# AN INVESTIGATION OF AUTOMATED DATA SYSTEMS IN PHOTOGRAPHIC REMOTE SENSING

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## SUMMARY

The thesis opens with an explanation of why the investigation is restricted to photography, why there is a need to automate the analysis of the photography, and why there is a need for an analysis system on which user and image scientist can work in close liaison.

The software used in current automated systems is discussed: particular reference being made to the scope of programs and their limitations. The substantial effort invested in spectral processing is highlighted, and the topic of spatial processing is introduced to illustrate how the analysis of the photography can be developed.

A review is made of the wide range of hardware available for remote sensing automated applications A distinction is made between the so called automated systems by dividing them into three types: digitising, enhancement and true analysis.

The type of computer system required to meet the needs of user and specialist is outlined in more detail. The concept of spatial processing is extended to the concept of picture processing and scene analysis, suitable for implementation on a digital computer system.

The needs of the general user are first considered in the development of a system utilising a small digital computer: this system is then subsequently extended to meet the needs of the specialist wishing to add new analysis routines which the user can try.

The severe limitations of the current and widespread practice of using only spectral data are stressed, and the value of supplying even more spectral data when using multi spectral photography is questioned.

The close co-operation of user and data handling specialist is essential if the end results are to be meaningful and cost-effective. The 'user' needs to rethink his dominantly manually operated processes and give more consideration to the advantages of 'automated' processes.

Remote sensing, data processing, image processing, pattern recognition, interactive systems.

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CHAPTER 1

INTRODUCTION

# CHAPTER 1

# INTRODUCTION

## 1.1 The subject related to Remote Sensing

An early use of aerial photography was for topographic mapping purposes; subsequently, aerial photographs were used for other types of survey such as land use mapping. In these surveys panchromatic and colour film were used. Later infra-red film, developed from military sources, found a use in vegetation work. Then ideas developed for increasing the information obtainable from aerial photographs by splitting the photographic spectrum into a number of bands. So instead of one set of information from one photograph it was possible to have several sets, one from each band. This was designed to give a much greater chance of correct interpretation.

From this sprang numerous other ideas concerning splitting the entire photographic spectrum into even narrower bands (Kondratyer 1972). Other regions of the spectrum such as radar, microwave (fig.1) and thermal infra-red were used to produce images for interpretation. The main rival to the photograph, the optical mechanical scanner, can produce up to 24 registered images, each taken in a very narrow band of the spectrum, of the same ground area.

This proliferation of image data produced an enormous problem of image data processing and interpretation, which was met by an equal proliferation of 'automated' image analysis systems. All these systems claimed use as the basis of an operational system, but very few are actually used operationally.

Figure 2.     'Scandig' drum scanning microdensitometer.

These are not to be confused with the very large, powerful and specialised satellite processing systems such as that developed by the Jet Propulsion Laboratory.

An excellent introduction to the topic of digital image processing in this field is given in the review article by G. Nagy (1972). This article explains in brief all the facets of this subject and provides a list of 224 key references. It concentrates on American work because at that time there was little or no work done on this subject outside the U.S.A.

However, this study is conducted in a British University, and therefore looks at this field from a European point of view. This is greatly different from the viewpoint of the world leaders in this field, namely the Americans. They have the money to spend on expensive scanners, satellite data gathering systems and big computers.

From the European point of view, small computer systems are more readily available and it is felt there is more potential for photographic systems that are well tried and cheap to operate. Satellite cover of Europe is relatively sparse and cloud covered, and scanners in Europe are few in number and expensive to operate. Photographs have the additional advantage of being cheap and efficient retrieval.

Considering the many hardware and software systems on offer, it seems the best approach is to start with a flexible digital computer system. The research and development can be done on these relatively slow machines, and as far as possible 'operational' systems can be based on special purpose machines.

Having decided on a small computer system, there is the problem of converting the photograph into a computer useable form. In Britain we are in the fortunate position of having Joyce Loebl, a leading firm in the manufacture of microdensitometers. Through the I.H.D. Scheme of the University of Aston it was possible to bring this firm into the research project. A microdensitometer (fig. 2) prepares the photograph by a process called digitisation. This can be done 'on line' in real time or the data stored on magnetic tape and processed later. There are other machines and methods of digitisation and these are also investigated in this thesis.

Initially in the field of remote sensing the hardware and software were borrowed from other disciplines and as a result the marriage of the two was not always successful. It was gradually realised that remote sensing could prove to be a powerful and economic method of gathering large amounts of potentially useful information. Clearly some tailor made automatic or semi-automatic system of data processing was required.

The relatively simple operations of image manipulating and enhancing were automated quite easily. However, development slowed down when attempts were made to automate interpretation; though this met with a certain limited success.

The present stage is one of a proliferation of data acquisition, but limited use of automatic interpretation. A number of parallel lines of development are now taking place in interpretation by automatic methods, collection of suitable and relevant imagery, and defining real uses for the automated systems.

The development of a useful system of image interpretation must take into account that the people who want results from such a system will in general be non-technical. However, as with all complex systems an expert is needed somewhere in the chain. For example even in map production expert photogrammatists are needed to manage the systems. Similarly people expert in image analysis and data handling will be required to look after an automated system.

In this study a research system is initiated, and methods to expand this are developed. The research system - developed with the knowledge that the user generally will not be a physical scientist - is an interactive one developed around a visual display unit and small computer. This enables the system to be used as a research tool in two fields: i) by the user to determine how and on what the system can best be used and ii) by the computer scientist to develop better image processing methods. Therefore this implies close co-operation between user and scientist.

