SEMI-AUTOMATIC IDENTIFICATION OF REVISION OBJECTS IN HIGH RESOLUTION SATELLITE DATA

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ABSTRACT

The methodology for topographic map revision is changing. With the storage of topographic maps in digital databases, maps can be produced "as required". To ensure production of maps which are accurate and complete, the databases must undergo continuous revision. A hierarchical system for topographic database revision, based on multiple resolution satellite data, is envisioned. Medium resolution data, for example from the RESURS satellite, would be used for initial change detection and signalling, while high resolution imagery, such as SPOT panchromatic data, would be used to identify and possibly delineate new objects in those areas where changes have been detected. The development is currently focused on the forested parts of Sweden (> 60% of the country), and revision objects under consideration are new roads and clear-cuts. A rule-based methodology for identification of revision objects in SPOT Pan images is under development. The rules are made "soft" by the application of fuzzy logic. Existing map data helps in differentiating between new objects and objects which have been previously mapped. In the test area, roads have been successfully detected based on spectral reflectance and shape. New clear-cuts have also been detected, although with some confusion with other objects. Further development of the rules is ongoing.

1. INTRODUCTION

The methodology for topographic map revision is changing. Until now map sheets have been revised regularly, e.g. with five or ten year intervals. After revision, new maps were printed and distributed. With the storage of geographic information in databases it is no longer the maps that need revision, it is the databases. In a situation where maps are being produced "as-requested" from a database it is of importance that the database is continuously updated.

The National Land Survey of Sweden (NLS) is responsible for the topographic mapping of Sweden. The topographic maps of scale 1:50,000 are stored in a digital database: "Geographical Data for Sweden" (GSD). The database is organized by map sheet. At present there are 619 topographic map sheets which cover most of the country, except for some of the northern parts. The latest version of the topographic map (the so called T5-version) is more detailed than previous versions, particularly in forested areas, where it includes, for example, rock outcrops, wetlands, tracks and clear-cuts. Approximately 1/4 of the topographic map sheets in Sweden are of this new type, and the upgrading of older sheets to T5 is ongoing.

Once completed, the T5 database will require continuous revision. Three main types of revision objects will be regarded; clear-cuts, roads and urban development. Entirely new features as well as extensions of existing features will be considered.

Development and implementation of cost-efficient methods for operational revision of the T5 map database is of highest priority to the NLS. For this reason, the NLS and the Swedish National Space Board have initiated a programme for "Topographic map revision from remote sensing data". Within this programme methods for semi-automated database revision are being developed at the Dept. of Geodesy and Photogrammetry, Royal Institute of Technology in Stockholm.

The programme is currently focused on semi-automated methods for revision in forested areas. The chances of successful automation are expected to be higher here than in areas of more complex landuse. Since more than 60 % of the country is covered by forest, automation of this part would mean a significant contribution to the cost-effectiveness of the revision process. In addition, two out of the three object types which are considered to be of interest for revision of the T5 maps are more or less linked to forests. (Logging roads are the most commonly "constructed" roads in Sweden).

This paper presents a semi-automatic rule-based method for detection and identification of forest revision objects for the T5 topographic maps from SPOT Pan images. In addition, a framework for operational revision of the nation-wide topographic map database from multi-resolution satellite data is briefly discussed.

2. OPERATIONAL REVISION OF MAP DATABASES

2.1 Map revision from satellite data

The revision objects under consideration (new roads and clear cuts) are characterized by strongly contrasting spectral characteristics to the surrounding forest. Previous studies have proved that it is possible to visually detect and identify the revision objects from as well Landsat TM, SPOT XS and SPOT Pan (e.g. Ahern and Leckie, 1987; Pilon and Wiart, 1990; Malmström and Engberg, 1992; Olsson and Ericsson, 1992).

It has been shown that panchromatic (SPOT Pan) and multi-spectral (SPOT XS) satellite data are just as suitable as aerial photographs (9,200m) for detection and identification of roads and clear-cuts (Malmström and Engberg, 1992). SPOT panchromatic data has also been extensively used for topographic map revision in developing countries, where it has been the only economically viable alternative for their extensive revision needs.

Approximately 175 SPOT scenes are required to cover Sweden. But changes do not occur everywhere at once, and high resolution data may only be required for accurate identification and delineation, and not for initial detection. Features with a strong contrast to the background are detectable even when they are many times smaller than the size of a pixel. Therefore, it is likely that new clear-cuts and roads will initially be detectable from lower resolution imagery.

