RULE-BASED INTERPRETATION OF HIGH-RESOLUTION SAR IMAGES FOR MAP UPDATING

Leena Matikainen, Mika Karjalainen, Harri Kaartinen and Juha Hyyppä
Finnish Geodetic Institute, Department of Remote Sensing and Photogrammetry
P.O. Box 15, FI-02431 Masala, Finland
Leena.Matikainen@fgi.fi, Mika.Karjalainen@fgi.fi, Harri.Kaartinen@fgi.fi, Juha.Hyyppa@fgi.fi

ABSTRACT

Automatic interpretation of high-resolution airborne E-SAR data (pixel size 1 m × 1 m, L band data with four polarizations, X band data with two polarizations) for map updating was studied. The image data were segmented into homogeneous regions and classified into a few classes using rules defined on the basis of reference data (eCognition software used). The main idea in the classification was to first use image-derived attributes (e.g. mean values and textural features) to classify 'certain' segments (i.e. segments with the typical characteristics of a class) and then to complete the result by also using contextual information on the classes of the neighbouring segments. An overall classification accuracy of 92% was achieved in the agricultural area of Sjökulla. The overall accuracy in the suburban area of Espoonlahti was 78%. The results of the study indicate that the images are well suited for automatic mapping of water, forest and open areas. Mapping of built-up areas is also possible but it is a more demanding task. Change detection between old topographic map data and the classification result was tested in the Sjökulla area. The results of the test demonstrate automated change detection in practice, but the usefulness of the results is limited by different class definitions in the available map data and classification result.

1. INTRODUCTION

The most important advantage of Synthetic Aperture Radar (SAR) images is that they can also be obtained in cloudy and dark conditions. In addition, SAR images provide information which complements the information obtained from optical aerial and satellite images (Hellwich et al., 2001). The use of SAR images for mapping applications was studied by e.g. Dowman and Morris (1982), and this subject currently attracts considerable interest (see e.g. Tupin et al., 1999; Borghys et al., 2002; Dierking and Skriver, 2002; Haack et al., 2002; Bentabet et al., 2003; Dekker, 2003; Grey and Luckman, 2003; Grey et al., 2003; Quartulli and Datcu, 2003).

SAR images differ significantly from optical images. Many different factors related to the SAR system and area under study affect backscattering (see e.g. Henderson and Lewis, 1998), and images often appear noisy and difficult to interpret. Promising results have, however, been achieved with advanced SAR datasets and techniques. The coherence information available from interferometric image pairs has proven useful for land-use/land-cover mapping (see e.g. Wegmüller and Werner, 1995; Engdahl and Hyyppä, 2003; Grey and Luckman, 2003). The availability of images with several frequencies and polarization modes (e.g. Pierce et al., 1994; Dong et al., 2001; Lee et al., 2001; Borghys et al., 2002; Lombardo et al., 2003; Macrì Pellizzeri et al., 2003) as well as interpretation methods which exploit the spatial (e.g. Dong et al., 2001; Borghys et al., 2002; Lombardo et al., 2003; Macrì Pellizzeri et al., 2003), structural (e.g. Tupin et al., 1999) and textural (e.g. Haack et al., 2002; Dekker, 2003; Dell'Acqua and Gamba, 2003) information content of the images improve the chances of successful interpretation.

High-resolution SAR images (pixel size about 1 m × 1 m, also called very-high-resolution images in the case of spaceborne data) can currently be acquired using airborne systems, but spaceborne systems which are under development will provide this type of data in the future. One of the potential future systems is TerraSAR. Data with characteristics similar to the future TerraSAR data are currently produced with DLR's (German Aerospace Center) airborne E-SAR system. E-SAR data have been used in classification studies carried out by e.g. Hellwich et al. (2001), Borghys et al. (2002) and Corr et al. (2003).

An important application area of remotely sensed data is updating of digital map databases. Efficient methods for the updating process are needed, and research is conducted to automate information extraction from image data (see Baltsavias, 2004). Most of the research has concentrated on optical images (see e.g. Armenakis et al., 2003; Knudsen and Olsen, 2003; Walter, 2004), but studies on the use of SAR images have also been published. For example, Dierking and Skriver (2002) studied the detection of changes from multitemporal polarimetric EMISAR images, Bentabet et al. (2003) updated road vectors using RADARSAT images and MSTAR SAR images of STARLOS sensor, and Grey et al. (2003) used multitemporal European Remote Sensing Satellite (ERS) coherence data to map urban change.

Our study had two goals. The first was to investigate the feasibility of high-resolution E-SAR data for mapping different land-use/land-cover classes and objects in Finnish conditions. Secondly, the study was part of map updating research the goal of which is to develop automatic methods for image interpretation and change detection between map objects and new imagery. Some aspects of method development are discussed in the article and the results of an automatic change detection test are presented.

