Semi-Automatic Revision of Topographic Maps from Satellite Imagery

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Abstract

The Norwegian Computing Center has in collaboration with The Norwegian Mapping Authority developed a semi-automatic prototype system for revision of some features in 1:50.000 topographic maps based on pattern recognition in SPOT satellite imagery. The system generates a proposal for new roads and new urban areas. Change detection is performed in two main steps: In the first step the unrevised digital map is used for detection of unchanged features in the imagery. In the second step, the features recognized in the first step are removed from the segmented data, and the new objects are detected from the rest of the features. The revision result is used for updating the map data base for production of "satellite revised maps". A satellite revised map is proposed as an intermediate map between the aerial photo based map revisions each 10th to 15th year.

1. Introduction

With a map revision cycle of 10-20 years for the main topographic map series (1:50.000) in Norway, the mapping organizations have been interested in trying to develop a semi-automatic map revision system based on satellite imagery. Our idea has not been to replace airphoto based map revision, but to supplement it with satellite imagery based map revision between the airphoto based revisions. The product could be "satellite revised" maps, published two to four times more often, with changes based on the satellite data printed in e.g. other colours to indicate the greater uncertainty with these changes.

The project started in 1988 as a joint venture between the Norwegian Computing Center (NR), the Norwegian Mapping Authority (NMA), the Ministry of Defence's Cartographic Department, and the Royal Norwegian Council for Scientific and Industrial Research (NTNF). The main part of the development has been performed at NR complemented with testing and some hardware dependent development at NMA. Revision of the road network and urban areas have been given preference since these features change most rapidly.

2. System Overview

The satellite imagery interpretation is divided into two main functions, map-guided detection of old features and non-guided interpretation of new features. The results from the first part are used to remove the old features from the image to determine which features can be new. The result from the second part can and should be visually controlled and edited before the features are converted to vector format to update the database.

The model for the general system design is shown in figure 1. On the far left, satellite images are stored in a database from which they are read into the preprocessing module. It is assumed that the images already have been radiometrically and geometrically corrected. The main function of the preprocessing module is to use segmentation methods for extracting structural objects, such as segments of roads or built-up areas, from the satellite imagery. In order to guide the segmentation process digital map data is extracted from the cartographic database. The structural objects which are recognized are normally line-like or region-like in shape according to the type of information which one wants to obtain from the satellite image. For example, if one is interested in updating roads, then one would use a segmentation method which extract line features, whereas for updating built-up areas, a method which extracts regions would be used

The core of the system is the image interpretation module. The basic information used in the module is (1) the result of the segmentation, (2) the original image, and (3) the old map represented in a raster format. The main function of the module is to use this basic information in order to identify new and changed map features, and to make proposals for revision. During execution, the user will see on the screen which map features the image interpretation module has identified as those which already exist on the old map, and those which are different from those on the old map. As features are identified, they are drawn on the screen, and different colours are used to indicate whether a feature is unchanged, changed, removed, or new. Because of the complexity of satellite imagery, it is important that the system indicates where uncertainties have arisen during the image interpretation phase. For example, the system may not be able to identify with certainty a particular linear feature, if the feature is in a noisy part of the image. These indicators can then help the operator when he is checking the result of the image interpretation.

The map manipulation module is connected to a cartographic database where map data are represented in a vector format. This module takes the map data from the area of interest and converts them to a raster format before sending the map to the image interpretation module. After image interpretation the proposals for map revision are returned to the map module so that the operator can check the result and make changes if

Figure 1. Main design of the prototype system.

required. When making these changes, the operator uses editing functions similar to those found on most digital mapping systems. The final revised map is then used to update the cartographic database.

In Norway, the map features for which there is the greatest requirement for revision are: roads, built-up areas, forested areas, and power lines. In this project, it has been decided to concentrate on roads and built-up areas.

