"ADVANCES IN THE AUTOMATIC PROCESSING OF SATELLITE IMAGERY"

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ABSTRACT
This paper reviews advanced research topics underway in the Environmental Mapping and Modelling Group at the Joint Research Centre in the area of image processing. Three main areas of current work are discussed. These are (i) development of neural networks for automatic classification of remotely-sensed imagery, (ii) use of expert systems in image classification and (iii) image partitioning based on enhanced segmentation methods. The methodologies behind each technique are presented.

INTRODUCTION

The extraction of useful information from satellite imagery is the main technical problem which lies at the heart of remote sensing. Image data from current operational satellites are difficult to use for many land surface mapping and monitoring activities especially those concerned with agriculture. The main reasons for this are:

- The spectral information recorded for pixels is not sufficient in most cases to uniquely identify vegetation species or surface cover types;
- The resolution cell of the satellite imagery, i.e. the pixel on the ground, usually includes a mixture of pure cover types since few landscapes have total homogeneity over a space scale of the order of tens of metres upwards;
- The image data volumes involved in national or continental scale remote sensing are excessively high.

For these reasons the operational exploitation of remote sensing requires the use of not only the best techniques available for interpreting large volumes of incomplete and often inadequate data but also statistical approaches for bridging the gap to very strict end-user requirements. At the JRC the Agriculture Project is concerned with all aspects of this problem and is attempting to make the vital connection between imperfect satellite data and operational usability.

Alongside this project, however, there are on-going innovative research projects within the Institute for Remote Sensing Applications concerned with attempting to find improved ways of extracting initial products from imagery. This work is currently concerned with developments in the following areas:

- Artificial Neural Networks
- Expert Systems or Artificial Intelligence
- Integration of GIS Information in Image Analysis
- Development of Image Segmentation or Partitioning Methods
- Exploitation of Parallel Computing

Three projects are currently underway which are each using a combination of these new techniques. They are:

(i) NEURAL NETWORK CLASSIFICATION (exploration of artificial neural network models and parallel computing)
(ii) EXPERT SYSTEM POST-CLASSIFICATION REFINEMENT (exploration of A.I. methods and integration of GIS information)
(iii) IMAGE PARTITIONING (exploration of new 'segmentation' algorithms and parallel computing)

In addition work is planned on the integration of these techniques. Collectively the combination of all these techniques should permit significant progress in the exploitation of remotely-sensed satellite imagery for operational applications.

NEURAL NETWORK METHODS FOR IMAGE CLASSIFICATION

The classification of satellite imagery is a standard pattern recognition problem. Neural networks have been found to offer many benefits in this field. Neural network research is motivated by the ultimate desire to simulate the extraordinarily efficient pattern recognition ability of the human brain and also to exploit parallel computing. Many models exist for artificial neural networks. At the JRC we have undertaken experiments mainly with multi-layer perceptron networks. These networks consist of up to 4 layers of interconnected processing nodes. Such networks have a layer of processing nodes which accept the input variables used in the classification procedure. Typically these will be the radiance values of the different channels from the satellite image. There are then one or two internal or 'hidden' processing layers and finally an output layer with one node per class that must be detected in the data. The principle of the network is that when data from a pixel is presented at the input layer the network nodes perform calculations in the successive layers until an output value is computed at each of the output nodes. This output signal should indicate which is the appropriate class for the input data -i.e. we expect to have a high output value on the correct class node and a low output value on all the rest. The nodes in a particular layer in the network compute weighted sums of the outputs from the layer below -the interconnections between the nodes can thus be viewed as carrying weighting factors. Also after each weighted sum has been calculated a kind of thresholding function is applied to the result either to amplify it or to suppress it. This is a very crude analogy of the behaviour of biological neurons. The functionality of the