2. STUDY AREAS AND DATA

2.1 Study areas

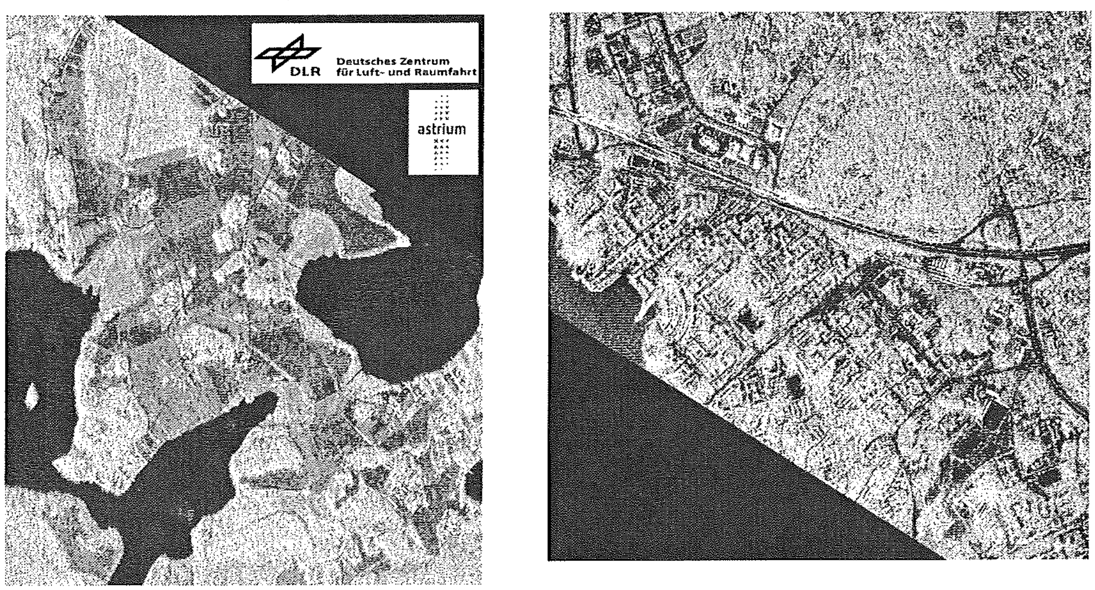
Two study areas near Helsinki in southern Finland were used: Sjökulla in Kirkkonummi and Espoonlahti in Espoo. The Sjökulla area (about 4.7 km^2) represents rural landscape with agricultural fields, meadows, forests (coniferous, deciduous, mixed) and lakes. Four main classes important for the topographic mapping of the area and distinguishable from the image data were selected for interpretation: water, forest, open (included fields as well as other open areas) and rushes. The Espoonlahti area (about 5.2 km^2) is a suburban area with different types of built-up areas (high-rise areas, low-rise areas and an industrial area). The areas outside the built-up areas are mainly covered with forest but there are also some open areas (e.g. meadows, sports fields). A small part of the area is covered with sea. Four main classes were also selected for interpretation in the Espoonlahti area: water, forest, open (incl. roads) and built-up. Built-up refers to areas covered with buildings as interpreted using the SAR images (actual building mapping with exact building locations was impossible).

2.2 SAR images

The SAR images (see Figure 1) were acquired using the airborne E-SAR system by DLR on 31 August 2000 (Sjökulla) and 2 May 2001 (Sjökulla and Espoonlahti). For the Sjökulla area, two datasets with different acquisition dates were thus available. L band images with four polarizations (HH, HV, VV, VH) and X band images with two polarizations (HH, VV) were acquired from both study areas. In the L band, the wavelength is about 23 cm, and in the X band it is about 3 cm. In the present study, we used geocoded multilook precision images that were processed and orthorectified at DLR using a digital elevation model derived from interferometric images (the interferometric images were also acquired with the E-SAR system). The pixel size of the images on the ground was 1 m × 1 m. These images were further rectified to the Finnish uniform coordinate system using projective transformation and nearest neighbour interpolation. The values used in the study were the digital numbers of the images.

In the L band 2001 image from Sjökulla, image brightness changed gradually between the near range (closer to the SAR antenna) and the far range, probably due to some unknown problem with the antenna elevation pattern compensation and a change in the incidence angle. In order to correct the brightness variation, the average pixel value was calculated for 21 forest plots located evenly between the near and far range. Assuming that similar forest plots in different parts of the image ought to have equal intensities, linear correction functions were determined for each L band channel and used to correct the brightness variation in the Sjökulla area (of course, the correction functions were not necessarily ideal for other types of land cover). In the Espoonlahti study area, this effect was not clearly visible and correction was thus not needed here.

