DETECTION OF FOREST MANAGEMENT OPERATIONS USING BI-TEMPORAL AERIAL PHOTOGRAPHS

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ABSTRACT:

The increased need for timely forest information is leading to the continuous updating of stand databases. In continuous updating, stand attributes are estimated in the field following a forest operation (cutting or silvicultural treatment) and stored in databases. To determine the changes caused by forest operations and forest damage, a semi-automatic method was developed based on bi-temporal aerial photographs.

The field data consisted of 2 362 forest stands, from which the changes between years 2001 and 2004 were collected from different databases. Stands were divided into three classes according to the type of change. The *No-change* class (1 890) included stands with no changes other than growth. The *Moderate-change* class (373) included stands with changes such as thinning, partly operated stand and improvement of young stand. The *Considerable-change* class (99) included stands with major changes such as clear cutting and severe storm damage. The data were randomly divided into training and test data. The aerial photographs were acquired for the years 2001 and 2004 with almost the same image specifications and the photographs were temporally registrated. As change detection is sensitive to location errors, locational adjustments were made at the stand and segment levels. Linear stepwise discriminant analysis and the non-linear *k*-nearest neighbour (*k*-NN) method were tested in classification.

The classification results at the stand level were found to be better than at the segment level. Compared to previous studies, the results of this study demonstrate remarkable improvement in the classification accuracy of moderate changes. The results showed that change detection substantially improved when the registration at the stand level was used, especially in the detection of thinned stands.

1. INTRODUCTION

Stand attributes in Finland have been traditionally gathered by periodical field inventories with inventory cycles of 10-15 years. The increased need for timely forest information is leading to the continuous updating of stand databases. In continuous updating, a stand database is kept up-to-date computationally using statistical growth models. After a forest operation (i.e. cutting or silvicultural treatment), stand attributes are estimated in the field.

A forest operation can be reported at the time of the work, but forest damage, for example, must be determined by some other method. There are also errors that should be controlled in the databases. Medium-resolution satellite images (e.g. Landsat TM images) have been successfully used for detecting considerable changes such as clear cuttings, removals of hold-over trees, soil preparations or drastic damage. The detection of moderate changes such as thinnings, preparatory cuttings or slight damage, has been difficult (Holmgren & Thuresson, 1998; Wilson & Sader, 2002; Heikkonen & Varjo, 2004). The reason for this is that typical thinnings, where about 20-40% of the basal area is removed, cause only subtle changes in reflectance (Olsson, 1994).

The reflectance captured by a single pixel in medium-resolution images is the average of the reflectance from an area of more than 100 m^2 on the ground. However, with high-resolution remote sensing materials, the disappearance of individual trees can be detected. For example, using data from airborne laser scanning (ALS), Yu et al. (2004) found 61 of 83 harvested trees. However, ALS is very expensive compared to aerial photography.

Operational high-resolution applications for change detection of vegetation cover are based on the visual interpretation of aerial photographs, although more automatic methods have also been proposed. Hudak and Wessman (1998) investigated a transition from grassland to shrubland using historical aerial photographs. The images were classified using variograms that characterised the image texture. Changes were determined by post-classification comparison. Kadmon and Harari-Kremer (1999) also studied vegetation dynamics using pixel-level spectral classification and then averaging the results to larger cells and differencing the cell values. In both studies, good results using automatic change detection were achieved; but compared to the context of the present study, the time-intervals were much wider and the changes more radical. In the study of Saksa et al. (2003), clear cuttings were detected using three approaches: pixel-by-pixel differencing and segmentation, pixel block-level differencing and thresholding, and presegmentation and unsupervised classification. Each method was found to be suitable for operational use. Hyppänen (1999) applied image differencing to bi-temporal aerial photographs. In that study, considerable changes were detected while moderate changes were not. Consequently, the problem of how to detect moderate changes automatically using aerial photography has remained unsolved.

In automatic change detection, the effect of disturbing factors should be minimised. These factors include differences in atmospheric conditions, sun angle, soil moisture, vegetation phenology and, in the case of aerial photographs, the differences in viewing angles (Singh, 1989). It is important to eliminate factors that might cause differences between similar stands in different parts of the images. By using the present satellite positioning systems, aerial photographs can be taken very close to each other at different times.