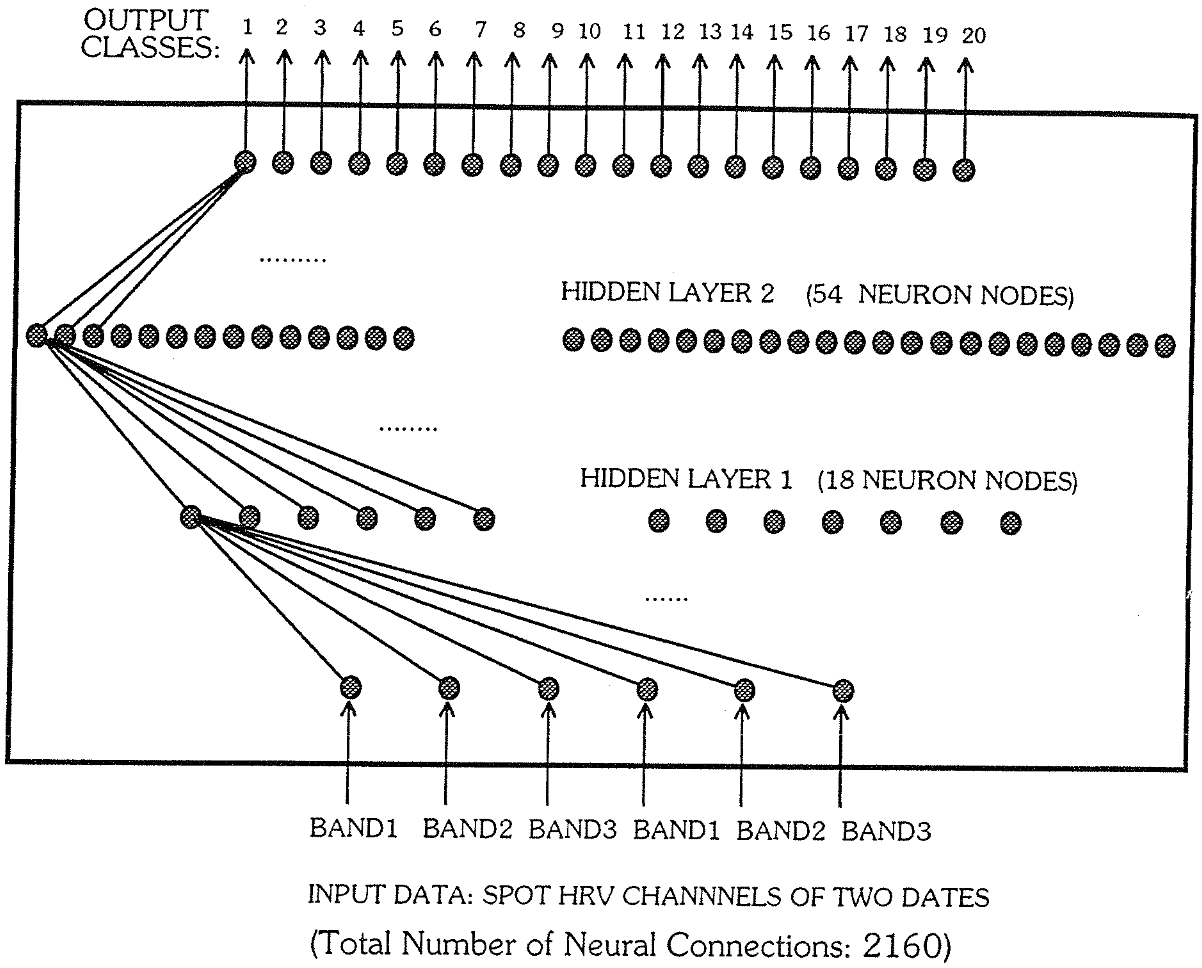

FIGURE 1. NEURAL NETWORK ARCHITECTURE USED FOR SATELLITE DATA

network is intimately related to the weighting factors associated to its internal weights. In fact these have to be trained by using example data taken from a ground data set. In this respect the neural network has to be used like a conventional supervised classifier. A typical network used in some of our experiments is shown in figure 1. This is a network for classifiying 6 channel satellite data into 20 separate land cover classes. The training of this network is described more fully in the paper in these proceedings by Kanellopoulos.