A hierarchical system is envisioned where medium-resolution data, for example from the new RESURS-satellite, is used for initial detection and signalling of potential changes, followed by identification and possibly delineation in SPOT Pan. RESURS has a spatial coverage of 600 x 600 km and only 3-4 images would be required to cover the country. Large coverage and high repeat coverage (3-4 days) makes RESURS potentially very useful for monitoring purposes. Successfully implemented, the hierarchical approach would efficiently concentrate the use of high-resolution data to those areas where changes are known to have occurred.

2.2 Methods for detection and identification of revision objects

In forested areas, recent clear-cuts and roads contrast strongly to the forest itself and change detection can be based on spectral characteristics alone, focusing on spectral anomalies. For identification however, the spectral anomalies are not sufficient. For example, roads, clear-cuts, and rock outcrops all have similar spectral characteristics, and other information is required to distinguish between them. In visual image interpretation, factors such as shape and context are important for correct identification of revision objects. Existing map information is used to distinguish between old and new objects of the same type. Additionally, the human vision system has an ability to generalize and recognize patterns that are only partly visible. It is for example possible to visually recognize a road even if only sections of it are clearly detectable in the image.

In automated image classification, other types of data (thematic or geometric) are often included in the classification, when identification of land use categories on the basis of their spectral characteristics becomes difficult. Such landuse identification is based on knowledge about the relationships between the landuse categories and the different ancillary data sources. The ancillary data, e.g. digital elevation models and digital maps of soil and geology, and knowledge are combined with spectral information, derived form the imagery. Relationships must be known (or hypothesised) and inferred via, for example, an expert system engine (Middlekoop and Janssen, 1991). The knowledge is commonly based on more or less complex rules. These may be simple Boolean rules of the type IF <condition> THEN <conclusion>, but there are also examples where much more complicated rules are used. Recent expert system development for image interpretation includes compact and transparent rules, natural language interfaces, inclusion of fuzzy membership functions, and symbolic approaches imitating human aerial photo interpretation (Leung and Leung 1993; Srinivasan and Richards, 1993; Wang, 1994; Dymond and Luckman, 1994).

Rule-based classification methods have one clear advantage over statistical image classification techniques; it is possible to mix data from different sources, which have different properties. The strict requirements on Gaussian normal distribution, which form the basis for the Maximum Likelihood algorithm, do not apply to rule-based classification. Another advantage with knowledge based methods compared to other classification methods is the high transparency. Spatial factors, such as size and shape of connected pixels (regions) or connectivity of one region to another, can be included in rule-based systems (e.g. Mehldau and Schowengerdt, 1990; Johnsson, 1994).

When interpreting an image, qualitative linguistic values are often used. Fuzzy sets can be used to mathematize these linguistic values. Fuzzy sets have been used in remote sensing for image interpretation and image classification (e.g. Gopal and Woodcock, 1994; Wang, 1994).

Using classical set logic each individual pixel either belongs entirely to a given class or does not belong to it at all. The underlying assumption for fuzzy set theory is that the transition from membership to non-membership is seldom a step function. In fuzzy logic the concept of partial membership of an element is used (Zadeh, 1965). A membership function which decides the degree to which the pixel belongs to the given class is calculated for each pixel. The function takes on values between 0 and 1, where 0 means fully outside and 1 means fully inside the class.

Different types of functions can be used to express membership; for example sigmoidal, linear and J-shaped functions. Linear membership functions are used for all the rules in this study (e.g. Centeno and Haertel, 1995). Figure 1 shows the linear membership functions for three classes, namely low, medium and high spectral reflectance. Pixelvalues in overlapping regions between two classes will have a partial membership in both. The membership values are determined by the functions.

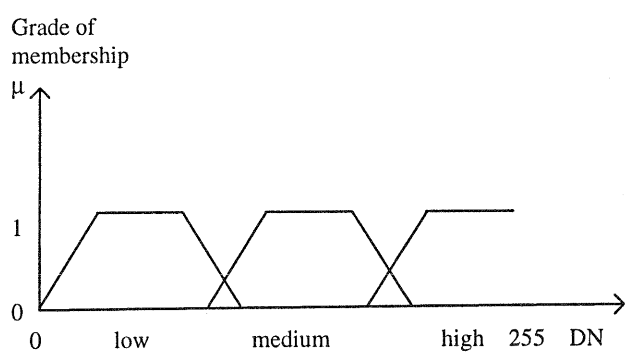

Figure 1. Linear membership functions for low, medium and high spectral reflectance

3. INVESTIGATION METHODOLOGY

3.1 Study area and investigation data

The study area is located in central Sweden and is almost entirely covered by coniferous forest. Logging is intensive in the area. The entire study area corresponds to the topographic map sheet Ljungaverk 17G NV and covers 625 km^2. A forested test area of 33 km^2 , including several new clear-cuts and roads was selected for this study. The test area includes a few lakes and marshes and some old roads and clear-cuts. The elevation ranges from around 250 to 475 m. above sea level.