3. Map-guided Detection of Old Objects

The old unrevised map is here used to guide the interpretation process. The relevant map features are converted to an internal raster format. Raster format is a more suitable representation of the map than vector for our applications, especially because the spatial relations are represented in a direct way as in the satellite imagery. Some information is built into the raster points, e.g. pointers to the neighbour points for each road raster point.

3.1 Roads

Roads are typically line structures with higher reflectance in the visible part of the electromagnetic spectrum than the surrounding environment, at least when the surrounding environment is covered by vegetation. We have found two suitable algorithms for the extraction of brighter lines on a darker background: "Original Minus Median" (Graça 1987) and "Template Matching" (Wang & Howart 1987).

The idea behind the first method is that the median filter suppresses singular and one dimensional structures, i.e. points and very thin lines. Accordingly, an image made by subtracting the smoothed median filtered image from the original image should contain line features and points. The points are regarded as noise here.

In the second algorithm, the image is filtered by a set of templates representing local line structure. The filter response values are measurements of how well the corresponding templates match the local line geometry represented by the templates. Fourteen templates are used, each with a pattern of weight numbers representing a smooth line of three pixels. The pixel values in the resulting image are the maximum response values from the filtes.

The interpretation algorithm described below uses the segmentation result directly as a "feature image" and a thresholded version of it as a binary image. The threshold is set by the user. The binary image is partly "cleaned up" by noise reduction consisting of two straightforward filter operators removing isolated single pixels and pixel pairs in two passes. In the first pass one pixel from each pixel pair is removed, in the second pass all isolated single pixels are removed.

Interpretation of the segmented image is performed as a line tracing process. Each road network in the raster map is located by a scan search. When a network is located, it is traced pixel by pixel. A dynamic list of junctions is kept to assure that each segment connected to the junctions are traced. Tracing is performed in parallel in the map and in the image. The map tracing is the active part guiding the position and direction of search for the road counterpart in the image data. The satellite imagery has in advance been geometrically transformed to the map coordinate system, however, corresponding objects can have slightly different positions due to small geometric errors in the image and map generalization. The system has therefore been designed to tolerate positional errors less than a user-defined constant. However, the topological relations have to be equivalent in the map and image.

The interpretation process dynamically selects between two interpretation algorithms. The least CPU-consuming is just to check if a line point is present in the binary image. However, a line point will only be present in the binary image if the contrast to the surrounding environment is relatively high (and the threshold has to be set relatively high to suppress as much noise as possible). When a line point cannot be found in the binary image, a profile analysing algorithm is performed on the feature image data. Intensity profiles are extracted in the different possible continuations for the road. The first derivative profiles are computed and analysed to locate a possible intensity top that can be the line continuation. The algorithm includes procedures to distinguish between small local intensity tops and less local tops.

A new map is produced by the interpretation process. Each map point gets a label telling whether it was recognized in the image data or not. The map is inspected by the user. Larger continuious parts of the road network which not were detected may represent removed roads and should be further visually checked.

3.2 *Water Bodies*

The main pupose of detecting water bodies is to locate sea shore line segments that can be confused with road segments.

The system includes interpretation of seas, lakes and rivers. For seas and lakes both water areas and the edges (sea shores) can be interpretated. Rivers are interpretated as darker lines against a brighter background. The interpretation process follows the same overall strategy as for roads.

Segmentation of sea shores is performed by a filtering algorithm analog to the "template matching" described in the previous section, except that edges are extracted instead of lines. The water areas are segmented by statistical classification performed outside the AUTOSAT system. Rivers are segmented by line template matching on a negative image.

3.3 *Urban Areas*

A method, named line interference filtering, has been developed to recognize urban areas. The idea behind the algorithm is the assumption that recognition of the road network is crucial for visual recognition of urban areas. Accordingly, the method first extracts the road network from the imagery, then a filtering operation is performed extracting areas where the line density is high. The resulting image is finally postprocessed.

