measurements in 1994 were to become familiar with the area, to collect some basic data for developing the interpretation method and to evaluate the possibilities to make field measurements on a large scale. The measurements in 1995 contain 259 points, half of which were used in the determination of rules and the other half in the estimation of the interpretation accuracy.

2.3 Land use and class hierarchy

The topographic map is composed of four major land use classes: water, forest, cultivated land and urban area. These classes include in practice the following areas:

- Water: rivers, canals, fishponds and lakes,
- Cultivated land: rice-, banana-, sugarcane- and vegetable fields, gardens,
- Forest: different types of forest,
- Urban: industry-, housing-, office-, traffic- and construction areas.

The class hierarchy used in the interpretation is presented in Figure 1. Lowest in the hierarchy are 33 spectral classes which were interpreted in the Maximum Likelihood classification. Before the rule-based postclassification, these classes were combined so that 8 classes corresponding to the terminal nodes of the tree were obtained. The major land use classes are set nodes or terminal nodes in the tree. Some rules in the rule-based classification gave support to the terminal nodes and some others to the set nodes of the tree.

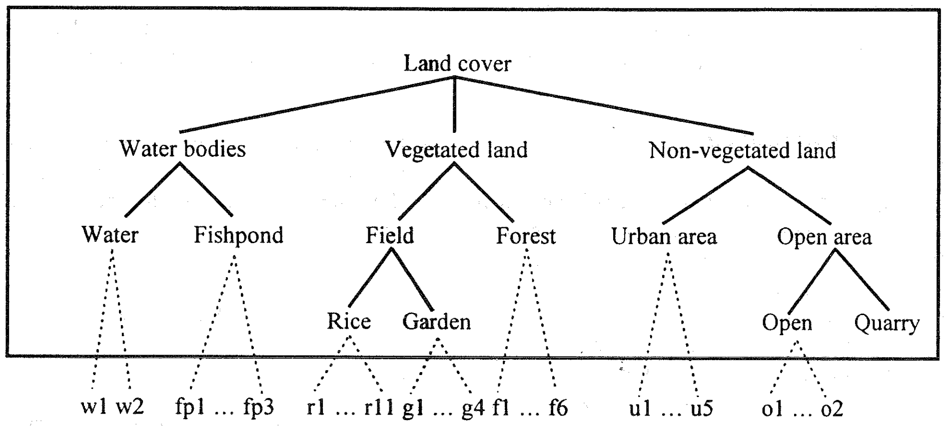

Figure 1. Land use and class hierarchy used in the interpretation.

3. METHOD

The interpretation method consists of segmentation, preclassification and rule-based postclassification of satellite and map data. In determining rules and believes for the rule-based classification, field measurements are used in addition to the data itself. Figure 2 shows the interpretation process.

3.1 Segmentation

Before interpretation, the satellite image is partitioned into spectrally homogenous, connected regions using a region-based segmentation method. Dealing with regions instead of pixels makes it possible to avoid noise in the interpretation result and, if needed, use spatial properties of the segments (for instance size, shape and neighbourhood) in addition to spectral information during the rule-based interpretation stage.

A method based on hierarchical region merging (Beaulieu and Goldberg, 1989) was implemented and used to segment the image. Initial segments are obtained by merging neighbouring pixels which are similar enough using a threshold value for each band. After that a merging cost based on segment sizes and means of DN's is calculated for each neighbouring segment pair in the image and the pair with minimum cost is merged. The merging costs are updated and merging is repeated until the desired number of regions is reached or the minimum merging cost exceeds a predetermined limit. For segmentation, the Zhong Shan image was divided into four subimages which were segmented separately and the results were then combined. Channels 3–5 of the TM image were used in the segmentation. The segmentation results have been evaluated visually and they are satisfactory.

3.2 Preclassification

The interpretation starts with the classical Maximum Likelihood method to interpret the segments based on training data. Channels 2–5 of the TM image were used in this study. The preclassification result contained 33 spectral classes, which were then combined to obtain the eight terminal classes in the class hierarchy, in order to start the next step in classification.

The class probabilities obtained from the ML-classifier for each segment or the accuracy of the preclassification results can be used to determine belief for terminal node classes in the rule-based postclassification. In this study, the accuracy of the results compared to the reference points was used.