1.2 The subject related to the general scientific field.

This thesis is an initial step in an investigation into automated methods, as distinct from machine aided or enhancement systems. Machine aided does not mean a half hearted attempt at automation, but an interactive or non-interactive system still relying on the human doing the interpretation. Enhancement systems are those that merely depict a changed version of the image, in either black and white white or colour: the enhanced version is aimed to show more than the original version.

One aim of this study is to find where automation can be useful and how it can be applied. At present the best use of automation proper lies in image screening, i.e. looking for one type, or at most a few types, of object in the image. At present a simple but effective classifier can be used for rapid image screening.

Computers are designed to do simple repetitive tasks millions of times with consistent accuracy. Thus, the present state of operational systems is best left to simple repetitive tasks on bulk data. For example measuring the crop acreage of wheat at a given time of year could be simply achieved. Whether there is any real need, as opposed to an artificially created need, for such a system, is at present unanswered.

It is not possible at present to produce a system that will give, for example, an interpretation of an image into a land use classification (Anderson,Hard 1973). This must be considered a long term exercise. An image may be classified into regions but these regions are based solely on the identifying ability of the software and are not necessarily related to any land use classification.

It is necessary to explain the difference between classification and recognition.

Sayre (1965) states "classification of a group of objects is a matter either of sorting them according to a given set of categories or of devising a set of categories by which they can be sorted"; whereas recognition is an attainment not a process like classification. Recognition is a certainty, whereas classification is subject to limitations of accuracy, i.e. you can recognise an 'object' and be able to point it out even though you cannot identify it, someone else can classify it as certainly, or probably, a Ford motor car.

The recognition involved in the bulk of the work in this thesis is called pattern recognition. The patterns to be recognised are usually sets of numbers representing some aspect of the image or part of the image, not necessarily a complete object. These sets of numbers are known as 'features' of the image and the main work to date in pattern recognition in remote sensing has been the extraction of useful features.

Pattern recognition is part of the larger field of Artificial Intelligence, which in turn is part of Cybernetics. Cybernetics being the control of automata and communication between automata.

Photographs communicate a large amount of information which we recognise, based on the complex patterns of size and shape produced by the interaction of tone and texture. Just using pattern recognition based on numbers or features in automation, obviously leaves out a lot of the human thought processes that go on during interpretation. The aim is to extract from the image a feature that can be used in a meaningful way to classify the object, this feature should be more than just a number it should describe some characteristic of the object, like rough texture or colour. This leads into more complex stages of recognition processes than can be achieved by 'pattern recognition'. These are known as picture languages (Duda and Hart 1973), where the features are no longer numbers but meaningful words. Each object can be described by a collection of these words - a picture language. This supposes that the collection of features can adequately describe all the possible objects encountered in the 'world' known to the system. It may never need to know 'a car', therefore a car does not and cannot exist in the world known by the system.

George F. (1970) gives the difference between simulation and synthesis as:

Simulation - the copying of human thought processes

Synthesis - the production of the same end result

Whether or not the processes in an automated system should attempt to model the human interpretative processes depends upon the aims sought and the results required. If any form of results are all that is required then a system that sythensises the human effort is adequate.

One of the aims of this thesis is to set up a flexible system that allows a user to investigate the relationship between a given feature and its meaning in the image. For example, take a feature of texture; there are a number of ways of measuring texture to produce a numerical value or word description. If each of these is written as a computer programme to the system, the user can apply them to a range of his type of imagery to find out which, if any, are useful and the best way to use them. Thus at the end he has the option whether to use a number crunching pattern recognition programme in automation or to use a more sophisticated picture syntax.

1.3 <u>The past and future</u>

The first steps towards automated analysis could well be attributed to the University of Purdue which, since 1943, has been working on programmes to extract information from pictures for engineering, scientific and military purposes. This progressed into using aerial photographs for earth resources.

In automating this process Ray and Fisher (1960) showed that a technique was developed to quantify the grey level of an image using a densitometer. In 1962 Rosenfeld showed that it could be possible to use automation to distinguish textures on samples of terrain imagery.

At this time there was a large and varied mixture of sensors being experimented with such as passive microwave, radar infra-red, geophysical, sonic, filtered photographs and line scanners. These gradually became dominated by the multispectral scanners and cameras of today.

Miller (1962) mentions the release by the military of scanning radiometers for some geophysical uses. These were uncalibrated and Miller shows a way to provide calibration. However, by 1968 the military had released to the University of Michigan a 12 channel scanner with calibration source.

Meanwhile back in the field of photography Lowe and Polcyn (1964) describe experiments using multiband cameras to obtain photography at different times of the day, every day for a year. This photography was used to see if multiband imagery could be combined to produce enhanced target to background contrast. At this time photographic enhancement and graphs of the spectral signature were used in analysis.

Doverspike et al (1965) in trying to automate this analysis, applied the microdensitometer to extract data from colour film, and use this for land use classification. This was not very successful.

However, in 1964 Holter and Legault showed that if the bands were imaged separately then there was a good possibility of getting some results from computer analysis. At the same time Legault and Polcyn showed how computer programmes were initially used to handle spectrometer data and investigate the target-background detection problem.

By 1968 Haralick was able to describe an adaptive pattern recognition algorithm which he used to analyse radar data of four modes. By that time the simple line scanning sensor had developed into a sophisticated multi-channel instrument. To handle the data generated the now well-known supervised methods were developed by Purdue (about 1967-1969) and incorporated in their LARSYSAA software system. At the same time SPARC (Spectral Analyser and Recognition System) was developed by Willow Run Laboratories. This is an analogue device designed to work, after training, in real time and detect a target from the background. A number of reports of these systems are contained in the Proceedings of the 6th Symposium on Remote Sensing of Environment 1969.