The "template matching" method described in section 3.1 is also used for detection of roads in urban areas. After template matching noise reduction is performed. The line segments is then thinned to single pixel width. The thinning operator is implemented as an iterative filtering operator, using 32 filters of size 3x3 representing different patterns of line edges. During each iteration, the filters remove pixels first from the left, then from the right until the line thikness is one pixel. The algorithm preserves the center pixel of the thinned lines. Thinning of our result images is obtained within 3-4 iterations for the test data.

The idea behind interference filtering is to make an operator that generates some kind of interaction between lines with a response that is proportional to local line density. At least two lines must be present to create an interaction. This means that single lines, as single roads and the coastline, will not create any response.

With a two-dimensional filter it is difficult to ensure that a line will not make interference with itself. To avoid this problem we designed one-dimensional filters, and these filters are run on only the parts of the lines that have an orientation that is close to orthogonal to the orientation of the filters.

The interference process is divided into three steps:

1. Decompose the line structures in the binary image into four new images containing respectively nearly vertical, horizontal, left-diagonal and right-diagonal lines.

2. Generate interference between the nearly vertical lines with a horizontal filter, between the near horizontal lines with a vertical filter, and so on.

3. Combine the four images into one image.

Step 1 is performed by filtering the binary image with the four simple filters in figure 2. Each filter extracts lines with orientation $\pm \pi/4$ of the direction the filter is designed for. Hence, all directions should be covered by two orthogonal filters (e.g. the horizontal and vertical filter). However, we have included the two diagonal orientations to make a smoother combined image in step 3.

Figure 3 shows the four simple interference filters. The filter response is equal to the number of lines covered by the filtermask. The interference filter operation is designed in such a way that a filter will not response if only the left or the right hand side of the center point of the filter covers lines. At least one line must be covered by the other part of the filter. The design ensures that the borders of the urban areas are preserved (defined by the outermost road).

4. Detection of New Objects

4.1 *Roads*

A feature image generated by template matching as described in section 3.1 is used. The feature image is manually thresholded with a relatively high threshold value to limit the amount of noise. The recognition result is, however, not very sensitive to the value selected. The detection algorithm is using both a feature image and a binary thresholded image.

In addition to roads the binary image will contain a lot of line segments that are not roads. Especially the coastline will appear very roadlike. The resulting map from map-guided detection of the water bodies is therefore used to remove all line segments having about the same position as the sea shores. In addition, lines inside larger urban areas, both old and the new areas detected as described in section 4.2 below, are removed. The road network inside urban areas is too complicated and detailed to be well recognized in imagery with a resolution of 20 and 10 m. The AUTOSAT system handles these areas just as urban areas without trying to extract any more information about them. However, small areas are not removed to limit the number of gaps generated in the main roads by removed urban areas.

The resulting binary image still contains some noise. The noise will often appear as short lines in a more or less random pattern. Visually, one will often see that these lines probably are not part of the road network (the random orientation), and for the same reasons these lines will be removed by the system at a later stage in the recognition process.

Figure 2. The four one-dimensional filters for extraction of (respectively, from left to right)) nearly horizontal, vertical, right diagonal, and left diagonal line structures.

Figure 3. The four one-dimensional filters to generate interference between (respectively, from left to right), nearly horizontal, vertical, right diagonal and left diagonal line structures.

Figure 4. The result from map-guided detection of old roads. Recognized road segments are shown in white, and non-recognized in black. The subsection to the left shows an area where larger parts of the road were not detected due to shadows from a steep, forest covered hill.

The line pattern in the binary image is now decomposed to elementary line segments, i.e. line segments with only two ends. The end points are labeled in the image, and for each elementary line segment a computer object containing a parametric description of the segment is created. The computer objects contain, amongst other information, the general orientation of the line ends, the position of the line, and its length.

The system uses a prototype description of a road line to determine "the profile" of the recognition process. Amongst others, the prototype contains information about how large gaps in binary lines can be, how large gaps in feature lines can be (i.e. sections of the road where there are no contrast to the surrounding environment), and how curved roads can be.