So far it has been found that the neural network method achieves a very high-level of performance in classification. Averaged results of the order of 80-85% accuracy for 20 classes have been achieved which exceed results obtained by more conventional methods by a significant margin (Kanellopoulos et al. 1991). The main problem in using such networks is that the training procedure can require many passes through the ground data until a good internal representation of the landscape is achieved. For this reason work is proceeding on exploiting parallel transputer networks to carry out this task. The main difficulty here is the mapping of the sequential iterative training algorithm into an efficient parallel process adapted to a specific transputer net architecture. Work is currently underway at the JRC on this problem.

EXPERT SYSTEM APPROACH IN IMAGE CLASSIFICATION

The second main activity on image understanding is concerned with exploiting ancillary knowledge and datasets. The exploitation of additional information, models, or knowledge is a widely-accepted approach for enhancing the products which can be extracted from images in fields such as machine vision. In remote sensing it is common to have additional map datasets available which could be used to provide constraints to augment the image data alone. It is clear that many features of the Earth's surface have particular geographic associations. For example vineyards are not found at high altitudes and arable crops do not normally occur on un-drained gley soils. Facts of this kind can help us to eliminate some of the errors and uncertainties arising from the use of satellite. Such facts can be exploited by using background maps (providing, for example, soil type and terrain height) and rules which are based on the knowledge available. Ideally the maps should be in a digital form in a geographic information system (GIS). In some cases rules can be of a "common-sense" variety (such as the statement about vineyards) or of a more expert variety (such as the statement about arable crops and gley soils). The expert system or knowledge-based system technique which combines facts and rules is thus an obvious technique to exploit available GIS map datasets in analysing imagery. In general the more "imperfect" the satellite data the more essential it is to use a rule-based approach. For example in agricultural areas with large very well-defined fields and for which good multi-temporal clear-sky image data is available it may not be necessary to augment the image analysis with a rule-based system. However when these ideal conditions do not apply the use of a rule-based system would be very beneficial. In fact in European agricultural applications of remote sensing the ideal conditions are very often not met. For example much of the agriculture in southern European / mediterranean areas is based on small fields or plantations which are difficult to recognise well in imagery. The highly-mixed pixels at the borders of the fields constitute a large proportion of the land surface cover leading to a high error level in image products. In northern parts of Europe a rather different problem applies: the presence of cloud which restricts the availability of multi-temporal imagery (Kontoes and Stakenborg 1991). A prototype system has already been developed at the JRC -see figure 2. The purpose of this system is to apply a rule-based procedure after the satellite imagery has initially been classified by conventional statistical techniques. The rule base is used to improve the initial classification of the imagery and is thus known as a post-classification refinement system. In practical terms the system uses an