A principal component (PC) transformation was applied to the Sjökulla images to reduce the dimensions of the data and to produce an informative image for visual inspection. The PC image contained four channels: the first PCs calculated from L band 2000, X band 2000, L band 2001 and X band 2001 images, respectively. Simple texture images of the Espoonlahti area were produced by calculating the variance in a moving window (25 m × 25 m) in each image channel.



a) b)

Figure 1. a) L band 2000 image with polarization HH (LHH2000) from Sjökulla. The area is 2600 m × 2200 m. b) L band image with polarization HH (LHH) from Espoonlahti. The area is 2500 m × 2500 m. Image data © DLR and Astrium GmbH.

2.3 Map data

Map data of the Sjökulla area from 1994 were used as old data to be updated. Fields and water areas of the 1:20 000 topographic map in raster format were available. For the Espoonlahti area, suitable old digital map data were not available.

Map data from 1999 (Topographic Database of the National Land Survey of Finland) were used as reference data for estimating the accuracy of the classification results for the Sjökulla area. The map data were converted from vector polygons into a raster map with a pixel size of 1 m × 1 m. Water was used as the reference data for water, forested swamp for forest, fields and meadows for open and peat-covered area for rushes. The classes on the map were thus somewhat different from those in interpretation and the reference data were not ideal. Forests are not presented as polygons in the Topographic Database, but forested swamps provided some reference data for forests (most of the forested swamp in the study area are from one large polygon). Fields and meadows were used as the reference data for open because they represent clear open areas, but there are also other types of open area in the study area (e.g. rocky areas). On the map peat-covered areas occurred in approximately the same places as rushes did in the interpretation result, and the peat-covered areas were therefore used as the reference data for rushes. The boundary pixels of the classes were excluded when estimating accuracy.

2.4 Reference points

In the Sjökulla area, a total of 37 reference points were used to develop classification rules (see Sections 3.1 and 3.3). Most of the points were collected in the field with Global Positioning System (GPS) measurements. Some points were added on the basis of visual interpretation of the imagery. In the Espoonlahti area, 87 points were used for rule development and 519 points for accuracy estimation. The points for rule development were selected and classified manually on the basis of the E-SAR imagery, an aerial ortho image and map data. The points were located inside homogeneous areas ensuring that the class was correct both in the SAR and aerial imagery. Due to the side-looking geometry of the SAR sensor, buildings in the SAR images shifted slightly from their real position and this had to be taken into account by the careful selection of the points. The reference points used for accuracy estimation were collected from aerial imagery and not specifically for the SAR image study. Some problematic points (e.g. buildings in the reference data but not in the SAR images) may therefore exist. Detailed information on object types and surface materials were available for the points used for accuracy estimation. The information was generalized by combining the points into a few classes: water, forest, open, building, garden/grass, garden/trees, car park, multi-storey car park and road. The points used for developing rules and estimating accuracy were separate sets of points. Some points, however, were located in almost the same places in both sets.

3. METHODS

3.1 General

A general workflow was planned for land-use/land-cover mapping and change detection between old map data and new imagery. The workflow is based on a region-based and knowledge-based approach to image interpretation developed in the context of map updating by e.g. Janssen (1993), Johnsson (1994) and Matikainen et al. (1997). As a commercial software package (eCognition), such an approach has been implemented by Definiens Imaging (2004). eCognition software was used in the present study for segmentation, classification and change detection. The software provides tools for segmentation and rule-based classification using fuzzy membership functions (see Benz et al., 2004). The planned workflow is made up of the following stages:

- Segmentation of the imagery, assisted by existing map data if available.
- Development of classification rules using reference points.

- Rule-based classification of the segments using image-derived attributes, contextual information on the classes of the neighbouring segments and existing map data if available (map data not used in this stage of the present study).
- Change detection (if old map data available).

In the segmentation stage, the imagery is divided into homogeneous regions for classification. If existing (old) map data are available, they are used to guide the segmentation so that segments derived from the imagery do not overlap existing land-use boundaries. This is likely to improve the quality of the final interpretation results and facilitates change detection.

Up-to-date reference data are needed to make up training data for classification. In the case of rule-based classification, they are needed to assist rule development. For region-based classification, an ideal set of reference data would consist of regions with sizes and shapes comparable to those of the segments to be classified. Determining such regions, however, is difficult. We ended up with a solution in which point-wise reference data are collected so that each point is located within a homogeneous area of the same class. The attributes of the segment located around the point are then assigned to each reference point, and the final reference data thus consist of regions defined by the segments. This approach is flexible; if the segmentation is changed, the shapes of the reference areas will also change. An alternative approach would be to use existing map data as reference data (e.g. Walter, 2004).