UPDATING TOPOGRAPHIC MAP IN SOUTHERN CHINA BY USING SATELLITE IMAGE AND ANCILLARY DATA

X. Yu, L. Matikainen, R. Kuittinen
Finnish Geodetic Institute, Finland

Commission IV, Working Group 3

KEY WORDS: Land Use, Interpretation, Updating, Segmentation, Rule-based System.

ABSTRACT

A study was made to develop a method for updating land use information in topographic maps by using satellite images together with old maps in the rapid developing area of Zhong Shan in southern China. The method consists of three main parts: region-based segmentation of a satellite image, preclassification of the segments based on their spectral properties and rule-based postclassification. In the rule-based postclassification, the preclassification result is combined with information derived from old maps by using the Dempster-Shafer theory of evidence for hierarchical cases. The method was tested in the Zhong Shan area by using a Landsat TM image and an old topographic map. In determining rules and belief values, field measurements were used in addition to the data itself. The rule-based postclassification improved the classification results and the information of the old map proved to be useful in interpretation of land use classes which are near each other in the spectral space. The biggest problem was the spatial resolution of the Landsat TM image, which was too low to detect some small but very important features of the study area.

1. INTRODUCTION

The need to update topographic and thematic maps increases as the frequency of changes in land use increases. These changes are relatively rapid especially in south-eastern Asia because of the rapid economic development. Traditionally satellite images are used for mapping as the only source of information and the results are only moderate even if visual interpretation or combined visual and mathematical interpretation is used (Ahokas et al., 1990). The main reasons for this are that the interpretation is mainly based on spectral information and the spatial resolution of the images is too low. New methods are needed to obtain better accuracy in the interpretation.

Most of the mapping tasks consist today of updating of old maps, which offers the possibility to use maps and satellite data together in the interpretation. If useful mathematical methods can be found, the combined use of several data in interpretation can lead to more accurate results. The Dempster-Shafer theory of evidence and its modifications to hierarchical cases offer a good possibility to combine different types of data in the interpretation (Gordon and Shortliffe, 1985, Shafer and Logan, 1987, Wilkinson and Mégier, 1990).

The aim of this study was to apply the Dempster-Shafer theory of evidence in updating topographic maps in southern China where satellite images and old topographic maps are available. The method consists of the following parts:

- Segmentation of the satellite image into spectrally homogeneous, connected regions using a region-based segmentation method,
- Preclassification of the segments into spectral classes using the conventional Maximum Likelihood classification method (Duda and Hart, 1973),
- Determination of attributes and rules for rule-based postclassification,
- Postclassification using the preclassification result, old maps and a rule-based interpretation method based on the Dempster-Shafer theory for hierarchical cases (Shafer and Logan, 1987).

2. STUDY AREA AND DATA

2.1 Study area

The study was based on data from the Zhong Shan area of size 20 km x 17 km. Zhong Shan is located in the Guangdong province in the southern part of China. It is an area that has developed economically very quickly in recent years. New office buildings, factories and private houses have been built, a lot of fishponds and roads have been constructed and a lot of gravel pits are used. Most of these changes have decreased the amount of cultivated land, especially rice fields. The land use has changed so much that there are large demands for up-to-date land use information for city planning and decision making.

The area is relatively flat. The differences in elevation are less than 10 m for agricultural land, urban area and water, while forests are located in the hilly area ranging from 10 m to 250 m. Some rice fields had been harvested and burned at the time of the satellite image registration.

2.2 Data

A Landsat TM image from 24 December 1993, a digitised land use map in raster format and a digital elevation model (DEM), derived from the topographic map of 1983 on a scale of 1:50,000, were used to produce an updated topographic map. The satellite image was rectified to the coordinate system of the topographic map.