When the system has generated a description object for each line segment, each segment/description object and its neighbours are checked to determine if any of the neighbouring line segments possibly can be a part of the same road. The distance between end points and the relative orientation of the line ends are computed. For each relevant pair of neighbours a possibility value for a connection line between them is calculated. Each possibility value is a product of partial possibility values. E.g., one of the partial values is relative orientation between the two line segments:

$$S_0 = ((-\Delta\alpha/\alpha_{max}) + 1)\, K_\alpha$$

where $\Delta\alpha$ is the orientation difference between the line ends, α_{max} is the maximal orientation angle difference that can be accepted, and K_α is a weight constant.

The neighbouring line pair which has the highest possibility value determines the connection line hypothesis. Each hypothesis is tested by trying to recognize a connection line in the feature image. The profile analysis algorithm mentioned in section 3.1 is used. Small gaps in the line, sections where no line structure is present, can be accepted according to the value set for the "feature line gaps" parameter. If a line structure is detected, a corresponding line is generated in the binary image, and the two neighbouring lines and their connection line are joined to form one line object.

Before making the proposal for new roads in the map, small line segments which could not be connected to other line segments are removed. These segments are supposed to be "noise". The resulting image can be visually compared with the old map and the original image as a background and manually edited by the user. The line structures accepted as new roads are then converted to the internal raster format, and the structures are linked to the old road network. The new roads in the resulting map are then converted to vector format and integrated with the old vector map.

4.2 Urban Areas

Two versions of the thresholded feature image (the line interference image) have been used as a binary image: First the thresholded smoothed feature image, and secondly the thresholded original feature image. By smoothing the feature image, noise reduction is achieved before recognition of urban areas. By using the thresholded original feature image more information is present, leaving smoothing as a postoperation to the recognition process.

The postprocessing analysis is built on knowledge about urban area features in satellite images, and how urban areas in maps are marked is important. Such features are size, smoothness of area contours, inner holes, and road density.

The algorithm consists of the following steps:

1. The information from the old map is added to the binary image pixel: Pixels in the old map representing old urban areas which are <u>not</u> candidate urban pixels in the binary image, are set to urban pixels.

2. The candidate urban areas in the binary image is traversed in order to mark the areas and simultanously generate a data description object for each isolated area (connected structure of pixels). Data description objects are generated for the following structures:

   - connected structures of pixels
   - outer border for these connected structures
   - inner holes in the connected structures.

Each connected structure is a candidate urban area. Features, such as the number of pixels,extention (maximum and minimum (x,y) coordinates), and position are calculated for all three kinds of area objects.

For the connected structures the number of pixels, Nf, in the feature image where more than N1 lines have interfered, is calculated. The candidate area description objects are linked together in a pointer list during the scanning. Each candidate area description object points to its outer border description object, and to the list of inner hole description objects. For the outer border the area is also a measure of border length.

3. The list of area objects is traversed in order to decide whether candidate area objects should be accepted or rejected. The rejection criteria are:

- area size < Nmin
- Nf < Nfmin

4. Holes in the accepted area objects are filled on these conditions:

- Absolute size: Number of pixels in the hole is less Nhmin
- Relative size: Size of hole is less than Ph percent of total area.

Holes having more pixels than the absolute size are never removed.

5. The resulting image containing the accepted area structures is optionally smoothed and thresholded. The smoothing is required if the binary image was the non-smoothed thresholded interference image. A standard median filter with kernel size 5x5 is used.

The following parameter values have been used in our tests:

Nl = 3
Nfmin = 4
Nmin = 2
Nhmin = 40
Ph = 7

These values are set partly as a result of experiments and partly due to knowledge about the response values in known urban areas in the interference image. More test scenes are necessary to determine the optimum parameter value.

5. Results

The interpretation system has been tested on a SPOT scene of Værnes near Trondheim in Norway. A 512x512 subimage from band 1 has been used (the green band, 20m resolution, see fig. 4) for detection of roads and urban areas, and band 3 (near-infrared) for detection of water bodies.

