INTERGRATION OF HIGH RESOLUTION AERIAL IMAGES AND AIRBORNE LIDAR DATA FOR FOREST DELINEATION

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ABSTRACT:

Forest boundary is one of the important parameters in Swiss National Forest Inventory (NFI). It is mainly delineated by aerial photo interpretation according to the defined "Forest/Non-forest decision" rules at each sample plot. However, it is not suitable for local assessment of forest stands with such kind of coarse grid sampling design. This paper presents an approach intending to delineate forest boundary automatically by integrating use of aerial images and airborne LIDAR. Empirical tests show that the proposed method offers an automatic process of forest boundary detection for various aerial images in a promising way. However, it's a challenge task to describe NFI forest /non-forest definition with automatic computer-based method and current study provides an encouraging basic for further development and testing.

1. INTRODUCTION

Forest is an indispensable foundation of human life. It fulfils multiple functions such as providing wood and foodstuff, protecting soil from erosion and stabilising the climate on a regional and global level etc. A third of Switzerland is covered in forest. While the plateau has only relatively little forest, by contrast the south side of the Alps is particularly rich in forest. In order to record in detail the current state and change within the Swiss forest in a representative and reproducible manner, the Swiss NFI has been carried out for three times by the Federal Council: between 1983 and 1985 (NFI1),1993 and 1995 (NFI2) and from 2004 to 2007 (NFI3) (Brassel,2001, Brassel and Brändli,1999) . A forest inventory is the procedure used to obtain information on the quantity and quality of the forest resource and many of the characteristics of the land on which the trees are growing(Husch, et al.,1982) . The Swiss NFI covers all essential data on land use, giving the surface area, the growth and the condition of the forest. Apart from the above important forest management indicators, the NFI is designed to be a multi-purpose inventory which entails a high demand on the methods implementation, flexibility in respect to the contents, inventory perimeters as well as data analysis.

The employment of aerial photograph is involved in Swiss NFI so that the cost of the ground survey could be reduced. An important application of aerial photograph lies on the classification of plot samples in forest and non-forest areas. Each aerial photo sample plot was classified according to the so-called "Forest/Non forest decision". The Forest Boundary Line (FBL) determines the border line between normal forest or shrub forest and non forest. It allows the evaluation of the forest width and forest inter-space. These values are needed, in order to reach a forest/non-forest decision. The interpreted boundaries at each sample plot belong to a regular 500m grid with 25 raster pointes. However, local assessment of the forest area and forest parameters is not suitable due to such a coarse grid design. Furthermore, subjective interpretation results and production-oriented uncertainty can't be avoided despite the careful training.

During the last decade, NFI research has focused on utilizing remote sensing data in forest inventory. Remote sensing data can make significant contribution to regional and global forest cover assessment. It is cost-efficient information for forest inventory and monitoring purposes(Pekkarinen,2002a). Satellite images have been widely applied in different forest inventory and monitoring tasks, e.g. estimation of forest characteristics (Lu, et al.,2004, McRoberts, et al.,2007, Tuominen and Haakana,2005), change detection (Desclee, et al.,2006, Yen, et al.,2005), etc. Haara et al.,(2002) propose a tree species classification method using semi-automatic delineation of trees on CIR (color infrared) aerial images. LIDAR (Light Detection and Ranging data) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. This technology has applications in archaeology, geography, geology, geomorphology, seismology, remote sensing and atmospheric physics. A number of studies reveal the successfully use of LIDAR-based techniques to estimate tree and stand attributes such as height, crown diameter, basal area and stem volume(Donoghue, et al.,2007, Morsdorf,2004, Naesset,1997).

There are about 7000 aerial images as well as LIDAR data covering the whole Switzerland in NFI3 which can be used for extracting forest features. These data allows the implementation of modern image processing methods and NFI may be partially automatic analyzed. In addition, the advantage of achieving reproducible and consistent result will be offered by using the available remote sensing data. Improvements are expected in areas where it is possible to replace or supplement decisions based on expert opinions, subjective interpretations, or estimation with measurable quantities.

This paper suggests an integration algorithm of high resolution aerial images and LIDAR data for the improved automatic forest boundary delineation. Image segmentation method is applied for obtaining homogeneous patterns while LIDAR data is used to remove flat area as well as buildings. The use of color and texture features extracted from the aerial images make it is possible to merge segments in a semantic way and lead to delineate forest boundary automatically.