Field measurements were made in the Zhong Shan area in November 1994 and 1995 respectively. The aims of the

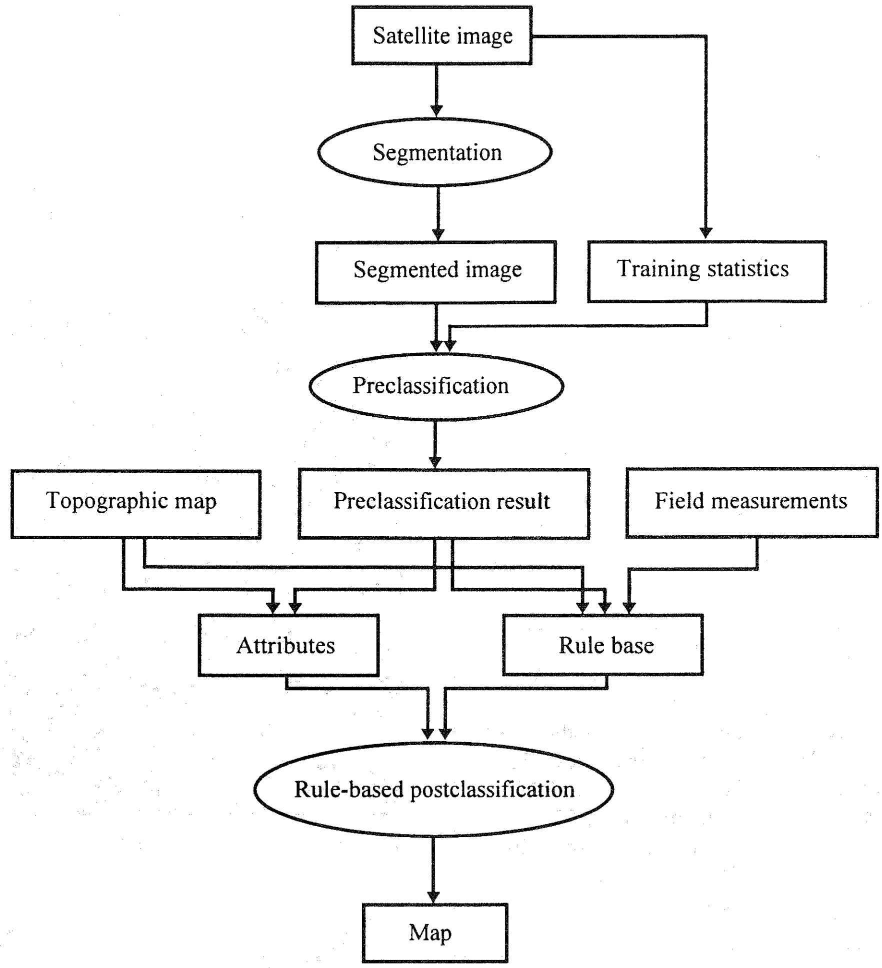

Figure 2. The interpretation process.

3.3 Postclassification

The advantage of a rule-based method is that different kinds of digital data can be used in the interpretation if the data is in image format and relevant decisions can be made from it. A satellite image itself is a valuable data source because of its multitemporal and multispectral properties, but the low spectral, spatial and temporal resolution limits its ability to identify objects with almost similar spectral signatures or objects which are smaller than the sensor's IFOV on the ground. In these cases more information is needed to correctly interpret the objects. The data from GIS, e.g. a topographic map, existing land use map. soil map and road network etc., usually provide such information.

Attributes. The attributes used in the rule-based postclassification are presented in Table 1. They were derived from the preclassification result and the old topographic map.

Data	Attribute
Topographic map	Land use class Height
Preclassification result	Land use class

Table 1. Attributes used in the postclassification.

Rules. Knowledge used in the interpretation could be taken from the experience and knowledge of objects, history and development of the objects, natural law and results of interviews with experts and users. Considering the nature of such kinds of knowledge, it may be partial or unreliable. This leads to a degree of uncertainty regarding the conclusions that could be drawn from the knowledge.

In this study, information about the landscape and its changes was collected by field measurements. Before a rule-base for the postclassification was created, investigations on the attributes and their relationships with ground classes were made. For instance, the old land use map was compared to the reference points and probabilities for changes in land use were calculated. The rules and belief values given by the rules were mainly based on these investigations. The rules were collected in a separate rule base.

A rule can confirm or disconfirm any class in the hierarchy (Figure 1) by assigning a confirming or disconfirming belief to this class. Because of the different information contents of the different data sources, rules derived from the preclassification result give belief to the terminal classes in the hierarchy, while rules derived from the topographic map give belief to the major land use classes. Most of the rules used in this study were based on one data source only. Exceptions to this were four rules based on both preclassification result and height data, which were needed to distinguish quarries from other open areas.

