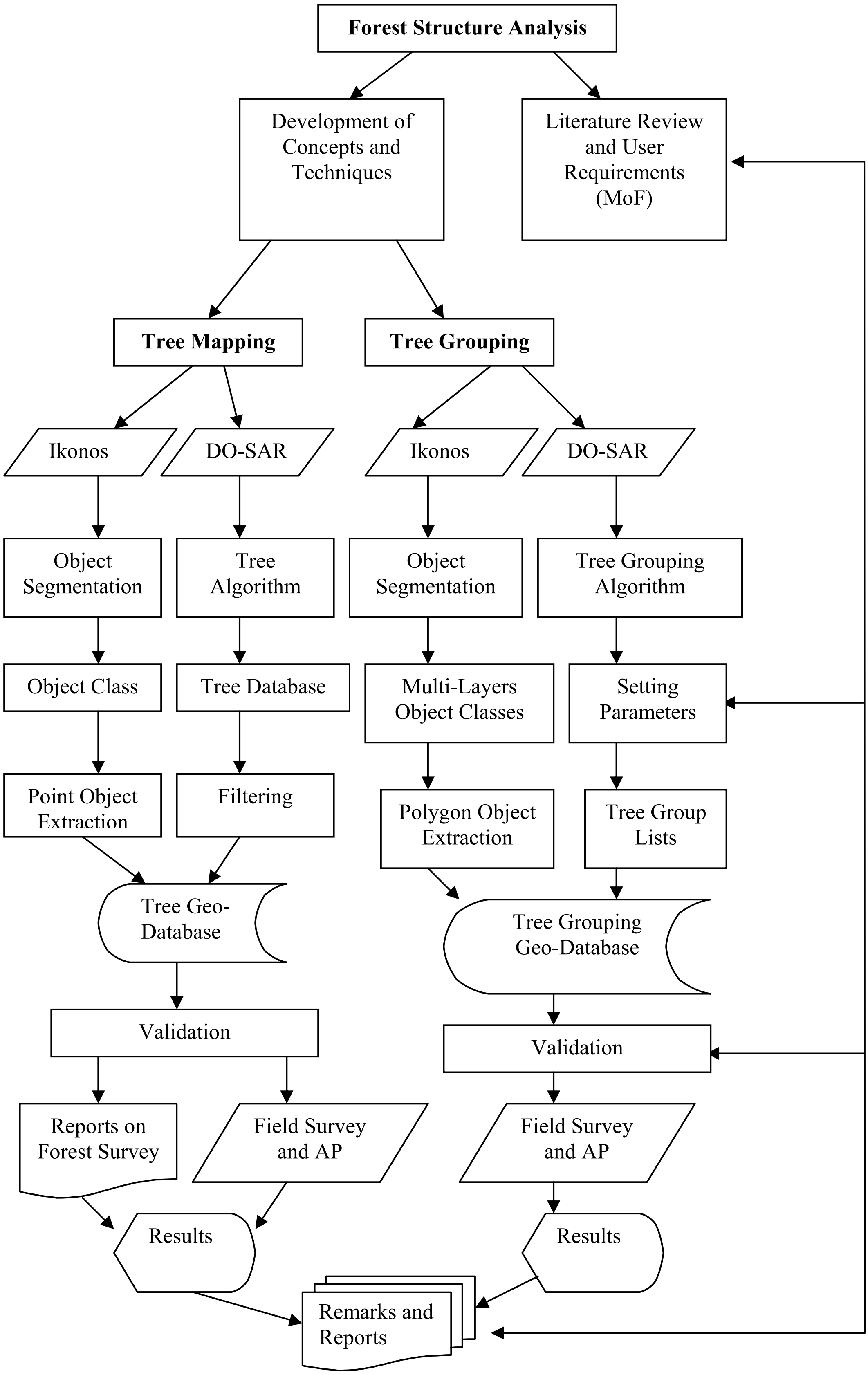

Figure 2. Flowchart of Forest Structure Analysis in Ikonos and DO-SAR images

3.0. RESULTS AND DISCUSSIONS

3.1. Tree and Tree Grouping Concepts

First, each tree can be confirmed as a tree when its canopy pairs with its shadow, concerning the direction and height of the sun for passive sensor or SAR sensor (Figure 3).