Figure 5. a) (upper left) shows the result from template matching ("the feature image"). The thresholded image is to the upper left (b), and the thresholded image after removing line segments in urban areas and the costline is to the lower left (c). To the lower right is the result from the road detection algorithm. A larger forest road is completely recognized (d).

5.1 Roads

Segmentation by "original minus median" gave a noisy result with a lot of small pixel segments. The smallest segments were deleted by the noise filters. In addition, the method is extremely sensitive to the threshold level. Only level 131 gave acceptable results. The template matching method was not sensitive to the threshold level and contained much less noise. However, the lines were wider using this method. We selected the template matching result for further processing.

The result of map-guided detection is shown in fig. 4. While interpretating the image, the feature image and profile analysis was used 73% of the time, the binary image was used in the remaining 27%. 76% of the roads were recognized. From the 24% not recognized 16% can be eliminated as noise (small parts a few pixels long which were not detected due to poor contrast or too large map generalization). This noise could be removed by postprocessing. The remaining 8% should be controlled visually by the user. Two larger road sections were not recognized for reasons of poor contrast and map generalization. One of these sections followed the coastline and had therefore been moved on the map more than our maximum distance difference parameter of 40 m in the terrain (this section amounts to 3%). The other section that was not found was lying in a shaded area caused by a relatively steep hill. Neither of the sections could be found by visual inspection of the original image data while performing interactive contrast enhancement.

Various steps for detection of new roads are shown in fig. 5. Fig. 5 a) shows the resulting image from template matching, described in section 2.1, of a lower middle section of our test scene, (band 1). In fig. 5 b) are the thinned line structures of the result from the template matching segmentation. Threshold value 13 has been used. Fig. 5 c) shows the result after removing the old, recognized roads and coastline, and the line structures present within old and proposed new urban areas. Lines within urban areas having an area of less than 100 pixels are, however, not removed to reduce the number of gaps generated in the line structures. Fig. 5 d) shows the result after the generation and testing of the hypothetical connection lines. For verified connection lines there have been generated lines in the binary image. Lines having a length less than 15 pixels are removed.

The large proposed road structure is a new forest road, and the complete road has been well recognized as one connected line. The straight line in the upper right part of the image is a pier. Most of the remaining line structures are private roads. The private roads were not present in the old map data so they were not removed and therefore proposed as new roads.

5.2 Water Bodies

SPOT band 3 (near-infrared) was used for interpretation of hydrographic features. For interpretation of the sea shores the system used the binary segmented image 62% of the time and band 3 directly for profile analysis 38 % of the time. 76% of the shores were recognized. From the 24% unrecognized 5% were due to real changes of the sea shore. A relatively large sea area had been filled in. The largest section of the 19% that were unchanged and undetected was again in a shaded area caused by a steep hill (the section amounts to about 5% of the unrecognized shores).

2% of the sea and lake areas were not detected. The changed areas amounts to about 2/3 of this. The rest of the areas were mainly classified as land due to shallow water (sea bottom was clearly visible in the water). Surprisingly, 88% of the rivers were reconized (only rivers wide enough to be represented with two lines were present in our map data). The borders of the rivers were detected using a binary image 52% of the time and a dark line feature image 48% of the time.

5.3 Urban Areas

The template matching algorithm was applied to extract line features. The thinned line feature image is shown in figure 6, while the resulting image from interference filtering is shown in figure 7. As expected, other line structures than roads have responded and created "noise". The airport in our test scene has given considerable response, as well as parts of the coastline, road intersections in rural areas and roads going into the urban areas.

The interference image is smoothed and thresholded before the recognition. In map guided recognition, 93% of the urban areas marked in the last map revision are recognized. The unrecognized parts are mostly in the outer edges of the areas.

The proposed urban areas from unguided recognition is shown in figure 8. The manually updated urban areas are are shown in figure 9 (air photo based revision). In general, the result is a coarse approximation to the new map data with some exceptions. Some small groups of urban areas are connected to larger structures, and the proposed new areas often tend to be somewhat larger than in the map. Some noisy areas are also present, and the airport has been detected as an urban area (correct?).