Examples of rules based on the preclassification result are presented in Table 2. All the rules derived from the old land use data are presented in Table 3 and all the rules derived from the height data in Table 4.

Condition	Action
If ML-class is fishpond	Confirm fishpond 0.50
If ML-class is fishpond	Confirm water 0.30
If ML-class is fishpond	Confirm garden 0.10
If ML-class is fishpond	Confirm open 0.05
If ML-class is water	Confirm water 0.90
If ML-class is garden	Confirm garden 0.65
If ML-class is garden	Confirm forest 0.20
If ML-class is garden	Confirm rice 0.10

Table 2. Examples of rules and believes determined from the preclassification result.

Condition	Action
If land use is water	Confirm water bodies 0.9999
If land use is cultivated land	Confirm field 0.60
If land use is cultivated land	Confirm water bodies 0.10
If land use is cultivated land	Confirm urban area 0.15
If land use is cultivated land	Confirm open area 0.15
If land use is forest	Confirm forest 0.50
If land use is forest	Confirm urban area 0.20
If land use is forest	Confirm open area 0.30
If land use is urban	Confirm urban area 0.9999

Table 3. Rules and believes determined from the old land use data.

Condition	Action
If height < 10 m	Disconfirm forest 0.90
If height ≥ 10 m	Disconfirm water bodies 0.70
If height ≥ 10 m	Disconfirm field 0.80
If height ≤ 25 m and ML-class is open	Confirm open 0.70
If height ≤ 25 m and ML-class is open	Confirm quarry 0.05
If height > 25 m and ML-class is open	Confirm open 0.25
If height > 25 m and ML-class is open	Confirm quarry 0.50

Table 4. Rules and believes determined from the height data.

Combination of evidence. When all the belief values that the rules give for a particular segment or pixel have been assigned to classes, the evidence is combined using the Dempster-Shafer method for hierarchical cases. The method calculates a final belief value for each class in the hierarchy taking into account the belief values of the whole tree. In this study, the segment or pixel was classified as the terminal class having the highest final belief.

4. RESULTS

4.1 Maximum Likelihood classification

Result of the Maximum Likelihood classification for a subarea of size 11.7 km x 13.75 km is presented in Figure 4. The confusion matrix of the Maximum Likelihood classification can be seen in Table 5. The classification was segment-based (Figure 3).

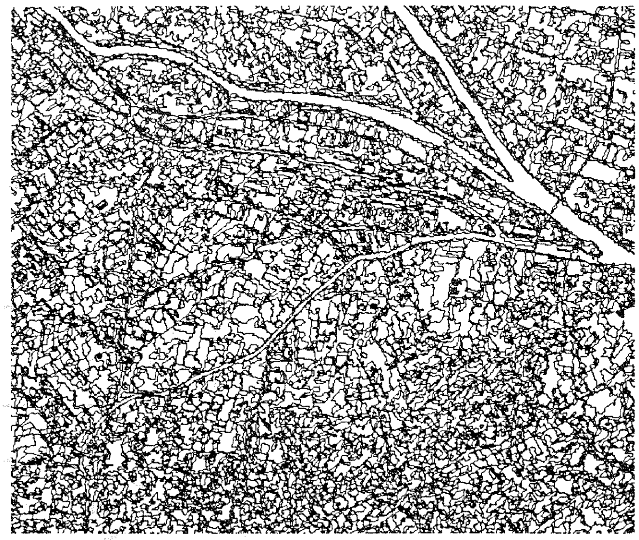

Figure 3. Segmentation result.