At the same time Rib and Miles (1969) were examining traces from multiband imagery. One of the conclusions they reached was 'The use of multi-channel imagery offers the greatest potential for automatically delineating various terrain types'. They also investigated variations due to film, filter, season and other effects, and more investigations of this type are badly needed to assess the value of multiband photography. Various recombination viewers have been developed to enable enhanced recombinations of the multiband photographs to be viewed (Collwell and Lent 1968), though these have never really been proved to be of operational use.

Photography as a data source became rivalled by scanners, mainly because the two main centres at Purdue and Willow Run operate scanners, and they are able to produce a great proliferation of results based on spectral analysis of scanner data. Another pressure came from political needs to justify large expenditure on scientific research and the space programme. A combination of the ERTS satellites and a political need for Land Use and Resource surveys gave a great boost to the data flow.

The easiest way to 'get results' was by using the spectral signature from the scanner data, since a good deal of work on spectral signatures had already been carried out. The predominant data source became scanners and the predominant method of analysis depended on spectral signatures. It is generally accepted that in air photo interpretation about seven factors govern the decision, yet currently the main emphasis and interest is being concentrated on one, the spectral signature.

A number of basic questions need to be considered:

1) Do unique signatures exist over a wide spectral region?
2) What is the variability of these signatures with time, season, climate, etc.,?

3) What other features of an image could be used?

4) What is the real need of the user? Would machine aids be adequate?

5) How does the user describe his classification?

6) How does the user 'recognise' an object himself?

7) Is it possible to teach the computer to recognise?

8) These sophisticated sensors and computers were created by scientists. Does the user really want them? Has anyone asked the user what he really wants?

This thesis looks at some of these questions and shows how to establish a system that can be used to find out just how much of the required information can be provided by automated methods.

## 1.4 An overview of Remote Sensing

The automated data processing is one part of a very complex chain of events. In order to realise just how data processing is related to the rest of the chain, the first year of the study was devoted to the understanding of this chain.

The input to the data processor is a density image that bears some relation to the scene under investigation. The output is a classification of use to some user community.

It is necessary to consider how well the photographic density image relates to the scene. The exposure that produced the image is modified by the camera lens and atmosphere, the actual density measured is dependent on the film and the microdensitometer. The detectability of objects is dependent upon the incident light and reflection characteristics of the object. In view of these effects it is necessary to determine whether two objects that can be seen as a different colour on the ground, will be represented by different densities on the film.

Yost (1974) gives an excellent introduction to remote sensing using photography. Most of the aspects of digital processing of photographic remote sensed data have been investigated but so many different disciplines have been tackling it from their own isolated viewpoint that there is no coherent approach to the whole field.

A brief description of some parts of the chain of events follows, but more detailed explanations are given in the references quoted in the first three chapters of this thesis.

1.4.1 Remote Sensing Chain of Events

| Physical State | Mathematical State |
|---|---|
| Downflow of Radiation | |
| Sun angle | Data measured by radiometer |
| Cloud cover | |
| Atmospheric absorption and scattering | Atmospheric model |
| Reflection from object on surface | Interaction of Electromagnetic radiation with structure of the surface* |
| Atmospheric absorption and scattering of upflowing radiation | Atmospheric model |
| Intensity distribution at the camera lens | |
| Intensity distribution at the film plane | Spectral transmission function of lens, and optical spread function of the lens, aperture and shutter* |
| Latent density distribution on the film | Optical transfer and spread function of the film* |
| Developed density distribution on the film | Chemical transfer function and H & D film curve* |
| Measured density distribution | Microdensitometer effects non linearity and callier effect |

| Physical State | Mathematical State |
|---|---|
| Digitised data on magnetic tape or in computer | Quantisation of continuous data to N discrete levels sampling interval (Nyquist) |
| Preprocessing digitised image | Formating to standard type for main processing. |
| Programme working | Classification theory, based on spectral signatures. |
| Output map | Classification accuracy and confidence, ability to produce classes requested. |
| Use of map | Extraction of relevant metric or statistical data from classification map. |

*Indicates that these items are not included in this study

### 1.4.2 Cameras

The Manual of Photogrammetry (1952) contains detailed descriptions of cameras, which vary in image format size from 35mm to 9" x 9". Most aerial photographs are vertical, as they are the easiest to use in photogrammetric mapping. Other types of photography, such as panoramic and oblique create problems in both photogrammetry and automated data processing systems.

Multispectral cameras range from a combination of standard 35mm cameras to specially built, multilens, one body cameras.

Single lens per body cameras can be loaded with colour or infra-red colour film for use as multispectral cameras. In this case the spectral bands extractable are either blue, green, red or green red, and infra-red. The bands are broad due to the structure of the film.

To obtain more bands, ordinary pan or infra-red pan film is used in a multi-lens array. Each lens has a different filter on it to record a separate spectral interval, and by using interference filters narrow wavelength regions can be imaged.

### 1.4.3 Scanners

These produce an electronic signal related to some brightness which is recorded direct onto magnetic tape. Narrower bands can be produced than with film/filter arrays, and some scanners use up to 24 separate bands. These produce far too much data to process so usually the best few channels are picked out. However, scanners have the serious disadvantage of poorer photometric resolution.

1.4.4 Photography

Films generally used are: True colour
Infra-red False colour
Panchromatic
Infra-red Panchromatic
Spectrozonal

Each film records an image in a certain spectral region only. The spectral regions of currently available films are broad and each film has to be handled and processed separately.