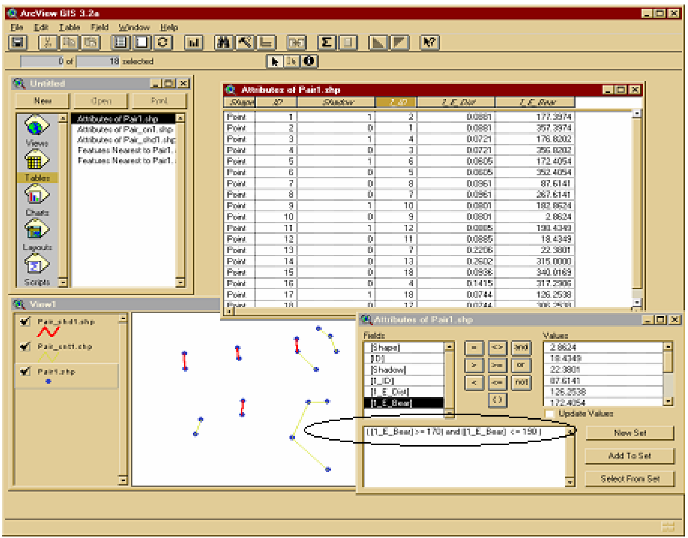

Figure 3. Finding a pair of tree shadow and the tree based on their distance and direction

Traditionally in forest survey/inventory, the basic element is the tree stem along its attributes, e.g. position, DBH, species, but currently few attributes could directly extract from remote sensing data/images. The stem is actually a point feature and this point feature is the basic input for assessing forest spatial structure (Pretzsch, 1999 in Olsthoorn *et al*., 1999). This paper tries to define alternative point features that allow using similar assessment on forest structures. ESRI user communities provide and share a lot of tools to test this tree definition. As mentioned it the tree concept, point-data of stem against point-data of canopy brings selective attributes e.g. maximum distance, NDVI value could be used and a hypothetical sun angle direction and the final result showed only an object that has an NDVI value and shadow in the expected direction and distance can be defined as a tree-point object.

Simulation

Second, for grouping trees a central parameter is 2D distance (x, y coordinate positions) among them are close enough or their canopies/crowns almost touch among others (Figure 4). It is important to classify besides species and size to measure distance automatically.

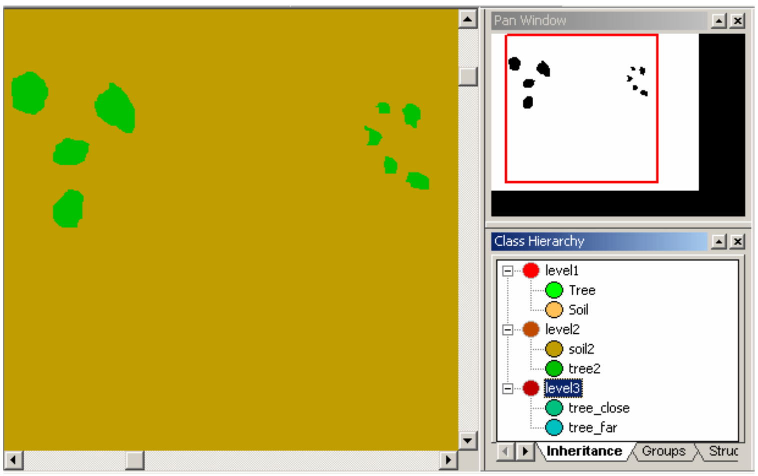

Figure 4. Grouping different trees based on distances and canopy sizes using multi-layers in eCognition

This definition of tree grouping considers on allometric investigation of Nugroho *et. al.* (2001) based on plot data of Prakoso and Suryokusumo (2000). Nugroho *et. al.* (2001) in their paper showed that there is a positive relationship between tangent of canopy (between canopy radius and different height between top tree height and height of periphery) and top tree height. The centroid of the canopy polygon is the starting point of measurement. This could be elaborated that the higher the tree would have larger area of canopy. Thus, large canopies could be grouped in one group of trees for a 2D-tree grouping, but such a maximum distance where their canopies almost touch among others limits them. In fact, this distance measurement for such indices is applicable to assess forest structure.