In the classification stage, segments are classified using the rules, various attributes calculated from the image data and contextual information. Knowledge derived from existing map data could also be used. In the present study, a classification approach with two basic steps was planned and tested using the tools of eCognition. Image-derived attributes (e.g. mean values and textural features) were first used to classify 'certain' segments (i.e. segments with the typical characteristics of a class), and the result was then completed by also using information on the classes of the neighbouring segments. To some extent, the method thus resembles human reasoning in visual interpretation. For example, the classification for a given area (e.g. forest) may first appear uncertain, but if the interpreter notices that the area has some characteristics of a forest and is mostly surrounded by forest (certainly recognized), he/she is likely to conclude that the area in question is also forest. We are unaware of other studies using an approach that is exactly the same. The approach has some characteristics in common with the photo interpretation method proposed by Thierry and Lowell (2001) for the creation of forest type maps and the road extraction methods presented by Fischler et al. (1981) and Gerke et al. (2004). In Thierry and Lowell's (2001) method, an interpreter identifies only features he/she believes to be "100 percent certain". Spatial interpolation is then used to fill in the gaps. In the method presented by Gerke et al. (2004), which follows the ideas of Fischler et al. (1981), road extraction is carried out first with a strict and then with a more tolerant parameter control. In the latter step, connections in the road network are taken into account. Contextual relationships between adjacent regions have also been used in interpretation by e.g. Tupin et al. (1999).

Finally in change detection, the classification result is compared with the existing map data to detect changes. The comparison is straightforward because segment boundaries are compatible with the map data, i.e. each segment belongs to only one class in the map.

3.2 Segmentation in Sjökulla and Espoonlahti

The segmentation method applied (Baatz and Schäpe, 2000; Definiens Imaging, 2003) is based on bottom-up region merging and a local optimization process which minimizes the growth of a given heterogeneity criterion. In the Sjökulla area, segmentation was performed using the PC image and a heterogeneity criterion that was a combination of colour (50%) and shape (50%) heterogeneity (colour corresponding to digital numbers in the image). The shape heterogeneity consisted of smoothness (50%) and compactness (50%). The scale parameter controlling the number and size of the resulting segments was 70 (for details of the parameters, see Definiens Imaging, 2003). The old map showing water and field areas was used as a thematic layer in the segmentation, and the segment boundaries thus became compatible with the map data. In the Espoonlahti area, channels LHH, LHV, LVV, XHH and XVV were used in segmentation (i.e. all channels except LVH which is similar to LHV). The heterogeneity criterion was the same as in the Sjökulla area, and the scale parameter was 60. In Espoonlahti, a lower segmentation level with very small segments was also created for the purpose of texture calculation (textural features based on subsegments are available in eCognition). The heterogeneity criterion for this level was colour 70%, shape 30% (smoothness 50%, compactness 50%), and the scale parameter was 15.

3.3 Classification in Sjökulla and Espoonlahti

The main classification stages and rules used in Sjökulla and Espoonlahti are presented in Tables 1 and 2, respectively. The rules were created manually in eCognition after examining the values of various attributes (mean values and standard deviations, shape attributes, textural attributes for Espoonlahti) in different classes using training segments and Matlab software (The MathWorks, 2004). The training segments were obtained by assigning segment attributes (exported from eCognition) to reference points as described in Section 3.1. Plots of the attribute values were used to help draw up the rules (for example, see Figure 2, which shows the mean values of training segments in different image channels in the Sjökulla area). The sequential order of the training segments from different classes in the case of different attributes was examined to find characteristic features that clearly separated one class from the others. Some calculations were also made (e.g. maximum or minimum values of a given class, distance to other classes) to find appropriate rules and threshold values. The final rule sets were selected by testing different rules in practice and evaluating the results visually.

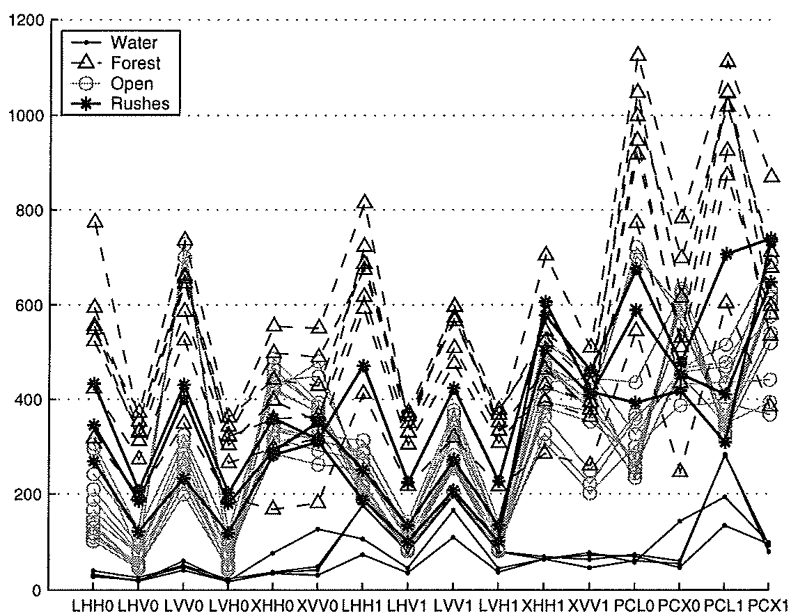


Figure 2. Mean values of training segments in different image channels in the Sjökulla area (e.g. LHH0 and LHH1 refer to LHH channels from 2000 and 2001, respectively).