Processing:- If separate films are used on a multicamera array, each film can be individually processed to the gamma required to correct for the different sensitivity of each film to each spectral region. If a multilens system is used where the images from each band are recorded on the same piece of film all bands will be of the same gamma. The photometric corrections in this case can be achieved by varying the camera shutter speed or the aperture, or when processing the digitised data in the computer. Sensitometric test strips should be processed with each batch of film and it is useful to have a test strip recorded on the film at the exposure stage.

Tone:- The camera records scene radiance modified by atmospheric scattering. Multispectral cameras record certain regions of this spectral distribution and further modify it owing to filter and film characteristics.

The tone is produced by a combination of factors:

i) spectral distribution and level of light source

ii) spectral transmission of atmosphere

iii) spectral transmission of filter and lens

iv) spectral reflectance of object

v) spectral sensitivity of film

vi) processing

### 1.4.5 Digitisation

This is the process of converting the photographic image into an array of numbers representing the photographic density. These numbers can then be processed by a computer.

Two classes of machine are available, the microdensitometer and the T.V. camera type. Both take measurements of contiguous small areas of about 50 x 50 microns on the film and convert the photographic density to a number.

The microdensitometer uses a stationary beam of light, the film is moved past this beam and the variation in intensity of the light beam is a measure of the film density. Typical digitising rates are from 100's to 20,000 points per second.

The T.V. camera class is either a T.V. camera or special flying spot scanner that scans a stationary image measuring the brightness. Digitising rates are typically one frame in 0.1 second but owing to its high speed and non-stationary light source it is not so accurate as a micro-densitometer.

### 1.4.6 Computer processing

Computer processing can mean:

a) processing the image to remove distortions

b) processing to enhance the image thus making interpretation easier.

c) classification of the image

d) investigation of the image to extract clues to object identity n

e) processing to compare images

f) processing to retransform the image to some new baseline.

If any classification or decision making is involved, computer processing of tonal images can be very slow. Simple transforms are best done by pieces of special hardware. Digital computers are, however, a very useful and flexible tool for the investigation of image structure giving clues to the best ways to automation. Total replacement of the human interpreter implies replacement of his reasoning power and specialist knowledge by some piece of machinery, and it is doubtful whether this stage will ever be fully achieved.

1.4.7 Field Work

For environment studies field work is a prerequisite to computer processing.

The main requirements are:

i) the observation of the condition and contents of a set of fields by eye to provide a training sample for the classification and image analysis.

ii) the use of the camera and spectrophotometer on the ground to obtain and investigate spectral signatures and their variation.

iii) the use of the spectrophotometer to measure the spectral distribution and variation of light transmitted through the atmosphere.

1.4.8 Spectral properties of vegetation

It was the observation of the variation in the spectrum of the reflected radiation from different types of vegetation that led to the idea that the information contained in this spectrum could be used to identify the vegetation. (Gates 1966, Gates et al 1965, Collwell 1968, Myers and William 1968).

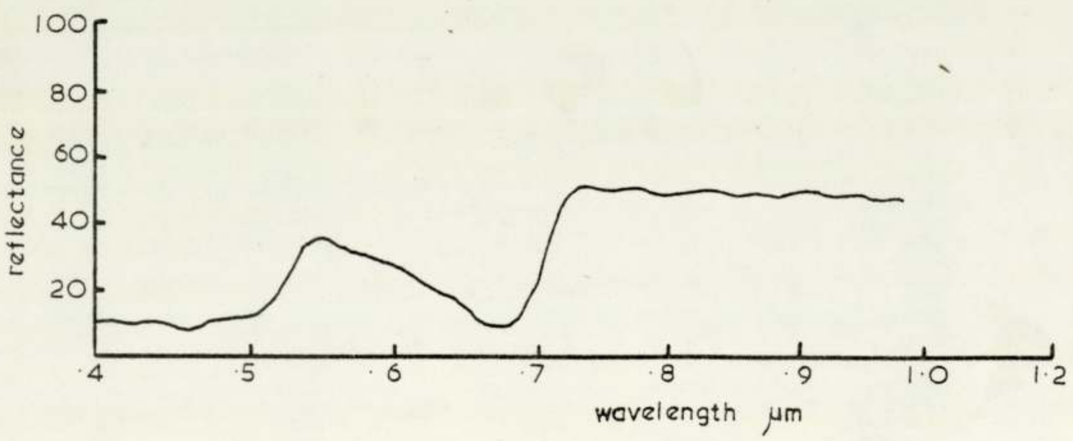


Figure 3. Spectral reflectance of typical green vegetation.

As Figure 3 shows the spectral reflectance in the photographic region (0.4 microns to 1.2 microns) of most vegetation is broadly the same (Knipling 1970).

The pigments and chlorophyll found in all photosynthesizing plants cause absorption in the blue and red (Gates DM (1970) and Wilson RC (1967)). They reflect green but not greatly. In healthy vegetation there is a sharp increase in reflectance at the near infra-red wavelength (0.75 microns).

The importance of this is that if the bands imaged cover suitable wavelength intervals, then the photographic density produced in each band by the reflectance should be characteristic of the vegetation. This works in a broad sense. Green vegetation on ordinary pan film (sensitive up to .7 microns) does not show up because of the position of minimum sensitivity of pan film. Infra-red film (sensitive up to 1.2 microns) is most sensitive in the infra-red region just where the vegetation is most reflective. This results in vegetation being darker on infra-red negatives. Simonett and Brooner (1971) give good examples of the pitfalls encountered in basing discrimination purely on colour. To be successful the photography has to be taken at a time when the discriminability of classes is a maximum. This is hardly likely to occur for all classes at the same time. Hence at best there will still be some classes where colour will not be an adequate discriminant. As pointed out in Simonett and Brooner (1971) "the predominant colour for all Kansas agricultural crops in late July is green. There are both wide colour value variations within categories and few value differences among categories. Colour, therefore, was not an adequate discriminant in the present study".