Real World Data

Third, a group of tree could be defined from 3D perspective using x, y, and z coordinate system by networking 3D tree position concerning the purposive difference distance and tree height (Figure 5).

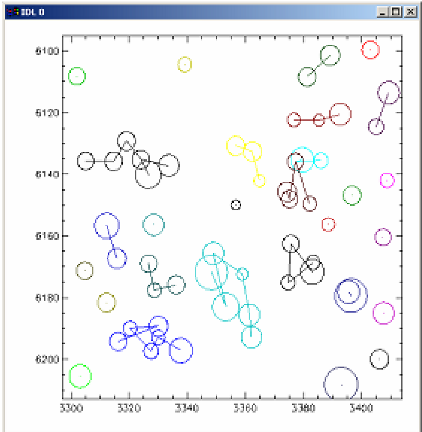

Figure 5. 3D tree grouping that based on distance and difference tree height

This definition of 3D-tree grouping tries to accommodate a real world situation when within a group would big trees and several small trees in between. The concept of network limits one tree not to have more than one link to other trees. The transect results of many tree plots could show that groups of tree related to a type of forest type, e.g. a clump of big trees could be defined as a biostatic ecological unit according to Oldeman (1990) or a mature class in Whitemore (1990). The expectation from this 3D-tree grouping is to link such a proposed index with various forests or land cover features used by the Indonesian MoF concerning also the qualitative nomenclature of **gap, building**, and **mature** (Whitemore, 1990) without original distances of tree objects in the geo-database.

3.2. Ikonos Image

3.2.1. Tree Definition

In order to apply the tree definition, Ikonos image would be a good point of departure. The selected sub-study area covers part of the Ikonos image. Segmentation should consider the minimum standard deviation value of 30 members as a rule of thumb for statistical requirement. The weighting factors of the Ikonos bands, e.g. PAN=0.5; BLUE=1, GREEN=1, RED=1, NIR=1) are applied. Then, it has been defined that a tree pairs with its shadow in certain requirements, e.g. sun angle direction, NDVI value, for testing purposes a teak plantation offers as a study area. Results show that it is more difficult to obtain a compact tree canopy than to obtain a respective tree shadow. This situation would be understood until secondary information and a fieldwork has been done. The secondary information is that the teak plantation has also an agroforestry system in it (a taungya/"tumpangsari") and this information has clarified by a fieldwork in July 2002 (Figure 6). The condition is such a way that a canopy reflectance of a teak tree is not a dominant within a pixel of NDVI (4x4 meter). The radius of the teak canopy is about 1-1.5 meters and the pineapple, chilly, and grass are found below the canopy and surrounding it; however the tree shadows are defined well with the object-segmentation approach. This result could produce tree point feature with its object attributes that would benefit to a monitoring of number of tree and tree growth. Moreover, these point features geo-database can be used as input for calculating aggregation or segregation indexes (Pretszch ,1999 in Olsthoorn *et al.*, 1999). This topic is still under-construction in our lab.