The SPOT panchromatic scene was recorded on August 13, 1995 and has been radiometrically and geometrically corrected (to the Swedish national grid) The registration angle was 5.24 degrees towards east (figure 2).

Figure 2. SPOT Pan image of the study area. Forest and water bodies are dark, while clear-cuts of different age, roads and wetlands are grey-white.

The topographic map is available in digital form from NLS. It is based on aerial photos from 1992 and field work from 1993.

The Geographic Resource Analysis Support System (GRASS; US CERL, 1993) in conjunction with programs written in C have been used in the study. GRASS is a raster based geographic information system which includes some basic image analysis capabilities.

3.2 Identification of revision objects

The identification of revision objects is based on characteristics which describe the objects in terms of spectral, spatial and contextual properties. The object descriptions are translated into rules which serve as the base for identification. The rules are of the form IF <condition> THEN <conclusion>, where the condition often includes vague statements such as "the spectral reflectance is high", and fuzzy logic is applied in order to translate the statements into mathematical terms.

Example roads

In addition to high spectral reflectance the shape of a road is important to separate it from other revision objects. These two characteristics were used to construct a rule which describes the revision object *road.* Each important characteristic, or factor, is seen as a class to which the membership for each pixel in the image should be evaluated. Additionally, the pixels are compared to the existing map to avoid detection of previously mapped roads. The following rule was used to identify roads:

IF high_spectral_reflectance
ANDIF line_shaped_and_thin
ANDIFNOT existing_road
THEN new_road.

Before it is possible to determine what "high spectral reflectance" is, the typical spectral reflectance of forest in this image and this area must be known. The median value for the image was computed as an approximation of the typical spectral characteristics of forest. No other land use type besides forest exists within the test area, and the approximation is based on the fact that the forested area is considerably larger than the area covered by water, clear-cuts, roads, rock outcrops etc.

Membership functions for the two first factors in the rule were calculated. Two map layers showing membership values in each pixel for *high_spectral_reflectance* (figure 3) and *line_shaped_and_thin* (figure 4) respectively, were created .

The membership functions were calculated in the following manner:

$$\mu(\text{high\_spectral\_reflectance}) = \begin{cases} 1 & \text{for } x > \max \\ \dfrac{x - \min}{\max - \min} & \text{for } \min < x < \max \\ 0 & \text{for } x < \min \end{cases}$$

where min = (median + 0.5 * standard deviation)
max = (median + 2 * standard deviation)

(cf. Wang 1994).

The thresholds (min and max), expressed in standard deviation from median in the formula, were estimated based on grey values in recent (unmapped) clear-cuts. Small changes of the factors used for multiplication of standard deviation (0.5 and 2) did not significantly affect the membership values.

All deviating pixels (i.e. the pixels with a membership function larger than 0) in the created layer were considered as candidates for identification both for clear-cuts and for roads.

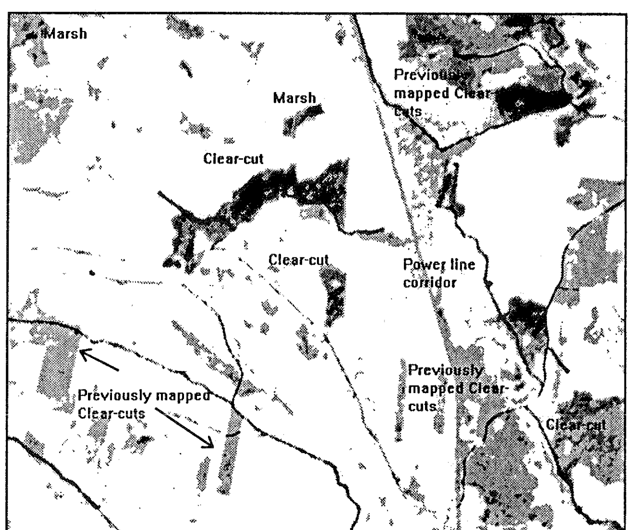

Figure 3. Membership values for fuzzy statement "high spectral reflectance". Dark areas have membership values close to 1. Bright areas have values close to 0.