2. MATREIAL AND METHOD

2.1 Aerial images

The true color (RGB) aerial images in our database have been made available by Swiss Federal Office of Topography (Swisstopo) with an average scale of 1:30,000. The images are oriented block by block and orthorectified with a resolution of 0.5m. The landscapes of Switzerland are very heterogeneous which can be divided into Jura, Swiss Plateau, Prealps, Alps, and South-western slopes of the Alps. Our test sites (green points in Fig.1) include mixed industry areas, agriculture areas, wines areas etc. which belong to Swiss plateau and Prealpine areas.

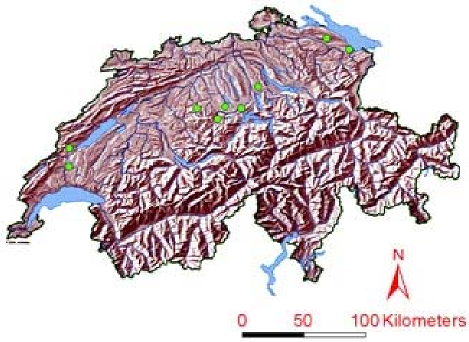

Fig. 1 Test sites

2.2 LIDAR Data

The LIDAR data was acquired between 2001 and 2004 by Swisstopo. Average flight height above ground was between 1000m and 1500m and the footprint varies between 0.8m and 1.2m. Fig. 2 shows the DTM of Switzerland where there is no LIDAR data above 2000m. Canopy Height Model (CHM) is a LIDAR-derived product for deriving relevant vegetation

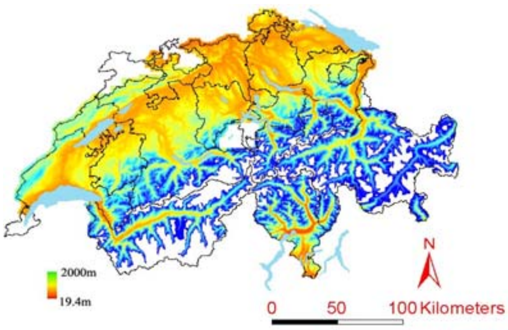

Fig.2 Swiss DTM © Swisstopo

information. From the raw data points, the Digital Terrain Model (DTM) and the Digital Surface Model (SM) is D interpolated (2.5m x 2.5m). The CHM is obtained by calculating the difference between DSM and DTM. Fig. 3 shows the DTM, DSM, and CHM of one analyzed aerial image.

Fig. 3a Aerial Image

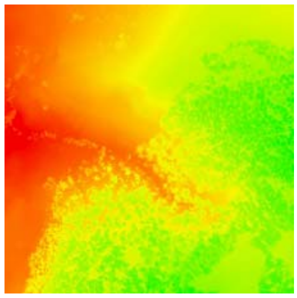

Fig. 3b DOM

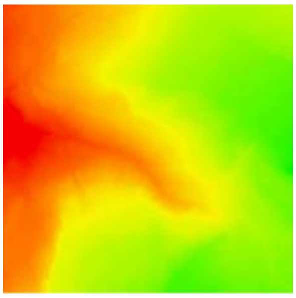

Fig. 3c DTM

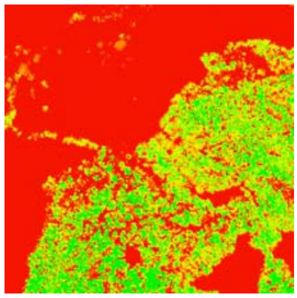

Fig. 3c CHM

Fig.3 Aerial image, DTM, DOM and CHM

2.3 NFI Sample Plot Design and Forest Definition

In the first NFI a 1km sampling grid was used. The intersections define the location of about 12'000 NFI1 sample plots in the forest. As in the NFI2 and NFI3, only half of the plots were investigated terrestrially.

As shown in Fig. 4 the NFI-specific forest definition is applied to aerial imagery in a regular 500m grid. For the terrestrial sample plots a coarse grid with 1.4km grid was chosen. The discrimination of forest and non-forest areas in aerial photographs requires an unambiguous reproducible forest definition. The used NFI forest definition is the aspects of a stocking evaluated by the following stand criteria that can be measured in the aerial photograph: width, crown coverage and dominant stand height:

· **Width:** The width of the stocked part of the interpretation area is at least 25m.
· **Crown coverage:** The crown coverage of the stocked part of the interpretation area has to be larger than or equal to 20%.
· **Dominant stand height:** The stocking has to have a dominant stand height of 3m.