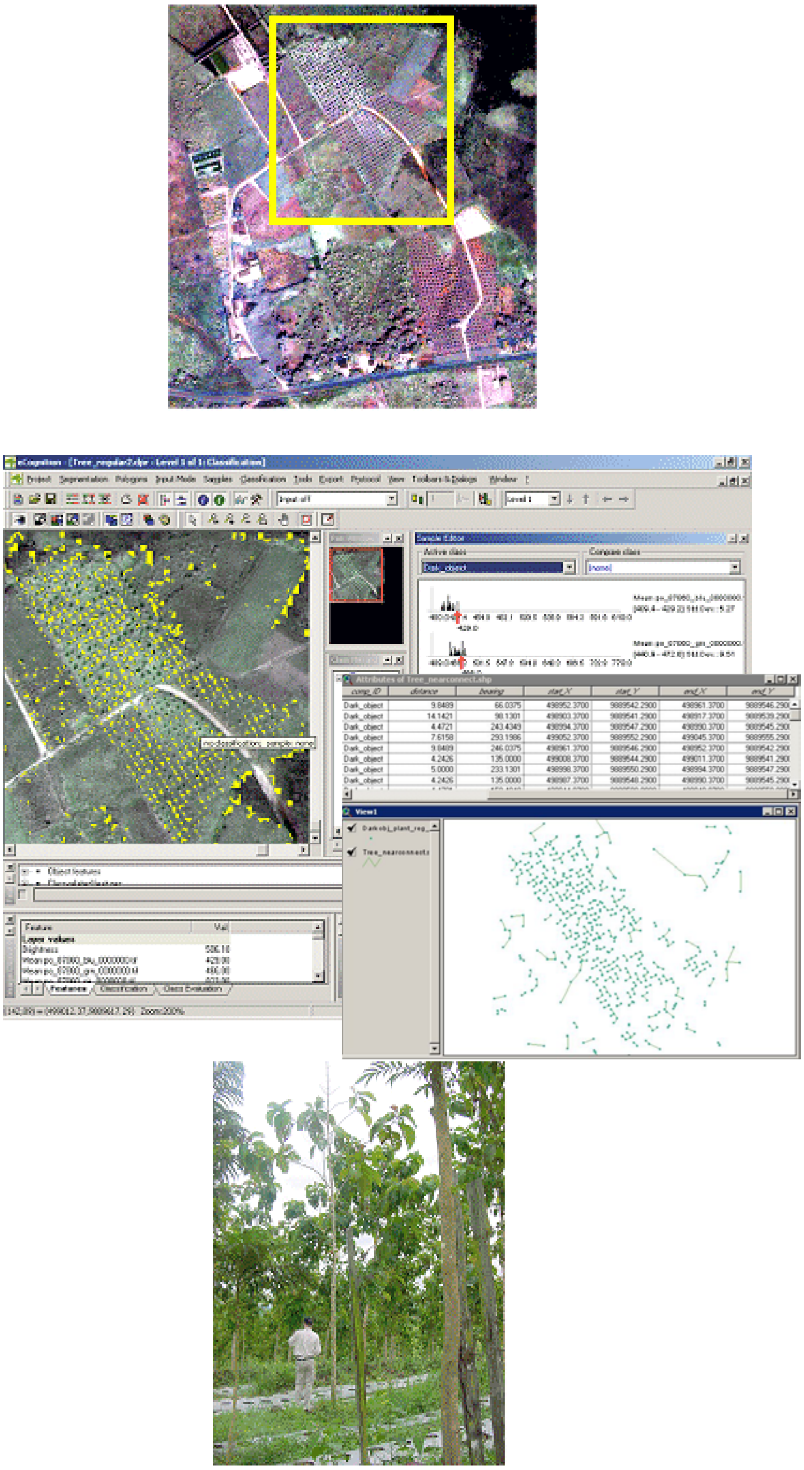

Figure 6. The Ikonos image of the subset study area, the finding of tree shadow and the ground view