The second part of the rule for road identification is based on the shape of roads. Different directional filters were used to enhance linear features in the SPOT image. The filters were constructed to enhance vertical, horizontal and diagonal lines. Four new raster layers, one for each direction, were created by filtering. The information in these four layers was combined and a raster layer showing linear features in four different directions was created.

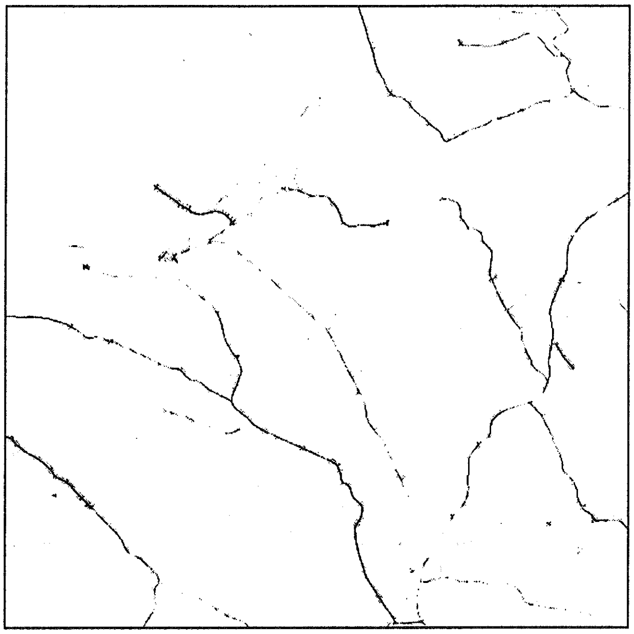

Figure 4. Membership values for fuzzy statement "line shaped and thin". Roads have membership values close to 1, and appear dark in the image.

A second membership function was defined for the class *line_shaped_and_thin* , based on the pixel values in the layer with linear features. The membership function was defined in the same way as for *high_spectral_reflectance,* using median and standard deviation. However, the minimum and maximum values for this map layer were set according to:

min = (median + 3 * standard deviation)
max = (median + 6 * standard deviation).

The two resulting layers are fuzzy sets. The logical AND operator defines an intersection between these two fuzzy sets (*high_spectral_reflectance* and *line_shaped_and_thin*). In fuzzy logic, the AND operation corresponds to the minimum value in the fuzzy sets. Thus, in the combination of the layers, each corresponding pixel in the two layers was compared and the one with the lowest value was chosen to obtain a map layer showing membership in the class *road* (e.g. Eastman 1993, Altman 1994). As a final step, a mask based on the topographic map was used to exclude previously mapped roads.

Example clear-cuts

The rule for identification of clear-cuts was constructed in the same way as the rule for roads:

IF high_spectral_reflectance
ANDIFNOT road
ANDIFNOT existing_clearcut
THEN new_clearcut

Here, the combination of map layers is based both on the logical AND operator and the NOT operator; corresponding to the complement of the fuzzy set for roads, and the minimum value of this complement and the membership value for high spectral reflectance. Finally, previously mapped clear-cuts were masked out to limit the confusion between old and new clear-cuts.

4. PRELIMINARY RESULTS AND DISCUSSION

The preliminary results are promising. Five known new roads were clearly detected, with practically no confusion with other objects of similar spectral characteristics (figure 5). The new roads are detected with membership values close to 1. Most of the old roads are also detected, but their membership values are lower. Since a mask was applied the fact that older roads are also detected is not a problem, but implies some robustness in the method. In the final map layer the new roads are clearly identified and the confusion with other objects is negligible; few pixels were incorrectly identified as roads.

In this dataset, the statement "line_shaped_and_thin" has more influence on the result than the statement "high_spectral reflectance". Almost exactly the same result was obtained from the single statement as from the two statements combined. The importance of different parts of the rules would, however, change from area to area. If, for example, there was a river present in this area, that too would be "line_shaped_and_thin" but it would have "low_spectral_reflectance".

Figure 5. Result from the rule for extraction of new roads. 5 new roads have been detected. The road pixels have membership values close to 1, and appear dark in the image.