Much of the reflectance is caused by "the random walk" of incident light in the mesophyll cells of the leaf (Gates D.M. et al (1965)). The near infra-red is a band lying between the electronic absorption of visible light by pigment and vibration absorption by water. It extends from .7 microns to 2 microns, and within this lies the photographic infra-red ranging from .7 to 1.2 microns.

The change in infra-red reflectance is nothing to do with water. Initially it is a change in orientation of stress leaves, then the collapse of the mesophyll. This does allow vegetation stress to be picked out by contrast with healthy vegetation.

However, to use spectral or density signatures to identify a large number of different classes of vegetation over a wide area is very questionable. This is because most of the reflectance characteristics are similar and by the time all the variables have combined there is no way to separate them.

For example (Olsen and Good 1962, Olsen et al 1970) tree foliage has more spectral variation within species than between species. This is due, among other things, to soil, topography vigour, and angle of leaves. Most digital processing to date has great difficulty in extrapolating over a small area without using more ground truth. The input of so much ground truth seems self defeating to the aims of remote sensing.

Even when all the variables are considered the spectral distribution of vegetation, water, non-vegetation and man made objects is significantly different to allow their density signatures to be separated. The identification of only four, and such broad, land use units is of very limited value.

Most surveys are of a detailed nature, for example, a forester needing to know the amount of each tree species or agronomist needing to know how much of each crop type. Without resorting to extensive and well timed ground truth surveys much detailed work is not possible with present spectral processing.

The present state of the art is that spectral signatures can be used over large areas for showing some types of vegetation/crop disease, or for broad surveys involving a few categories or over very small areas for more detailed surveys.

It is to overcome these limitations of spectral signatures that a system was developed to allow users to investigate the structure of their imagery to see if their classification requirements could be met by automation. In this project use is made of a collection of algorithms as feature extractors in an interactive computer system to investigate description of the image by these features. This may then lead to operational automation. As Evans (1968) suggests "the generation and manipulation of appropriately chosen descriptions is a highly promising avenue of attack on the machine processing of such complex patterns as aerial photographs......". Minsky (1961) and Macleod (1970) also make similar suggestions.

# CHAPTER 2

# SOFTWARE

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# SOFTWARE

## 2.1 Preamble

The system developed in this project is based on a small digital computer and all the automated analysis is, therefore, software orientated. This is not to say that computer programmes are the best solution, but they are an easy way to try out various algorithms. It may be that once an algorithm has been successfully developed it is better to build a special purpose machine to implement it. For example 2-D Fourier Transforms are better operationally used by optical processors.

As this is an investigation into analysis rather than image handling, operations like geometric corrections and intensity normalisation, or enhancing, are considered only where they support actual analysis.

This chapter outlines the scope of present software, what it does and its usefulness. Details of the mathematics or the actual programmes or algorithms are not always given since many of these are included in the references quoted.

The main aim of automated analysis is to extract, from the image or object, features that can be used in the classification. This leads to the two standard phases of pattern recognition, those of feature extraction and feature classification. Classification is dealt with in this chapter under the headings of supervised and unsupervised classification. As an alternative to actual classification there is feature description which the author believes could be the future trend in recognition systems. (See Chapter 4)

Feature extraction is dealt with in several stages. First relating to spectral features in spectral processing, then more generally in spatial processing and finally in chapter 4 where a fairly comprehensive list of other types of features are considered. With the system developed in this thesis it is possible to programme these algorithms, add them to the analysis system and investigate them in an interactive mode.

An additional item of boundary finding, or object isolation, is considered. This can be very useful in isolating distinct objects which, knowing that there is no background to consider, can then be passed to a feature extractor. The object can then be classified or described.

Thus with the aid of this chapter and chapter 4 it should be possible to select suitable feature extracting algorithms, code them into computer language and test their suitability on a particular class of imagery.

## 2.2 Spectral Processing

The need of remote sensing for computer aided data processing systems was caused mainly by the use of a wide range of more complex data acquisition instruments. Initially this was the development of multispectral sensors taking images in a few bands, though even here the main solution was to use recombination (additive) viewers. The main impetus came with the development of scanners that produced images in about 12 bands. Then additional incentive came with

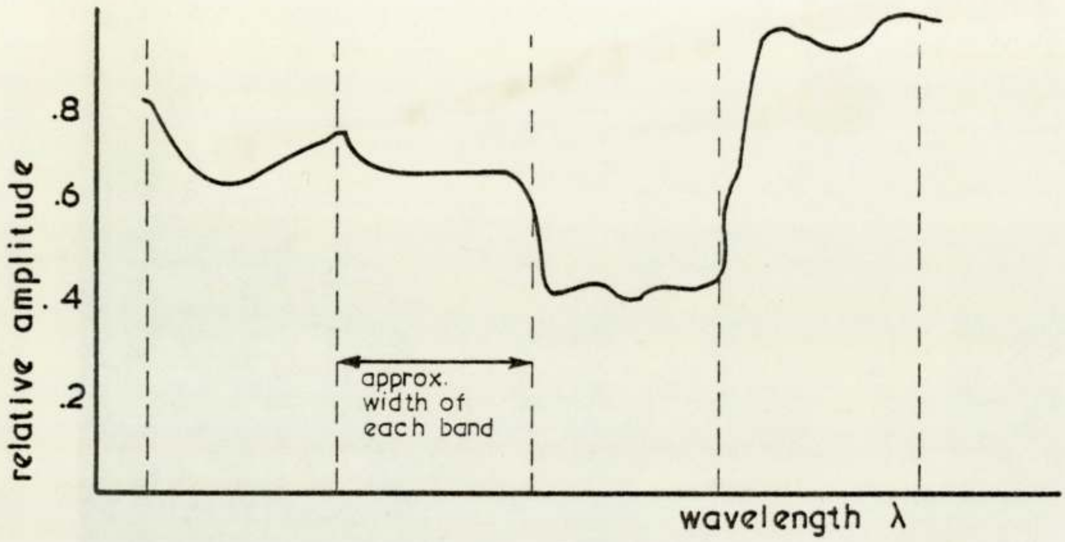



Fig. 4a. Spectral distribution of an object and spectral bands.