The rules for classification were created separately for both study areas and somewhat different approaches were used. In the Sjökulla area, water could be clearly separated from land using the first PC calculated from the X band 2001 image (other useful attributes could also be found). Forest segments had typically higher values in the L band channels than open segments (see Figure 2). Rushes had values between forest and open and there was some confusion with both. In the first stage of classification, land was distinguished from water. Land segments were then further divided into forest and open, in the event that forest or open appeared as a certain classification (rather strict threshold values were applied). Many segments remained unclassified, and the next step was to detect areas that were likely to be areas of rushes among them. In addition to rules based on image channels, the spatial context of the segments was taken into account. To become classified as rushes, a segment had to be located near water or beside rushes already recognized (five iterations were made and the areas of rushes grew gradually). Finally, unclassified segments were classified as forest or open by taking into account the neighbourhood (relative border of the segment to forest or open) in addition to an image-derived attribute (LHV2000 mean). After classification, change detection was carried out by comparing the classification result with the old map (fields and water areas). The change detection result has six classes (map from 1994 – images from 2000-2001): not field – open, not water – water, field – open, field – not open, water – water and water – not water.

L band channels were also useful in the Espoonlahti area in distinguishing forest from open. In addition, a textural feature 'mean area of sub-objects' appeared to be useful for recognizing forest segments. Some built-up segments had higher values than others, especially in the X band channels and textural channels. On the other hand, many built-up segments had values similar to other classes, especially forest. Water was more difficult to distinguish than it was in the Sjökulla area. The first stage consisted of classifying certain forest, open, built-up and water segments. For built-up, for example, many different attributes combined with the OR operator were used. If any of the attributes had a value over (in some cases under) a given threshold value, the segment became classified as built-up. After the first classification, many segments remained unclassified, and the result was completed by taking into account information on the neighbouring segments. For forest and open, this information was used in addition to image-derived rules. For built-up and water, only a high proportion of built-up or water in the neighbourhood was sufficient for classification. This is due to the nature of the classes and the difficulty in detecting the built-up areas completely. The final stage was the enlargement of built-up areas with forest and open segments mainly surrounded by a built-up area. This stage was carried out in order to produce an alternative result with larger built-up areas covering roads and yards, for example, in addition to buildings in a densely built-up environment.

Table 1. The stages and rules of classification used in the Sjökulla area.

Classification stage	Class	Attribute	Type of membership function *)	Operator to combine the membership values **)
1	Water	X band 2001, the 1st PC, mean X band 2001, the 1st PC, stdv (standard deviation)	\\ \\	AND (min)
	Land	Not water		
2	Forest	LHV2000 mean LHV2000 stdv LHH2001 mean LHV2001 mean LVV2001 mean	/ / / / /	Arithmetic mean
	Open	LHH2000 mean LHH2000 stdv LHV2000 mean LHV2000 stdv	\\ \\ \\ \\	Arithmetic mean
3 (5 iterations)	Rushes	a) LHH2000 mean LHV2000 mean XHH2001 mean b) Relative area of water within 50 m Relative border to rushes neighbour objects	⊓ ⊓ ⊓ / /	a) Arithmetic mean b) OR (max) a & b) AND (min)
4 (5 iterations)	Forest, addition	LHV2000 mean Relative border to forest neighbour objects	/ /	Arithmetic mean
	Open, addition	LHV2000 mean Relative border to open neighbour objects	\\ /	Arithmetic mean
5 (change detection)	E.g. Field – Open Field – Not open	Old map (fields and water areas) Classification result	0 (false) or 1 (true)	AND (min)

*) The membership function defines the membership of a segment to the class in question as a function of the attribute value. For example, when a membership function / is used, an attribute value below a lower threshold value gives a membership of 0 and an attribute value over a higher threshold value gives a membership of 1. Between the threshold values, the membership increases gradually as defined by the membership function.

**) The operator defines how the membership values resulting from different attributes are combined to obtain the final membership to the class in question. For example, in the case of water (the first row) the fuzzy AND operator (corresponds to the minimum of the values) is used to combine the two membership values.

Table 2. The stages and rules of classification used in the Espoonlahti area.