Three new clear-cuts were successfully identified and the confusion with older clear-cuts was avoided by application of the mask (figure 6). The membership values differ between the three clear-cuts. The two northern ones mainly have membership values between 0.8 and 1, while the clear-cut in the south-east has significantly lower values, mostly between 0.3 and 0.5. However, even without mask they are clearly separated from older clear-cuts, for which the membership values range between 0.1 and 0.3, with a few exceptions. There is more confusion between new clear-cuts and other objects than between new roads and other features. Visual comparison with the topographic map indicates that most of the other areas with high membership values are marshes. The image was registered in August, at the end of an extremely dry summer, which would explain the bright reflectance from these areas. There is most likely no water in the marshes and the vegetation is dry and partly woody. In the future a forest mask will be used, which will exclude not only old clear-cuts but also marshes, and rock outcrops.

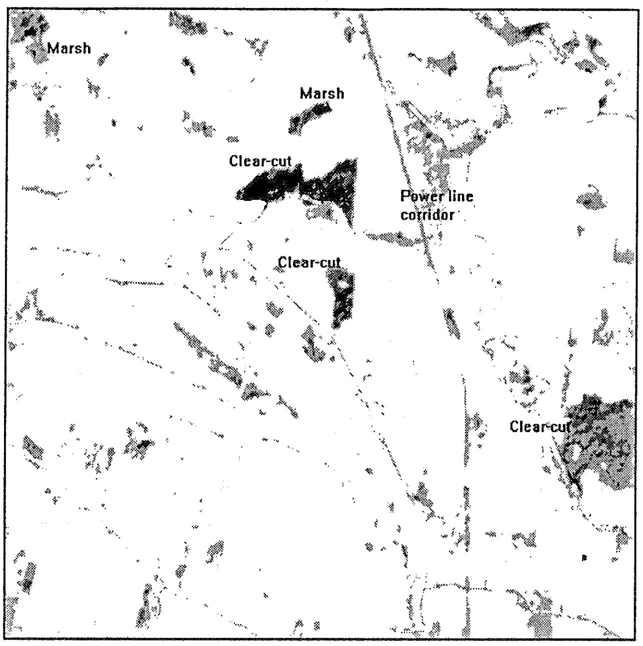

Figure 6. The result from the rule for extraction of new clear-cuts. Three known clear-cuts were detected. The pixels in these clear-cuts have medium to high membership values. Erroneously included areas mainly correspond to dry marshland and a powerline corridor. Further processing is required to remove these errors. These areas mostly have medium fuzzy membership values.

A power line corridor runs through the area from north to south and is clearly visible in the data layer showing areas with high spectral reflectance (figure 4). It is also present in the map layer with clear-cuts, but it has low membership values (figure 6). It was not identified as a road since the filters which were used to enhance linear features were constructed to detect thin linear objects. However, powerlines are also present in the T5 map and masking will consequently help solve this problem.

The difference in spectral signatures, and membership values, between the new clear-cuts indicates the need of some ancillary data for identification purposes. The age of the clear-cuts is the same, but they face different directions which might explain the difference. A digital elevation model will be available later in the project, and it will be possible to use factors like slope and aspect for identification. Some other spatial and contextual factors which will be tested are:

- size and shape of individual regions
- existence of straight line segments that make up the border of the region
- the spatial distribution of several adjacent regions
- closeness to existing roads/clear-cuts.

Inclusion of these factors will limit the risk of confusion between, for example, clear-cuts and previously undetected marshes, and make the identification more robust. Naturally the rules will become more complicated when the number of factors is increased. However, the rules should still be constructed in a clear and simple way to keep the transparency high. They should be generally formulated, and they should not be scene specific.

The major advantage of using fuzzy membership is the ability to formulate "soft" decision rules. No "hard" decisions are made at an early stage of the analysis process, and thus the risk of omitting pixels that potentially belong to a revision object is reduced. The confidence in an identification is represented by the combined fuzzy membership values from separate statements. The fuzzy membership values will also be useful for delineation of revision objects, since connected pixels with varying membership values can be allowed to form an object. The possibilities of deriving an accurate object boundary is thought to increase this way. Iterative changes of the borders are possible, based on different degree of membership.

5. CONCLUSIONS

This study has shown that a rule based approach can be used for detection and identification of map revision objects (roads and clear-cuts) for the topographic map of scale 1:50,000 (T5-version), from SPOT panchromatic data. The application of fuzzy logic in the rules results in a more flexible detection of potential revision objects, than does classical set logic.

The detection of new roads was successful, with negligible confusion to other objects of similar characteristics.

The detection of clear-cuts was, at this stage, almost entirely based on spectral reflectance and, as in traditional image classification, there was some confusion with other, similar objects. When the rules are extended to include a larger number of factors, the identification procedure will be more clearly separated from ordinary classification, and this type of problem may be avoided. The T5 map will also be used for masking to a larger extent in the future.

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