The objective of this study was to investigate whether bi-temporal aerial photographs taken with similar image specifications and adjusted at stand and segment levels are useful in change classification, especially in detecting moderate changes such as thinnings.

2. MATERIAL AND METHODS

2.1 Material

The study area is located in Western Finland near the town of Kauhajoki (22°18' E, 62°24' N). The forest holdings are mainly privately owned and are in a so called "stripsharing" configuration so that the holdings are usually long and narrow. The landscape of the area is dominated by flat terrain. The elevation varies between 125 and 185 m above sea level. The main tree species are pine (*Pinus sylvestris* L.) and spruce (*Picea abies* (L.) Karst.). The main broadleaved species are silver birch (*Betula pendula* Roth.) and pubescent birch (*Betula pubescens* Ehrh.) There are also several low-density stands in the study area. The main site types are fresh (26% of the area), dryish (42%) and dry (25%). The site types are according to Kuusela and Salminen (1969) and the fertility of peatlands is determined and classified using the same system as that for mineral soils (Laine & Vasander, 1993).

The field data consists of 2 362 forest stands. The stand attributes were measured during summer 2002 based on a visual stand level inventory system that is used in Finland. In this system, the stands are initially delineated by visual interpretation of aerial photographs. The forest characteristics of the stands are then estimated visually with the aid of some measurements in the field, and the initial delineation is confirmed.

The changes in stands between 2001 and 2004 were determined from different databases of the Regional Forest Centre and all stands were checked visually using bi-temporal aerial photographs. The uncertain cases were checked in the field. Subsequently, all stands were divided into three classes according to the type of change. The *No-change* class consisted of stands with no changes other than growth (1 890 stands). The *Moderate-change* class consisted of stands with moderate changes (373 stands), i.e. thinning, seed tree felling, tending of seedling stand, improvement of young stands, removal of hold-over trees, soil preparation, slight storm damage, partly operated stand and forest road building. Slight storm damage means that storms have felled only few trees in the stand. The *Considerable-change* class consisted of stands with major changes (99 stands), i.e. clear cutting and severe storm damage. Severe storm damage means that storms have felled many trees or groups of trees in the stand.

The image data consisted of two aerial photographs covering the study area. The latter photograph was taken as close to the former one as possible with respect to time, date and location (Table 1). The photographs were acquired using a Leica RC30 camera and an antivignetting and an infrared radiation filter. The nominal scale of the color-infrared photographs was 1:30 000. The photographs were first scanned with a photogrammetric scanner at 14 μm resolution into RGB-images with no tone adjustment. Secondly, the images were ortho-rectified to a spatial resolution of 0.5 m by using 11 (photo01) and 13 (photo04) control points that were located from digital base maps and a digital elevation model. The digital elevation model had a resolution of 25 m. The root mean square errors (RMSEs) of the rectification were 5.1 m (photo01) and 3.2 m (photo04). These photographs were used as base photographs for the extraction of spectral features.

	Aerial photograph	
	photo01	photo04
Latitude	62.4127	62.4125
Longitude	22.3045	22.3016
Altitude (m)	4,751	4,622
Date	23 June 2001	27 June 2004
Time (UTC)	7:55:58	7:29:06
Course	271	271
Solar azimuth angle (^{o})	52.8	60.2
Solar azimuth angle (^{o})	42.8	40.1

Table 1. The metadata of the aerial photographs

2.2 Methods

As change detection is sensitive to location errors, the final adjustment of the aerial photographs taken at two time points was based on statistical correlations that were computed independently for each stand and segment. The geographic location of the new photograph was determined by shifting the location at the photograph to one of the cardinal points one pixel at a time. The search range was ten pixels from the original location and covered 21*21 pixels. At each location a Pearson's correlation coefficient was computed for the digital number values (DNs) of the pixels that referred to a given area after the shift. Pixels on the buffer zone in the new photograph and pixels that were outside the stand (segment) boundaries in the old photograph were not taken into account. The width of the buffer zone was ten pixels from the stand (segment) boundary. The location that resulted in the largest correlation was selected. The process was repeated for each of the channels. A stand might not be the most suitable unit for change detection because some changes may occur in part of the stand only. Change detection was therefore also carried out at the segment (=sub-stand) level and results were adjusted to whole stands. In the segmentation procedure, the most recent aerial photograph was segmented based on the DN values of the three channels and the stand boundaries. With the help of the stand boundary, the segment was attached to the area of one stand. In the other words, the segment boundary did not cross the stand boundary (Figure 1).