Classification stage	**Class**	**Attribute**	**Type of membership function**	**Operator to combine the membership values**
1	Forest	LHH mean LHV mean LVV mean Mean area of sub-objects (texture measure)	⊓ ⊓ ⊓ ⊓	AND (min)
	Open	LHH mean LHV mean LVV mean	⊓ ⊓ ⊓	AND (min)
	Built-up	XHH mean XHH stdv XVV mean XVV stdv LHH mean / LHV mean XHH window variance, mean (texture m.) XHH Average mean difference to neighbours of sub-objects (texture m.) XVV Average mean difference to neighbours of sub-objects Mean area of sub-objects	_┌ _┌ _┌ _┌ ┐_ _┌ _┌ _┌ ┐_	OR (max)
	Water	LHH mean LHH stdv LVV mean LVV stdv LVH mean LVH stdv XVV mean XVV stdv LHH mean / LVV mean Area	⊓ ⊓ ⊓ ⊓ ⊓ ⊓ ⊓ ⊓ ┐_ _┌	AND (min)
2 (5 iterations)	Forest, addition	LHH mean LHV mean LVV mean Relative border to forest neighbour objects	⊓ ⊓ ⊓ ⟋	Arithmetic mean
	Open, addition	LHH mean LHV mean LVV mean Relative border to open neighbour objects	⊓ ⊓ ⊓ ⟋	Arithmetic mean
	Built-up, addition	Relative border to built-up neighbour objects	⟋	
	Water, addition	Relative border to water neighbour objects	⟋	
3 (additional stage to produce an alternative result, 5 iterations)	Built-up, enlargement	Relative border of forest and open objects to built-up neighbour objects	⟋	

4. RESULTS

Figure 3 shows the classification and change detection results (field/open areas) for the Sjökulla area. The accuracy of the classification results compared with the reference map (see Section 2.3) is presented in Table 3 (for description of the accuracy measures, see Helldén, 1980). Classification results for the Espoonlahti area are shown in Figure 4 and the accuracy of the results compared with the reference points (see Section 2.4) in Tables 4 and 5.

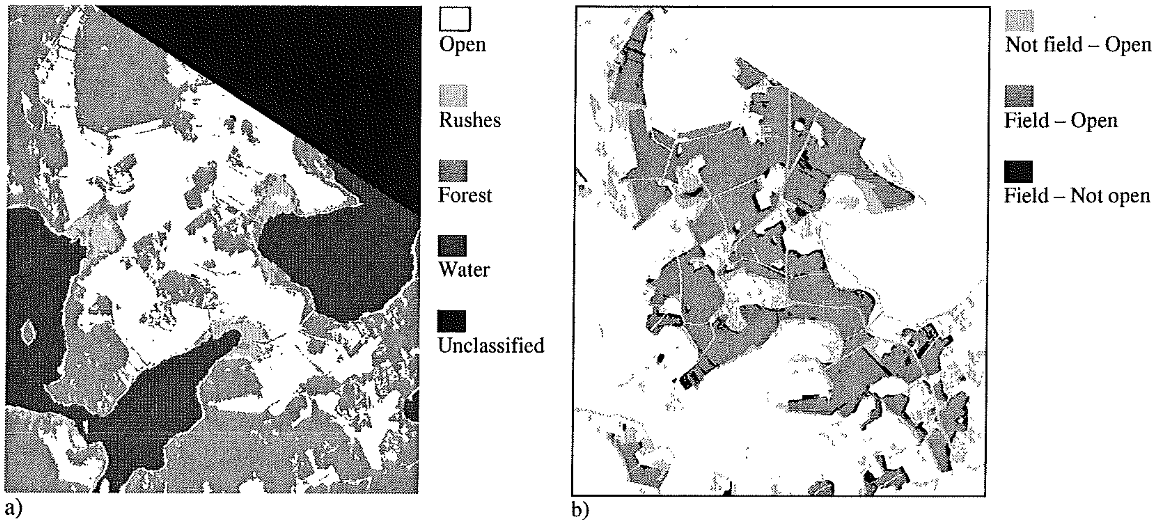


Figure 3. a) Classification and b) change detection results for the Sjökulla area. The change detection result is shown for field/open areas (map in 1994 – images in 2000-2001). Fields of the map © The National Land Survey of Finland, permission number 709/MYY/04.