For a positive forest decision the following conditions apply: The minimum width is 25m with crown coverage of 100% and the required dominant stand height. With increasing width the minimum crown coverage is allowed to decrease. The smallest acceptable threshold for the crown coverage is 20% at a minimum width of 50m.

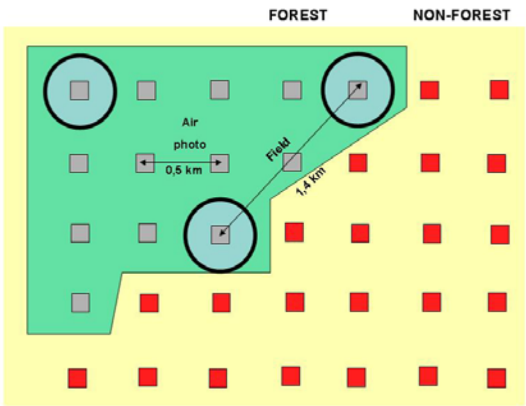

Fig.4 Swiss NFI sample design

The forest boundary line (FBL) is interpreted at each sample plot. It determines the border line between normal forest and non forest. It allows the evaluation of the forest width and forest interspaces which are needed to reach a Forest/Non-forest decision. Fig. 5 shows the forest boundary line on a convex and concave forest edge.

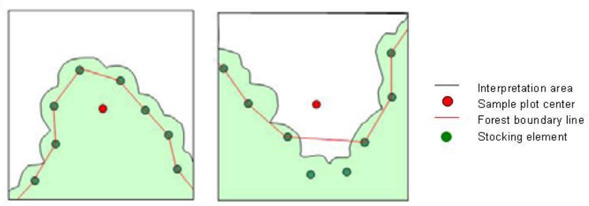

Fig.5 Forest boundary line on a convex and concave forest edge

2.4 Forest Detection with LIDAR Forest Mask

LIDAR is a well-established technique in terms of its capability of direct measurements on canopy structures (Maltamo, et al., 2004, Naesset, 2002). From the obtained CHM data, we develop a forest mask for the forest area detection. This is performed by using a moving window approach. (Fig. 6)

Fig.6 Forest mask with a moving window

Let $V_{i,j|K}$ is the pixel value in CHM within the $K \times K$ window centred at position (i, j), then according to NFI forest/non-forest definition that the tress in forest should higher than 3m as well as with 20% crown coverage, we calculate the percentage of the pixels which are high than 3m within the current window. Let T is the sum of pixels which are high than 3m, let $p = T/(K \times K)$, and if $p > 20\%$, then the current pixel at position (i, j) will belong to forest, otherwise it will belong to non-forest. At last, we shrink the edge of the results obtained from the forest mask with a small size window. Fig. 7 shows the detection result of the forest mask. (green color: detected forest area; red line: manual forest boundary)

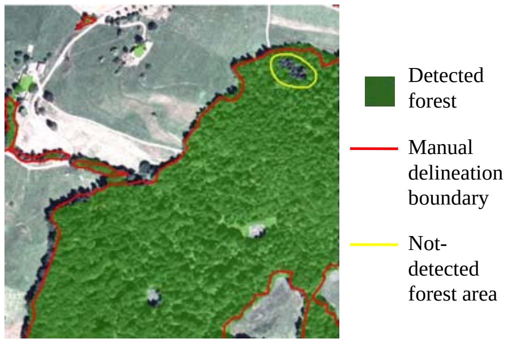

Fig. 7 Forest detection with forest mask (moving window)

However, the forest area will not be detected for low quality CHM area (area with yellow circle in Fig.7). This forest mask is not practical when the CHM is not well distributed or under certain canopy conditions.

2.5 Forest Delineation with Integration of Aerial Image and LIDAR data

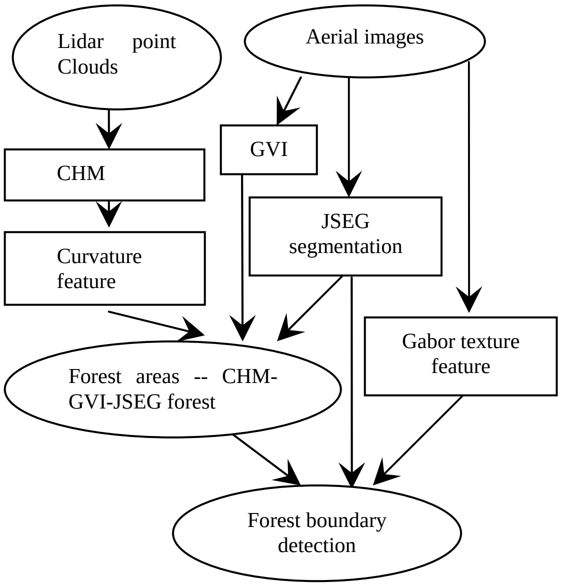

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Fig. 8 Schematic workflow of overall process