3.2.2. 2D-Tree Grouping

Ikonos image that is used in this study has been geo-referenced and it looks like an ortho-image, therefore a 2D-tree-grouping concept could be verified. Previously, the object segmentation has to meet such requirements and these are also applied in this process. The sub-study area was chosen and it is a research station of orangutan and silviculture at Wanariset, Samboja. The object segmentation and defining classes were performed in multi-layers approach to maintain detail and aggregation of databases in several levels of hierarchies. First, object segmentation was performed to be able to recognise any individual object, e.g. tree, small house. Second, object segmentation was intended to obtain larger objects merging the neighbouring object(s) selected from the first level segmentation. This would lead to connectivity with strong spatial characteristics of an object class. Such an object contains a unique ID and its unique position respectively. Third, the objective of segmentation is to increase object size without changing the available object class from the previous level (Level 2 or second step). This third level showed that trees with smooth texture were merged in a larger connected object (Figure 7), but the individual information on the previous level remained in the geo-database. To ensure the object segmentation of multi-layers results, a validation with the ground measurement was done (Figure 7). This simple overlay validation showed that houses, experiment field, and groups of trees of terrestrial measurement were quite fit to “stair-case” of pixel derived area-objects respectively.

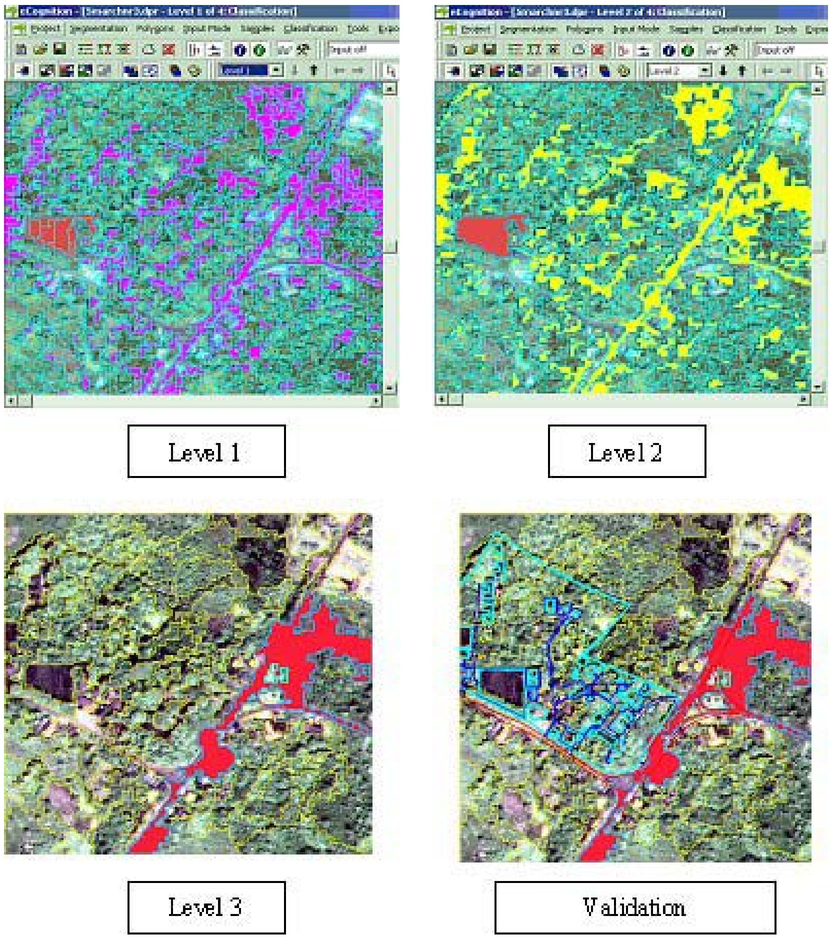

Figure 7. 2D-tree grouping using multi-layers object segmentation

3.3. Dornier SAR

The Dornier SAR (DO-SAR) image is an interferometric airborne SAR and this means that a digital elevation model can be derived. This paper is trying to continue discussion of 3D tree mapping, but it will focus on the tree grouping aspect. Dr. Hoekman developed a special user-friendly program of 3D tree grouping based on IDL to further process of 3D tree mapping and the to be validated in the real world situation.