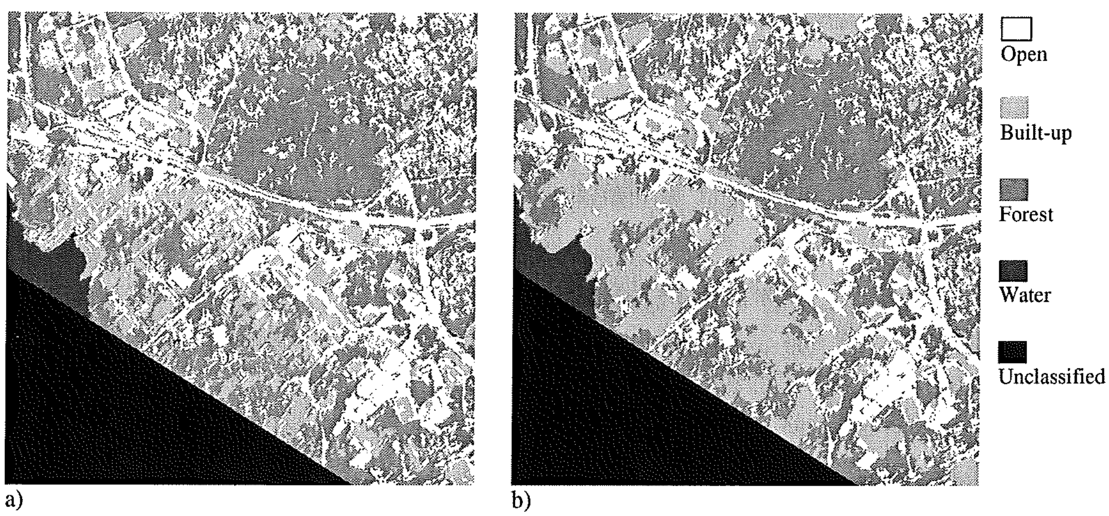


Figure 4. Classification results for the Espoonlahti area. a) Result after classification stage 2 (see Table 2). b) Result after classification stage 3.

Table 3. Confusion matrix and accuracy estimates for the classification result for Sjökulla.

Classification result	**Reference map**				
	Water	**Forest** (forested swamp)	**Open** (field, meadow)	**Rushes** (peat-covered area)	**All**
Water	1035596	0	1411	142	1037149
Forest	7568	258173	60681	58061	384483
Open	62835	4468	1219547	16650	1303500
Rushes	13135	516	1540	77972	93163
All	1119134	263157	1283179	152825	2818295
Interpretation accuracy	**93%**	**98%**	**95%**	**51%**	
Object accuracy	**100%**	**67%**	**94%**	**84%**	
Mean accuracy	**96%**	**80%**	**94%**	**63%**	
Overall accuracy					**92%**

Table 4. Confusion matrix for the classification result for Espoonlahti (result after classification stage 2 / result after classification stage 3, see Table 2).

Classif. result	**Reference points**									
	Water	**Forest**	**Open**	**Building**	**Garden/ grass**	**Garden/ trees**	**Car park**	**Multi-storey car park**	**Road**	**All**
Water	11 / 11	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	11 / 11
Forest	0 / 0	104 /102	15 / 14	21 / 17	0 / 0	12 / 12	3 / 3	1 / 1	8 / 7	164 /156
Open	0 / 0	3 / 3	93 / 90	28 / 20	8 / 8	4 / 4	24 / 19	2 / 1	82 / 74	244 /219
Built-up	1 / 1	2 / 4	3 / 7	67 / 79	1 / 1	5 / 5	8 / 13	3 / 4	10 / 19	100 /133
All	12	109	111	116	9	21	35	6	100	519

Table 5. Confusion matrix and accuracy estimates for the classification result for Espoonlahti (result after classification stage 2).

Classification result	**Reference points**				
	Water	**Forest** (forest, garden/trees)	**Open** (open, garden/grass, car park, road)	**Built-up** (building, multi-storey car park)	**All**
Water	11	0	0	0	11
Forest	0	116	26	22	164
Open	0	7	207	30	244
Built-up	1	7	22	70	100
All	12	130	255	122	519
Interpretation accuracy	**92%**	**89%**	**81%**	**57%**	
Object accuracy	**100%**	**71%**	**85%**	**70%**	
Mean accuracy	**96%**	**79%**	**83%**	**63%**	
Overall accuracy					**78%**

5. DISCUSSION

A relatively high accuracy rate was achieved in the classification of the Sjökulla area (see Table 3). The overall accuracy compared with the reference map data was 92%. Water and open areas were accurately classified (mean accuracies 96% and 94%, respectively). The mean accuracies of forest (80%) and rushes (63%) in particular were lower, but it must be noted that the reference data for these classes did not correspond exactly to the classes in classification. The visual appearance of the classification result is mainly satisfactory. The region-based classification produced homogeneous regions, and the classification result resembles topographic maps of the area. Use of existing map data in segmentation facilitated change detection (each segment belonged completely to one class of the old map), but the effect on the general visual appearance and accuracy of the classification result was small. This was found out by performing another segmentation and classification without using map data (overall accuracy 91%, the most remarkable change in the classification of rushes). Some prominent errors also occur in the classification result, for example, small shadow areas of forest that have been classified as water.