High resolution aerial images can improve efficient forest management at fine scale(J. Hyyppä, 2000, M. A. Lefsky, 2001). Benefit from the high spatial resolution of NFI aerial images, we apply JSEG (Deng and Manjunath, 2001)image segmentation method to obtain homogenous sub-areas. This method is one of the color image segmentation methods which provide robust segmentation results on a large variety of color images. From the CHM, we calculate curvature feature for building's remove. A vegetation index named GVI (Green Vegetation Index) is calculated for non-green fields removing.

Combing GVI and curvature feature with certain conditions applied into sub-areas after JSEG segmentation, we can obtain forest areas (CHM-GVI-JSEG). The comparison between Gabor wavelet texture features between CHM-GVI-JSEG forest area and sub-areas obtained from JSEG lead to successful forest boundary delineation. Fig.8 shows a schematic work flow of the overall forest delineation process.

3. EXPERIMENTAL RESULT AND CONCLUSION

JSEG has one parameter which controls the region merge process during the segmentation. In our experiments, we set it as 0 so that we can obtain over-segmented sub-areas which have more homogeneous texture pattern. Examples of the forest delineation result are shown as Fig.9a (high-lighted with white lines) while Fig. 9b shows the manual forest boundary delineation result according to NFI forest definition. (high-lighted with red lines)

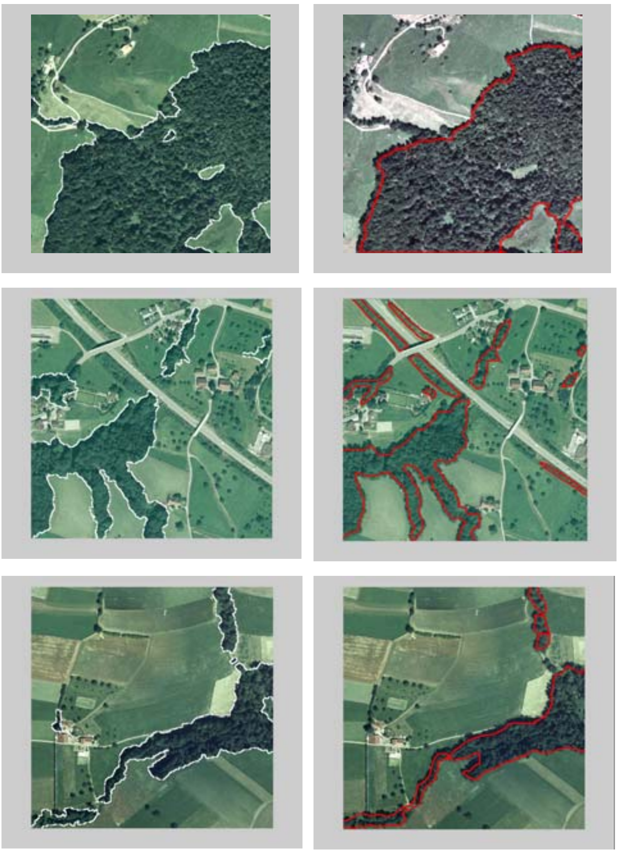

Fig. 9a Final forest Boundary derived from JSEG   Fig. 9 Manual delineation

Experimental results indicate that forest area can be distinguished by using remote sensing data, e.g. aerial images and LIDAR data. The color features extracted from aerial images remove successfully non green areas while the curvature feature extracted from LIDAR remove building areas. The comparison of texture features extracted from Gabor wavelet between CHM-GVI-JSEG forest area and sub-areas after JSEG segmentation gives the chance for detecting sub-areas with low quality CHM and lead to forest boundary delineation in more semantic way. The approach presented in this paper offers an automatic process for forest/non forest detection in Swiss NFI.

It's a challenge to describe NFI forest /non-forest definition with automatic computer-based method. For example, some temporary unstocked areas are still delineated manually as forest because their forest land-use functions. It will be difficult to interpret such kind of subjective definition with low level features extracted from remote sensing data. However, current study provides an encouraging basic for further development and testing.

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