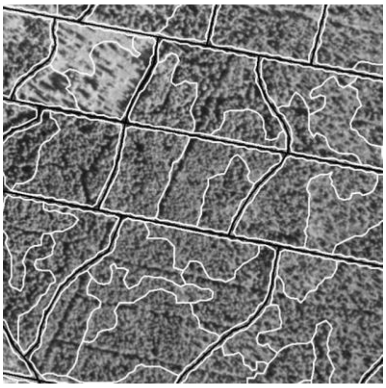

Figure 1. Stand (black) and segment (white) boundaries in aerial photograph (near-infrared channel). Copyright for the aerial photograph owned by Blom Kartta Oy

Altogether, 9 156 segments were used. The segmentation algorithm was same as in the study of Hyvönen et al. (2005).

Altogether, 75 features both at the stand and segment levels were extracted, of which 36 were spectral features extracted from the original photographs and 39 were features from the adjustment of and regression between the photographs. These features were used in the change detection analysis.

Two different methods for change detection were tested; linear stepwise discriminant analysis and the non-linear *k*-nearest neighbour (*k*-NN) method. The classification functions of the discriminant analysis and the weights of the variables of the similarity distance functions, as well as the number of the neighbours of *k*-NN method, were estimated for the three change classes in the training data. The multi-objective optimisation, combined with the *k*-NN method, was used to choose the weights of the variables of the similarity distance functions, as well as the number of the neighbours of *k-NN* method (Haara, 2000). The nonlinear programming algorithm presented by Hooke and Jeeves (1961) was used to find the combination of decision variables that minimised the objective function. The optimised objective variable was the sum of the Kappa value and the percentage of correctly classified *moderate-change* stands. Both methods, i.e. the estimated classification functions of the discriminant analysis and *k*-NN method with the training data as the reference data, were then applied to the test data. The accuracy of the classification was studied at the stand level.

The accuracy of the classification results was evaluated by means of confusion matrices (Campbell, 1987) and the overall (OA), producer's (PA) and user's (UA) accuracies were calculated (Congalton et al., 1983; Story & Congalton, 1986). The OA can give too optimistic results if the proportion of one class is high (Campbell, 1987) and for this reason the κ (kappa) coefficient was calculated (Congalton & Mead, 1983).

3. RESULTS

When stands were used as classification units, the overall accuracy of the discriminant analysis was 91.1%, the Kappa-value 0.74, the omission error 16.1% and the commission error 7.2% (Tables 2 and 6). The main interest concerned thinned stands, of which 90.7% were found. When segments were used as classification units and the results were studied at the stand level, the overall accuracy of the discriminant analysis was 90.1%, the Kappa-value 0.71, the omission error 13.8% and the commission error 8.8% (Tables 3 and 6). Of the thinned stands 89.7% were found.

When using the *k*-NN method, the overall accuracy was 91.5% and the Kappa value was 0.72 (Tables 4 and 6). The proportion of correctly classified thinned stands was 82.5%. When the classification was done at the segment level, the stand wise overall accuracy was 86.6% and the Kappa value 0.62 (Tables 5 and 6). In this case, 86.6% of the thinned stands were found.

After rectification (at the image level) 12 stands had been moved more than 5 pixels in every channel in the direction of x and 18 stands in direction of y in the final adjustment between the aerial photographs. Only one stand of these was in the *No-change* class.