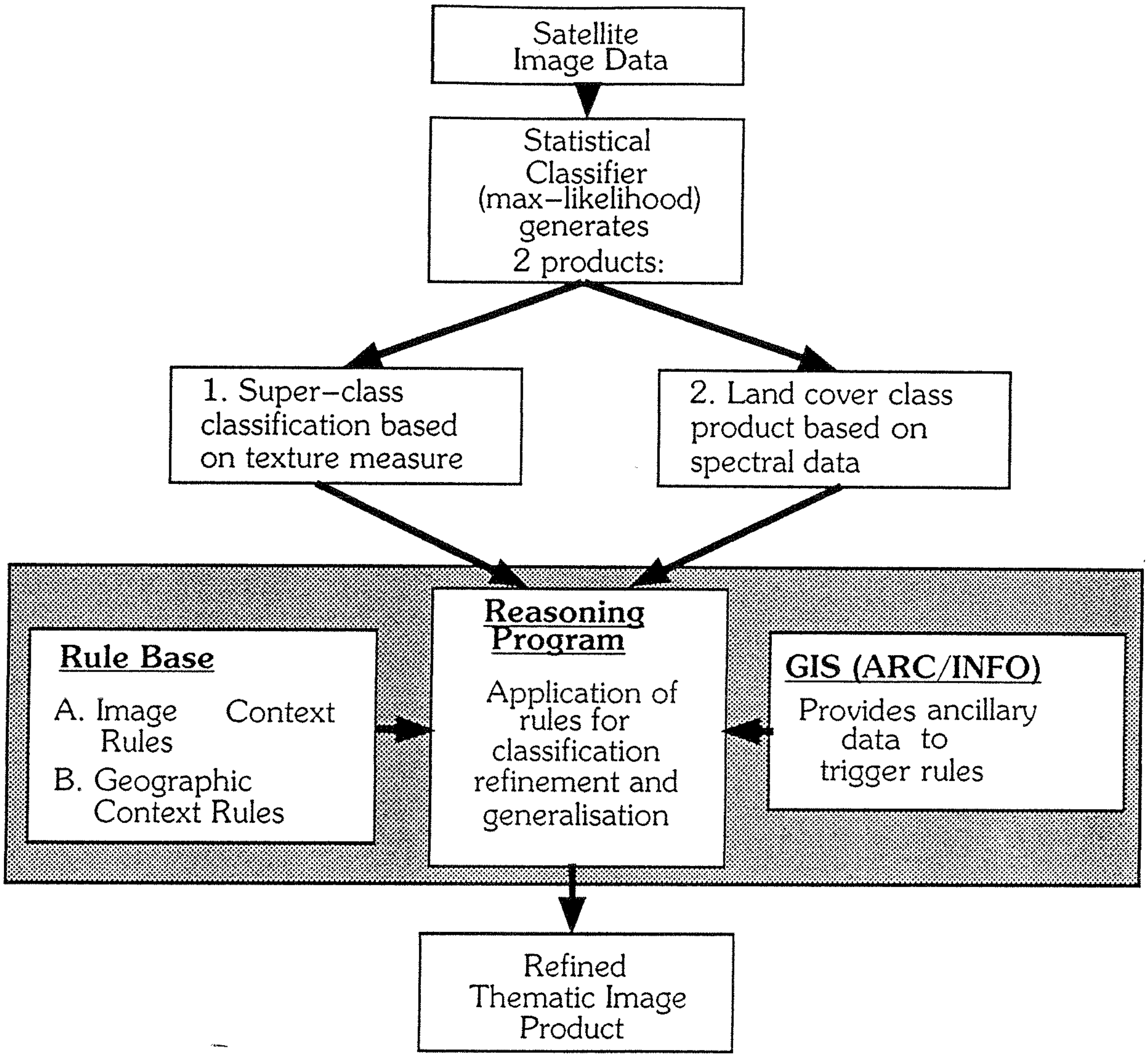

FIGURE 2. PROTOTYPE EXPERT SYSTEM FOR IMAGE ANALYSIS

ARC/INFO GIS to provide background data and uses rules concerned not only with geographic context but also with 'image context'. This latter type of rule is concerned with filtering the image product using properties of the neighbourhood in the image. For example it is unlikely that single 'rape-seed' pixels will be found in the middle of a 'forest'. The spatial properties of the initial classification product can thus be utilised for some additional refinement.

One of the most important features of any rule-based system is a method for "reasoning" -i.e. a method for combining uncertain information. For example many rules that could be used to state contextual geographic associations will not indicate definite YES/NO situations but more realistically "tendencies". The combination of uncertain information is a vital part of any rule-based system. At the JRC we have implemented an approximation to the Dempster-Shafer theory of evidence (Gordon and Shortliffe 1985). This allows multiple pieces of evidence (both confirming and disconfirming classes) to be combined mathematically in a realistic way (see Wilkinson and Mégier 1990, Wilkinson 1991).

Some experimental tests of the rule-based method have been carried out in the Loir-et-Cher department of France. In order to refine the initial image products for a predominantly agricultural area a rule base was built to exploit a background soil map and road proximity map. The results from this work are described more fully in the paper by Kontoes in these proceedings. Overall significant improvements have been achieved by using this technique.