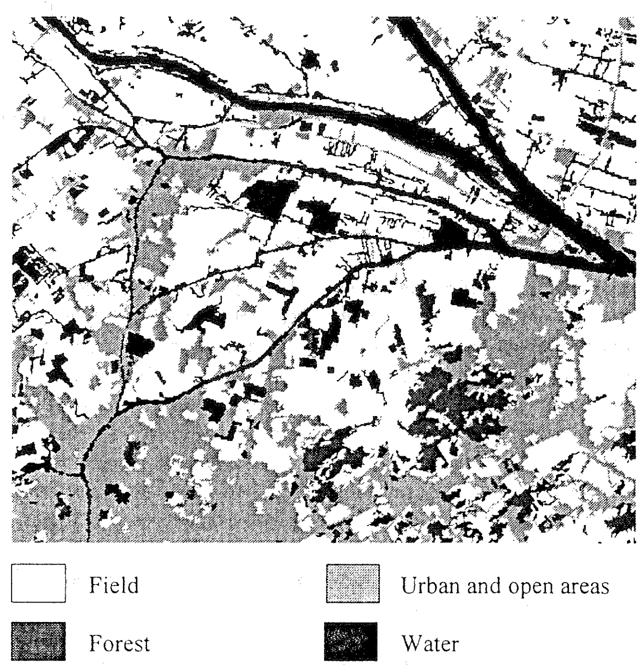

Figure 4. Result of the segment-based Maximum Likelihood classification.

Reference classes						
Class	Water	Field	Forest	Urban	Open	Total
Water	7	0	0	0	0	7
Field	2	52	6	2	3	65
Forest	0	1	9	0	0	10
Urban	2	7	1	13	5	28
Open	0	1	0	2	17	20
Total	11	61	16	17	25	130

Table 5. Confusion matrix of the segment-based Maximum Likelihood classification.

4.2 Rule-based postclassification

Table 6 presents the confusion matrix of the rule-based classification when also this classification was based on segments. When the rule-based classification was pixel-based, the confusion matrix presented in Table 7 was obtained. The result of the pixel-based classification is presented in Figure 5. It should be noted that segments had been interpreted in the Maximum Likelihood classification stage also in this case.

Reference classes						
Class	Water	Field	Forest	Urban	Open	Total
Water	7	0	0	0	0	7
Field	2	52	2	1	3	60
Forest	0	1	13	1	0	15
Urban	2	7	1	13	5	28
Open	0	1	0	2	17	20
Total	11	61	16	17	25	130

Table 6. Confusion matrix of the segment-based postclassification.

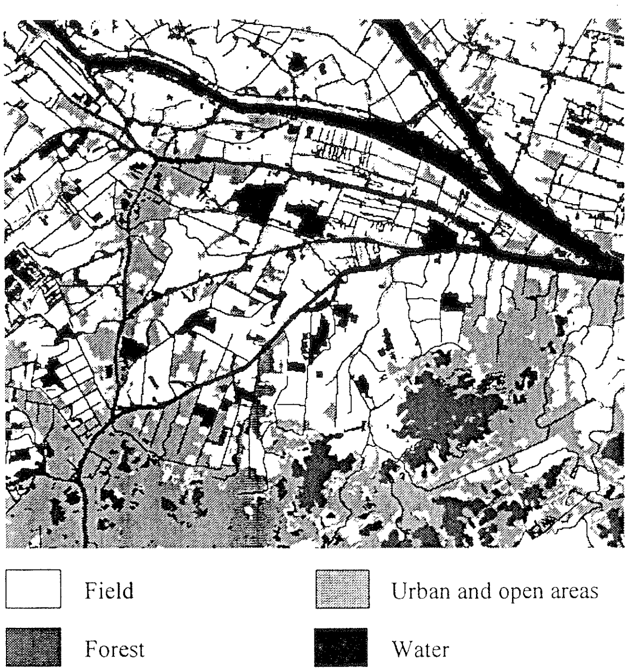

Figure 5. Result of the pixel-based postclassification.

Reference classes						
Class	Water	Field	Forest	Urban	Open	Total
Water	7	0	0	0	0	7
Field	2	53	1	0	3	59
Forest	0	0	14	1	0	15
Urban	2	7	1	14	5	29
Open	0	1	0	2	17	20
Total	11	61	16	17	25	130

Table 7. Confusion matrix of the pixel-based postclassification.

The mean accuracy and the total accuracy of the classifications are presented in Table 8. In addition to the classifications discussed above, a pixel-based Maximum Likelihood classification was made to allow evaluation of usefulness of the segmentation as a preprocessing operation.