Figure 6. The thresholded and thinned line image. To the right is a subsection of the image to the left showing an urban area (Værnes).

Figure 7. The resulting image from interference filtering before postprocessing.

The method is fairly robust with regard to the parameter settings, except for the parameter N_{fmin}.

The results from the line interference operator have been compared to 1) multispectral classification 2) classification using two texture bands in addition to the multispectral bands, and 3) Multivariate Image Analysis (MIA).

In 1) and 2) a maximum-likelihood classifier was used. Several measures of texture are described in the literature. In Haralick 1973, 14 different measures are defined. The 11 first of these have all been tested. The measures "sum of squares: variance" and "entropy" turned out to give the best results and these two measures have been used here. Four classes were used in the classification task. Class statistics were generated from training areas. The classification result for class urban was smoothed by a median filter of size 3x3. For both results 88% of the old urban areas are recognized, however, when texture was used fewer areas were wrongly proposed us urban. The unrecognized parts were mainly in the outer edges. The central urban area was recognized retaining the U-shape, as well as other smaller areas, but there were large areas which did not correspond to urban areas. Both results are inferior to the results from interference filtering. However, the classification results are sensitive to the class statistics. Defining more classes and combining the classification results could improve the overall result.

The MIA system (Esbensen et al. 1989) is developed for multiband imagery and calculates principal components of the multiband image. These are visualized pairwise in "score-plots", allowing for tentative class delineations in the feature space. MIA was applied on SPOT band 1 and 2, in addition to four texture images made from band 1 with the texture features "contrast", "sum of squares: variance", "sum variance", and "entropy" (defined in Haralick 1973). MIA outlined noisy candidate urban areas which were further processed by 3x3 median filtering, three iterations of dilation and two iterations of erosion, followed by 9x9 median filtering to remove noise and create larger continuous areas. The candidate urban areas showed up to mostly cover real urban areas. However, a lot of urban areas are also missing.

6. Conclusions

Our experiments so far indicate that it is possible by semi-automatic methods to extract most of the necessary information to perform a coarse revision of topographic maps at a scale of 1:50000. Manual control and editing of the automatic interpretation result is clearly necessary, and the higher degree of uncertainty should be clearly shown by printing the changes in other colours. The satellite based map revisions will be more uncertain than the airphoto based photogrammetric revisions, but with a map revision cycle of 10-20 years at the present time in Norway, semi-automatic revisions two to four times more often would make the maps much better approximations to reality.

The proposed method of interference filtering seem to be superior to the other methods tested to recognize urban areas, even if textural features are introduced. Additional built-in logic in the high level post-processing could further refine the result. Our method for road recognition was able to detect a new forest road completely without any fragmentation. This also indicates that to achieve a very good result using satellite imagery of this resolution, it is important to perform the revision before too much vegetations grow up along side of the road.

As far as we know, no other system for semi-automatic satellite based topographic map revision exist. However,

Figure 8. The interference image after postprocessing (the urban area proposal).

Figure 9. Air photo based map for the same urban area generated manually.

experiments performed by e.g. Coulombe et al. (1989) and Marceau et al. (1989) confirm our experience that textural features indeed improve the classification results over multispectral classification only. On the other hand, classification with textural features seem not to produce results reliable enough for topographic mapping. Methods for road detection have been proposed and tested by various authors, most of them based on high resolution airphotos (e.g. Graça 1987). Wang & Newkirk (1988) have shown promising results for detection of highways in Landsat TM imagery. They use similar prediction logic for road connecntions etc. However, the predictions are not used to initiate further image analysis (feedback) to detect more roads by more sensitive algorithms.

Further development and operational use of the system is not yet determined. A fruitful way to go to create an operational system could be to integrate the image interpretation software with a commercial GIS/image processing sytem.

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