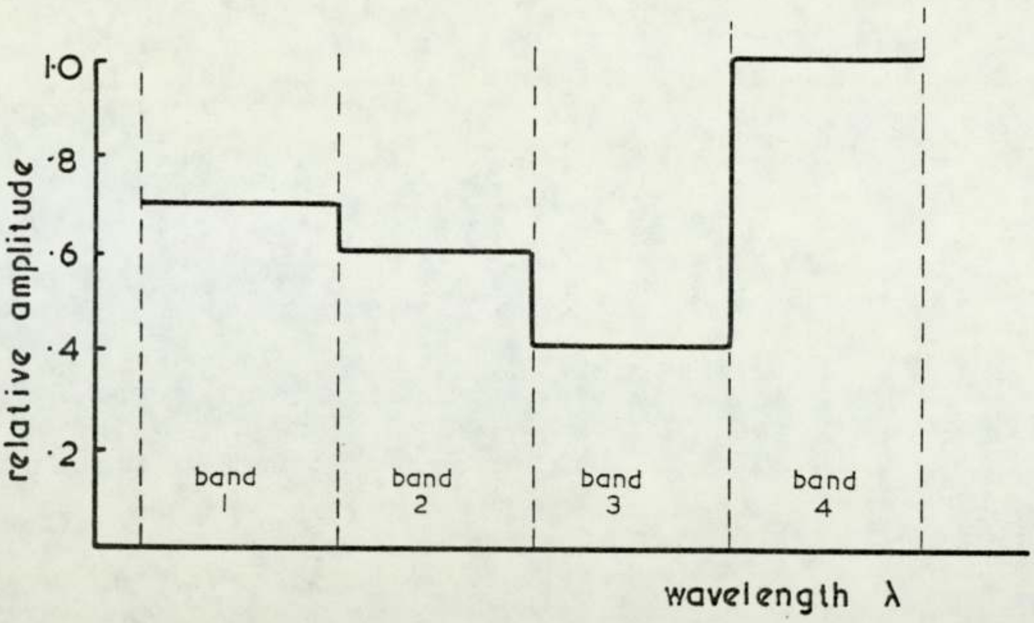



Fig. 4b. Representation of 4a in four spectral bands

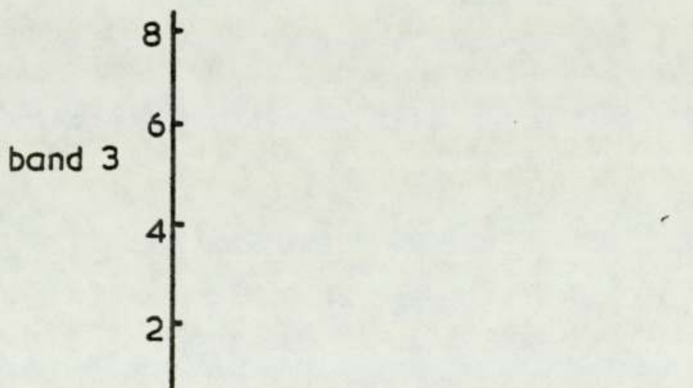



Fig. 4c. Representation of object with spetral distribution 4a as a spectral signature in orthogonal spectral space using bands 3 and 4

the launching of the LANDSAT satellites which are returning a vast amount of imagery to earth. Obviously to handle all this information efficiently a great effort in automation was required. Two centres in America, the Environmental Research Institute of Michigan (ERIM) (formerly Willow Run Laboratories) and the Laboratory for Applications in Remote Sensing (LARS) have applied themselves to the task of automated image analysis.

With the experience of using imagery returned from space satellites (Rindfleisch et al (1971), O'Handley and Green (1972) and Billingsley (1970)) some of the main problems of handling and enhancing the digitised imagery were easily solved: the real problem was that of automating interpretation.

The first line of approach was to use the spectral content of the image, and extract what is known as a spectral signature (Swain (1972)). The theory behind and faults of this approach are well documented in the literature. The theory of processing data from scanners and digitised photographs is identical, as they both can be treated as sets of discrete points. This spectral signature is obtained by taking the density of the same image point from each band, and collecting the set of numbers together to represent that point, (Figs. 4a.b.c.).

The basis of pattern recognition is to present the image to some device (computer programme) and extract a feature of the image on which a classification is made (Fig.5). Each class of objects to be identified should have a feature that will separate it from the other classes.

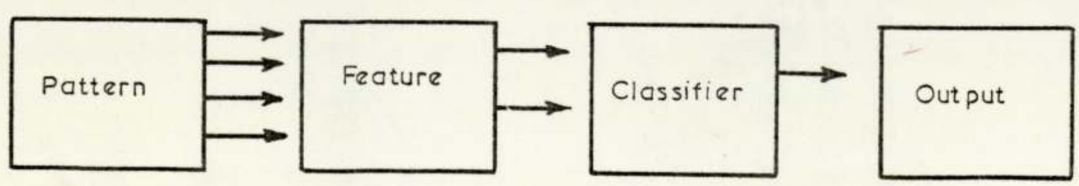



Figure 5. Components of the recognition task

In spectral processing we have a simple and easily measurable feature, i.e. the spectral signature. There are two main methods of classification of this feature: supervised and unsupervised (Preston (1974)).