The Espoonlahti area with plenty of small features (e.g. roads and buildings) was more difficult to interpret than the Sjökulla area. The overall accuracy compared with the reference points was 78% (see Table 5). The mean accuracies of water (96%) and forest (79%) were nearly the same as in the Sjökulla area. The mean accuracy of open (83%) was lower, as expected (in Espoonlahti the reference data for open included gardens, car parks, roads and other open areas, in Sjökulla they included fields and meadows). The mean accuracy of built-up was 63%. The reference data for built-up included building points and, as mentioned in Section 2.4, some of them possibly located beside buildings in the SAR images. The visual evaluation of the image data and classification results confirms that built-up areas were the most difficult to interpret. Despite the high spatial resolution of the images, buildings are often difficult to detect and their exact locations impossible to determine due to speckle, surrounding vegetation and effects related to imaging geometry (layover, shadows, displacements). Many buildings, especially in low-rise areas, are not visible in the image data and these areas are thus missing or partially presented in the results. The additional classification stage (see Figure 4b and Table 4) increased the number of building points classified as built-up. On the other hand, it enlarged the built-up areas to also cover the surroundings of the buildings. Different texture measures including variance calculated in a moving window and measures based on subsegments were valuable for detecting built-up areas.

On the basis of the visual evaluation of the images and results from both study areas, it can be concluded that the E-SAR data are well suited for automatic mapping of water, forest and open areas. Mapping of built-up areas as large entities is also possible but is a more demanding task. The high spatial resolution of the images might allow mapping of individual buildings, but in practice this is very difficult as discussed above. Special methods would be needed to acquire useful information on the geometry of the buildings (see e.g. Balz and Haala, 2003). The main roads are relatively clearly visible in the imagery, and with specific road detection algorithms, mapping of roads might be possible. In our study, roads were included in open areas. The availability of images from different viewing directions would be advantageous for mapping built-up areas and roads (see e.g. Tupin et al., 2002). The feasibility of the imagery for classifying more detailed land-use/land-cover classes (e.g. different types of built-up area) and the benefits of integrating them with optical images could be subjects of future research.

The region-based and knowledge-based classification approach applied in the study was useful for classifying the high-resolution SAR images with different channels. Various attributes based on segment properties and neighbourhood relationships could be used and flexible classification procedures could be developed. The general idea of using image-derived attributes to first classify certain segments and then to complete the result by also using information on neighbouring segments gave promising results, but further investigations on the benefits and feasibility of the approach are needed. Rules developed for the Sjökulla and Espoonlahti areas are not directly applicable to other areas and datasets. They could, however, be used as a starting point for the development of rules. Further study could include calculation of polarimetric parameters and the development of more general rules based on the scattering characteristics of different classes (see e.g. Pierce et al., 1994). It must also be noted that rule development for knowledge-based classification is a subjective task with an innumerable number of possible solutions. Rules selected in the present study represent one alternative. Similar or even better results might be achieved with a completely different set of rules and stages of classification.

The usefulness of the change detection result from Sjökulla (Figure 3b) is limited due to the difference in classes between the old map and the classification result (fields on the old map were compared with the open areas in the classification result; distinguishing meadows from fields, for example, was impossible using the imagery). The result does, however, demonstrate in practice automated change detection between map and image data, and some real changes, such as enlarged fields, were also found. The results of automatic change detection could provide useful information on possible changes in the area for further stages of map updating, especially if the content of the map was compatible with the information obtainable from the imagery. Updating a forest map with the E-SAR data, for example, might be a feasible application. Classification and change detection methods developed and tested in the present study could be directly applied (with necessary modifications of the rule sets).

6. CONCLUSIONS

Automatic interpretation of high-resolution E-SAR images for map updating was studied. The airborne E-SAR system produces data with characteristics that are similar to future TerraSAR images. The image data were segmented into homogeneous regions and classified into a few classes using rules defined on the basis of reference data. The main idea in the classification was to first use image-derived attributes (e.g. mean values and textural features) to classify certain segments (i.e. segments with the typical characteristics of a class) and then to complete the result by also using contextual information on the classes of the neighbouring segments. In the agricultural area of Sjökulla, an overall classification accuracy of 92% was achieved (classes in interpretation were water, forest, open and rushes). In the suburban area of Espoonlahti, the overall classification accuracy was 78% (classes were water, forest, open and built-up). Experiences from the region-based and knowledge-based classification approach were promising.

The results of the study indicate that the E-SAR data are well suited for automatic mapping of water, forest and open areas. Mapping of built-up areas as large entities is also possible but constitutes a more demanding task. Road mapping might be possible with specific road detection algorithms. Further research would be required on the feasibility of the imagery for classifying more detailed land-use/land-cover classes.

Automatic change detection between old topographic map data and the classification result was tested in the Sjökulla area. Different class definitions in the available map data and classification result limit the usefulness of the results (fields on the map were compared with open areas in the classification result), but for updating some other types of map (e.g. a forest map), the classification and change detection methods developed and tested in the present study could, however, produce useful information

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