The parameters that can be set are:

1. Setting Quality Criteria
   - r2Q = minimum size crown projection
   - r3Q = minimum size crown volume
   - DQ = minimum ‘Quality’ of crown boundary
   - IntQ = minimum backscatter intensity crown surface

2. Setting Identity Criteria First Step
   - xT = maximum difference in x-position
   - yT = maximum difference in y-position

3. Setting Identity Criteria Second Step

- zT = maximum difference in z-position
- r2T = maximum difference in crown area
- r3T = maximum difference in crown volume

4. Defining an Aggregation Intensity (Delta_r3)

The validation has done using the visual interpretation of aerial photographs of 1:20,000 taken in December 1996 and Ikonos image taken in December 2001 at certain intact secondary forest area. The result showed that by setting the combination carefully a rough conclusion could be derived as follow:

First Approach, Validation:
1. Visual Aerial Photo Interpretation and Plot vs Tree Mapping
   - Number of Tree in Visual and Plots are higher than Tree Mapping, but they have similar pattern,
2. Visual Aerial Photo Interpretation scanned and geo-corrected vs geo-corrected Tree Mapping (ENVI)
   - 2D tree grouping of visual are similar to geo-corrected Tree Mapping in both visual and overlay techniques.
3. 3D Anaglyph (ILWIS 3.1) vs Tuned (Intensity = 98 and D factor = 1) of Tree Aggregation mapping using rubbersheeting technique of image processing (rotate and scaling using PAINT SHOP).
   - 80-90 percent trees are correlated both in spatial and size.

Second Approach, Regression Analysis (SPSS ver 9.0):
1. Aerial Photo Classification vs 3D Tree Aggregation
   - There is a positive high correlation between Number of Tree (TR) and Number of Group (GR):
     - Linear with R squared = 0.995*** where b0 = 3.9129 and b1 = 0.2921 (TR = Independent Variable)
   - There is a positive high correlation between number of group and number of tree (GR/TR) and Land Features (Sec Forest-Agric. Estate-OpenArea+Trees-Burnt/Damaged Forest-OpenArea):
     - Linear with R squared = 0.967*** where b0 = 0.1149 and b1 = 0.1407 (Rank of Land Features = Independent Variable)
     - Exponential with R squared = 0.974*** where b0 = 0.2360 and b1 = 0.2452

Further criteria or such an index can be proposed in order to be able to explain different nomenclature such as whether the burnt secondary forest of MoF can be related to a gap nomenclature of Whitemore (1990). There are also many useful matters that can be developed for further research work especially when users, e.g. MoF needs a special index or indicator to assess their forests and the investigation of tree grouping or clump can be further go on the higher level of relationship among tree grouping.

4.0. CONCLUSION AND RECOMMENDATIONS

The measurements taken through radar imaging data and the spatial information from multispectral data allow defining spatial structure in a quantitative way. Single tree-crown shape as well as tree distribution defines the spatial structure of the forest. Trees objects could be quantitatively clumped in various degrees and different hierarchy levels using several parameters, e.g. distance to the closest neighbour tree(s), tree height, and canopy structure. Starting with a tree-crown classification, the higher scale levels in forest structure (tree-groups) can be constructed with a set of spatial decision rules. This implies a hierarchical classification integrating different scale levels in the classification process. Trees can be grouped in a quantitatively way without loosing individual tree information to be integrated into the smaller scale geo-database, e.g. forest density cover type. The natural tendency of tropical lowland forest is to develop a 'clumped' distribution of mature trees. The ‘natural’ mature tree-crown as well as their natural neighborhood has a unique spatial structure. Deviations from the crown structure as well as the 'natural' distribution might indicate forest function loss, degradation or recovering stages in the forest development. Therefore, the reconstruction of the forest spatial structure should allow making estimation up to what extend the forest can be considered 'intact'.

Efforts and research activities on very-high resolution remote sensing images have been emerged since the nineties and it will still continue on both cases because of technological driven as well as demand from users. Further research topics on integrating various scales or resolution could be directed to produce such indicators that could be easily understood by users, e.g. MoF for their planning and management activities.

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