2.2.1. Supervised classification.

This is the method pioneered by ERIM & LARS in their spectral processing of scanner data. It is well documented so it will be described here only briefly.

First to define a few terms:

A pixel is one digitised picture element
A pixel vector is the set of pixels, one from each band, of the same image point

The method (Swain (1972)) involves selecting a sample of sites from each class on the imagery for which the identity is known. Pixel vectors of these sample sites are taken and statistical information is built up to include such items as the 'mean' and 'variance' of the pixel vectors from sample sites. The pixel vectors are taken from all the unknown areas to find to which sample they are most similar; the vectors are then classified according to the class of this sample.

This preselection of known areas is the main characteristic of supervised classification. To put this more formally, if the pixel vector is X then find the class C to which X has the highest probability of belonging. Let this be P(c), then if P(c) is greater than some threshold, assign the vector X to class C. This threshold is set by the initial samples, so that any vector not belonging to one of the possible classes is rejected.

This can be programmed into a very short and efficient loop. For actual listings and comparisons of times see Phillips

TL (1969).

2.2.1a Refinements to the basic concept.

There may be slight variations (Hoffer and Goodrick (1971)) due to one cause or another along a given flight line. To compensate for this adaptive processing can be applied. Each time a pixel vector is identified as belonging to a class the new vector is incorporated in the statistics of that class.

Using more than one vector in the classification may improve results. The aim is to try and collect together all the vectors from an unknown field, thus giving a more accurate value to compare to the sample set: the problem of delineating the unknown field also exists.

If there are a large number of channels or bands of imagery it may help to select a subset of these, and base the classification on a smaller number of bands, reducing the data flow and speeding classification. Malila et al (1973) give an algorithm for the selection of subsets of channels.

To speed the process in the initial setting up of the training samples, the minimum number of possible pixels can be used. Nalepka and Hyde (1973) give an algorithm of the minimum number required to produce a given accuracy.

In using alternative equations (in finding to which sample the unknown pixel vector lies) Wacker and Landgrebe (1972) suggest methods of finding some measure that identifies which group the unknown vector is most like.

2.2.1b Problems encountered.

Some of the problems mentioned here are caused by using only the spectral signature as a feature, some are due to the nature of supervised analysis:

1) It takes time to establish the training sets. It needs great care to ensure that the pixels selected actually cover the area known, and that the true nature of the features are known; wheat at different stages of growth has a totally different spectral signature.

2) Supervised analysis will select only those classes contained in the training set.

3) Training sets need to be established throughout the flight line.

4) Instrumentation giving inconsistent samples can affect the image.

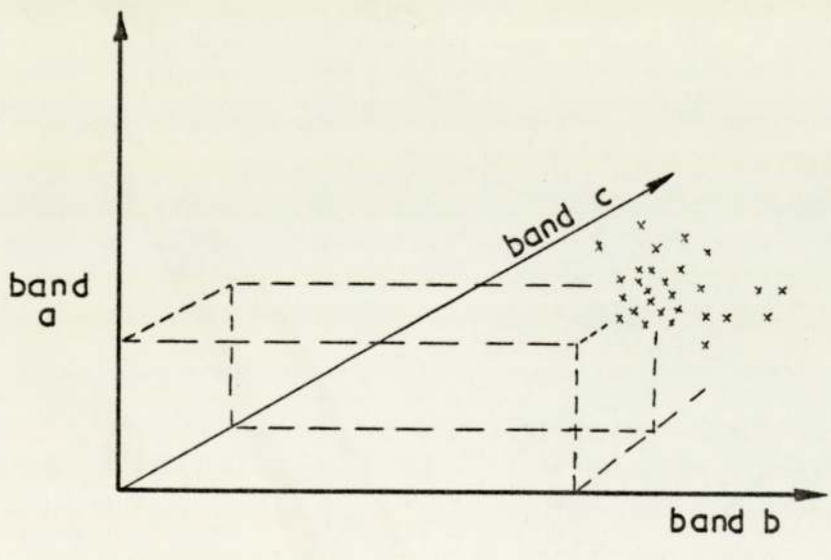
5) Many other problems are discussed in Hoffer and Goodrick (1971), and Rib & Miles (1969).

2.2.1c Examples of the use of this method.

Numerous references in the proceedings of the Ann Arbor conferences; Todd et al (1973), use the LARSYS supervised system for land use mapping. The paper by Ellefsen et al (1973) is significant in that it compares a classification that the system LARSYS can actually produce with a suggested USGS Remote Sensing Land Use Classification which is far too complex. For examples of soil mapping and soil with vegetation cover mapping respectively see Kristof and Zachary (1971), and Kristof and Baumgardner (1972).

2.2.2 Unsupervised classification.

This is the second main method of classification and it is often known as clustering. As with supervised classification its use will be illustrated with the simplest of features and the one that has brought this method into great use: the spectral signature.




Cluster formed in 3-D spectral space

Figure 6. Cluster formed in 3-D spectral space

When pixel vectors of the spectral signature are plotted on an axis system they tend to form clusters or groups in space. The grouping of the vectors taken from a multiband image of water will often be distinct, and separate from the group representing vegetation (Fig. 6). If all the vectors from the image were plotted it should be possible to separate out groups representing the classes required. Unsupervised classification is the delineation of these groups, or clusters, defined by the data. The main difference between this and supervised classification comes when the clusters that represent various classes are labelled. Supervised classification requires training sets to initially label the clusters. In unsupervised classification the groups or clusters are established for the whole image, then their corresponding class is identified by reference to a sample of the imagery containing the ground truth.