Classifications				
Class	1	2	3	4
Water	47 %	78 %	78 %	78 %
Field	78 %	83 %	86 %	88 %
Forest	69 %	69 %	84 %	90 %
Urban	32 %	58 %	58 %	61 %
Open	72 %	76 %	76 %	76 %
Total	67 %	75 %	78 %	81 %

Table 8. The mean accuracy and total accuracy of different classifications. Column 1 is the pixel-based ML-classification, column 2 is the segment-based ML-classification, column 3 is the segment-based ML-classification followed by the segment-based postclassification and column 4 is the segment-based ML-classification followed by the pixel-based postclassification.

5. DISCUSSION AND CONCLUSIONS

The rule-based postclassification improved the interpretation results, especially when it was pixel-based. The biggest changes in the postclassification occurred in the hilly areas where some forests had been misclassified as field in the preclassification, and on the other hand in the flat area where some fields had been misclassified as forest. Some of the forest and field areas are very similar in the spectral space which causes the errors in the Maximum Likelihood classification. For interpretation of these classes, the old land use data and height data are very useful. It improved the result both in the pixel-based and in the segment-based postclassification.

A very remarkable change in the pixel-based postclassification was that the numerous narrow canals of the old land use map, which were missing in the segment-based Maximum Likelihood classification, appeared in the results. This change cannot be seen in the error matrices because of the small number of reference points available for the accuracy evaluation. When the postclassification was segment-based, the canals were also missing in the final result because of errors in the segmentation stage.

Mixels and errors in the segmentation cause a basic error which is impossible to remove in the interpretation stage. A big problem in the study area is that many features are too small to be reliably detected in Landsat TM images. For instance, the width of many canals is about one pixel or less and thus the canals disappear in the region-based segmentation process, although the segmentation results are otherwise quite good. To improve the interpretation results, images with higher spatial resolution are needed.

The advantage of the segmentation in this study was the increase in the Maximum Likelihood classification accuracy compared to a pixel-based classification (Table 8). A segment-based classification gives a result with homogeneous regions like in a map. If segmentation is not used, good generalisation procedures are needed.

In this study, only three information sources were available in the rule-based postclassification, and the belief values, which were based on relationships between reference points and classification attributes, were the same for all the test area. The changes in the postclassification compared to the Maximum Likelihood results were quite straightforward. For instance, every segment or pixel which was cultivated land on the old map, forest in the Maximum Likelihood classification and the height of which was between 0 and 10 metres was postclassified as rice. A more ideal solution would be belief values which change continuously depending on characteristics of each segment or pixel. For instance, the probability that a field changes to urban area is much bigger near the town centre than far from it and the probability that forests exist increases as the height increases. However, to reliably exploit this kind of information, more reference points than what was available for this study would be needed.

The future research will focus on use of SAR images and SPOT panchromatic images together with Landsat TM images and use of spatial information, such as neighbourhood relationships of segments, in the interpretation process. The interpretation method has been designed and implemented so that it allows addition of these new data sources. The most difficult problem is to find good rules which give realistic and objective belief values based on the different data sources.

REFERENCES

Ahokas, E., Jaakkola, J. and Sotkas, P., 1990. Interpretability of SPOT data for general mapping. European Organization for Experimental Photogrammetric Research, Official Publication No. 24.

Beaulieu, J.-M. and Goldberg, M., 1989. Hierarchy in Picture Segmentation: A Stepwise Optimization Approach. IEEE Transactions on pattern analysis and machine intelligence, 11(2), pp. 150-163.

Duda, R. O. and Hart, P. E., 1973. Pattern Classification and Scene Analysis. John Wiley & Sons, New York.

Gordon, J. and Shortliffe, E. H., 1985. A Method for Managing Evidential Reasoning in a Hierarchical Hypothesis Space. Artificial Intelligence, 26(3), pp. 323-357.

Shafer, G. and Logan, R., 1987. Implementing Dempster's Rule for Hierarchical Evidence. Artificial Intelligence, 33(3), pp. 271-298.

Wilkinson, G. G. and Mégier, J., 1990. Evidential reasoning in a pixel classification hierarchy — a potential method for integrating image classifiers and expert system rules based on geographic context. International Journal of Remote Sensing, 11(10), pp. 1963-1968.