	Estimated		
Observation	No-change	Mod.-change	Con.-change
No-change	874	68	0
Mod.-change	35	139	0
Con.-change	0	0	44

Table 2. Classification results of the discriminant analysis at the stand level, stands as a priori classification units.

	Estimated		
Observation	No-change	Mod.-change	Con.-change
No-change	859	83	0
Mod.-change	30	144	0
Con.-change	0	2	42

Table 3. Classification results of the discriminanat analysis at the stand level, segments as a priori classification units.

	Estimated		
Observation	No-change	Mod.-change	Con.-change
No-change	900	40	2
Mod.-change	52	121	1
Con.-change	1	3	40

Table 4. Classification results of the *k*-NN method at the stand level, stands as a priori classification units.

	Estimated		
Observation	No-change	Mod.-change	Con.-change
No-change	834	107	1
Mod.-change	41	130	3
Con.-change	0	3	41

Table 5. Classification results of the *k*-NN method at the stand level, segments as a priori classification units.

	Kappa	OA%	OM%	CM%
disc., stand	0.74	91.1	16.1	7.2
k-NN, stand	0.72	91.5	24.3	4.5
disc., segment	0.71	90.1	13.8	8.8
k-NN, segment	0.62	86.6	18.8	11.5

Table 6. Classification results of the discriminant analysis (disc.) and the *k*-NN method (*k*-NN) at the stand level. stand: stands as classification units, segment: segments as classification units. OA%: overall accuracy, OM%: omission error, CM%: commission error.

4. DISCUSSION

A semi-automatic method for change detection in boreal forests using bi-temporal aerial photographs was developed. The photographs were taken as close to each other as possible with respect to time, date and location. The change detection was tested at the stand and segment levels.

Considerable changes were classified, at best, without error. The results of moderate changes were also clearly better than achieved by some earlier studies (Saksa et al., 2003; Haapanen & Pekkarinen, 2000). The use of correlation coefficients for image matching at the stand level and in the classification together with other spectral features was considered to be the key element in obtaining the good results.

The use of the *k*-NN method with multi-objective optimisation was also found to be very effective for detecting changes at the stand level. The large number of possible features in the distance function requires an efficient algorithm for determining the optimal formula of the distance function. Furthermore, the definition of the formula of the objective function is crucial for achieving the optimal solution. For example, when the Kappa value was the only objective variable in the optimisation, the Kappa value of the classification of the reference data was same as in the discriminant analysis. However, the classification results of the *Moderate-change* class were then considerably worse.

In practice, obtaining aerial photographs with the same spatial specification is not a problem. Nevertheless, in Finland, weather conditions limit the number of suitable days for aerial photography. Weather conditions may therefore complicate the acquisition of photographs with similar temporal specifications and thus limit the operational use of the method. In this study, photographs with similar specifications were obtained, which enabled an exploration of how reliable change detection is when using the bi-temporal aerial photographs in nearly optimal conditions. Even where bi-temporal aerial photographs are taken at identical locations, the time difference may play an essential role; the shadows of the treetops move several metres in a rather short time. If these shadows are captured in both images, on the ground or some other way, the rectification adjustment based on DNs correlations, might move the stands so that the shadows are matched. Thus, the real objects might not be matched in the best possible way and the classification results would then be questionable. The effect of shadow movement was also noticed in the study of Im and Jensen (2005).

There are some issues that require further study. First, one image-pair may not be enough to cover the area of interest. The mosaicking of images introduces error, which must be quantified in further studies. Secondly, another source of error is the practical training data from operational databases, which, as noted in this study, contain incorrect operations. Thirdly, the method studied should be tested with diverse image material, for example, with images taken with no-optimal image specifications and with images digital by origin. Fourthly, the use of texture features in the classification, together with stand level rectification, should be studied. Tuominen and Pekkarinen (2005) and Hyvönen and Anttila (2006) found that the use of textural features is advantageous in estimation and classification procedures. The effect of different methods of classification on the accuracy of the estimation should be studied. Heikkonen and Varjo (2004) found that nonparametric classification methods worked better than the parametric method tested here. With a maximum likelihood classifier there was a strong tendency to over classify the *Moderate-change* class, as was also the case in this study.

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