Work has also been undertaken on the construction of an interactive window-based user interface for the rule-based system (Goffredo 1991). The purpose of this system is to allow a user at a workstation to interactively interrogate images on-screen and to view classification results and to see which rules apply to particular pixels. Full information about the rules is provided to the user besides detailed explanations. This provides the possibility for the user to understand how the classification refinement decisions have been taken by the automatic system. This has potential both in researching and developing optimal rule bases and also in educating users about important environmental relationships.

NEW PARTITIONING AND SEGMENTATION APPROACHES

The segmentation of imagery is another important image processing technique which has considerable importance in remote sensing. Segmentation is normally regarded as the task of spatially grouping pixels which have identical or very similar spectral properties on the assumption that homogeneous regions can be defined which represent significant features on the land surface such as fields, forests, towns, water bodies etc. By segmenting the images we have the possibility of more accurately classifying fields (by using the average properties of the pixel group instead of a noisy individual pixel) and also to more easily break the landscape into units which can be compared with conventional map data or even entered into digital databases and GIS. Also field units are easier to handle in statistical analysis than individual pixels. The main problem with segmentation is that the complexity of the landscape and the high numbers of mixed pixels make it very difficult to realistically extract useful land cover units. Spectral variations of pixels even within the same field due to variations of density and orientation of the crop and bare or 'weedy' patches can cause significant problems. Also at the edges of fields there are always a high proportion of badly mixed pixels because they will often overlap adjacent fields, hedgerows, tracks etc.

Work has also been undertaken on this problem at the JRC within the last two years. The conventional methods of performing segmentation (used much in machine vision) are either to attempt to detect borders of homogeneous spatial units (by detecting sharp changes or edges in the pixel radiances) or to find spectrally-similar and spatially-adjacent pixels by a region-growing technique which starts from 'seed-pixels' and looks for neighbours which can be realistically joined to them in a spatial group. The problems with both techniques are well-known. Essentially the presence of mixed pixels means that edge detection may produce only edge fragments rather than complete borders and region-growing misses out areas which are near the edges of fields or which are slightly spectrally impure. Again important improvements can be made to these techniques if we exploit spatial context information. At the JRC we are currently working on the integration of region-growing and edge detection and also using a rule-based approach to join pixels to segments on the basis of spatial context when there is good justification for doing so even if the spectral data alone would deny this possibility. The result of this is to create a spatially simple description of the landscape which is effectively a segmentation although some of the spectral criteria for segmentation are violated. For this reason we prefer to label the method as image 'partitioning'. The method is founded initially on the best merge region-growing technique devised by Tilton and Cox (1983). This is a good region-growing method because it largely avoids order-dependence difficulties associated with many segmentation methods. Basically the procedure is iterative and involves the merging of the most spectrally similar pair of adjacent pixels in the whole image at each iteration. The method is not however without its drawbacks -a significant one being that it is very time-consuming. For this reason we are now developing an implementation for a parallel transputer network. Further information on this can be found in the paper by Schoenmakers in these proceedings.

CONCLUSIONS

The successful exploitation of remotely-sensed satellite imagery places great demands on our ingenuity and ability to utilise computational image analysis techniques. It is generally expected that real progress in the field of remotely-sensed image analysis will come through exploitation of novel approaches such as those based on use of expert knowledge and connectionist or neural computing. There are still significant hurdles to overcome before such approaches take their place in the operational tool-kit of the remote sensing analyst but important steps have now been taken in this direction. The development of portable software packages to implement such techniques will be an important component of this new direction. It is hoped that the work already undertaken on prototype systems at the JRC will lead to new packages and to a much wider employment of these new techniques at least in experimental developments if not yet in operational applications. There is still much to learn about the nature of visual imagery and its understanding and we are pleased to be able to contribute to what is currently an extremely exciting and rapidly-developing area of research.

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