The use of training sets as guidance is not the ultimate aim of a true recognition system: both supervised and unsupervised methods need constant reference to the training set. A true recognition system could identify an object based on a set of descriptions, and this is where the use of more features is significant.

In relation to clustering the basic data are a mixture, and the aim is to use samples from the mixture to estimate the parameters of the separate groups.

Two issues are involved:

1) the similarity between samples
2) the method of partitioning the samples into groups

The basic assumptions made are that the samples come from a known number of groups and the a-priori probabilities of the groups are known. This is used in a decision directed approach, where the classifier is based on the location and distribution of the groups. The approach can be applied, sequentially updating the classifier, each time a decision is made. Or it can be applied in parallel, by waiting until all samples are assigned to groups before updating the classifier.

The partitioning into groups can be done in a number of ways which are well documented (Duda & Hart (1973)). The goodness of the partition can be treated by the use of a criterion function (Je) (Duda & Hart (1973)). For example Je could be the sum of the average squared distance between the means of the clusters.

A partition can be established and the criterion function measured. The partition is changed in such a way that the criterion function is optimised. To start this partitioning process an initial partition has to be constructed. This can be done by a range of methods from examination of printouts of clusters to mathematical searches of the cluster space.

2.2.2a Forms of clustering.

Hierarchical - there are two forms, agglomerative and divisive. Agglomerative starts with all the single pixel vectors and successively merges them. A criterion function is used to find the best merge at each stage, and the optimum stage at which to terminate.

Divisive starts with one cluster containing all the pixel vectors and successively splits the clusters. Generally, nearest neighbour and furthest neighbour algorithms are used as a criterion function, and these tend to find only compact well separated clusters. Results can be very sensitive to noise.

K-means clustering (Su and Cummings (1972), Haralick et al (1971)) is an iterative approach that starts with a roughly estimated partition, e.g. the means of the clusters are guessed. During the iteration each pixel vector is assigned to one of the partitions. At the end the partitions are re-calculated using the newly assigned points and the iteration started again. Results can be sentitive to the initial partition and the number of groups in it.

Sequential clustering (Smedes et al (1972)), (Nagy and Tolaba (1972)) is a one pass operation over the data set. Each point is examined in turn: if it is like an already established cluster it is assigned to it, otherwise it is kept as the possible start to a new cluster.

2.2.2b Refinements

The number of clusters can be limited by merging nearby ones or deleting small ones. In some cases deleting the smallest 70% of the clusters may remove only 5% of the points (Nagy and Tolaba (1972)).

Two types of clustering can be used together, or even combined with supervised classification to get the best of both (Su and Cummings (1972)).

Better measures of sample similarity and cluster separation can be defined (Duda and Hart (1973)).

One picture line can be clustered at a time then, to increase speed, the clusters can be combined with the general store of clusters.

2.2.2c Advantages of clustering

1) Only a minimum of control data are needed, e.g. the number of clusters and the threshold of the similarity measure.

2) Pattern characteristics that vary along the flight line can be tracked by clustering. The cluster may move slightly but it will still retain its original notation.

3) There is no need to collect training samples

4) Clustering may give an insight into the natural structure of the data.

2.2.2d Disadvantages of clustering

1) Clusters can overlap or be very diffuse

2) A bad initial partition can create havoc

3) Clustering can be very time consuming especially if an iterative method is used.

4) Clustering could force an unnatural grouping by forcing a fit to too few clusters.

In addition to these two main classification methods: supervised and unsupervised, there is also picture description - which is discussed in Chapter 4.

## 2.3 Spatial Features

It is useful to consider features other than spectral. These other features are mainly concerned with extraction of spatial information, particularly that relating to the texture of the object. In most cases the computer extracts those features in the form of numbers which have no real meaning in terms of our visual interpretation of an image. However, sets of these numbers, assembled into feature vectors, can usefully delineate between certain classes.

There is not usually a unique value to a vector representing a given class: more usually a vector will show that the object belongs to one of the possible classes.

Two approaches can be used:

1) Small contiguous or non-contiguous blocks of the image may be taken and analysed. These blocks may or may not be wholly from within one class or object.
2) Regions that correspond to one object may be identified: in this case all points in the analysis are known to be from one object and information on the boundary shape is available. This implies pre-processing for object isolation and boundary finding, a topic dealt with in Chapter 4.

However, once the basic block of points is obtained there are a wide range of features that can be extracted. These same features can often be extracted from isolated regions as well as regular image blocks.

One word of caution, all these features, based as they are on statistics of the image, are not invariant unless normalised: for example reduction to zero mean and unit variance, or principle components analysis, or equal probability quantisizing.

2.3.1 Simple Statistical features.

These features are derived using well known mathematics, and simple intuitive ideas. The statistics include mean, variance, covariance and standard deviation.

The more intuitive features include:-

i) Runlength probability - the frequency that a run of elements occurs, of length 'n' of the same grey level. This can be plotted as frequency against run length. The actual density can be ignored or added as a third dimension.

ii) Edge per unit area - the edge is defined as the difference in grey level of neighbouring pixels. The total edge is the sum of this over the whole image block.

iii) Difference distribution - a plot of the distribution of the size of change of grey level of neighbouring pixels. This is plotted as frequency against size of change.

### 2.3.2 Complex Statistical features.

The field of feature extraction has little theory to help in choosing of suitable feature extraction algorithms: at present it is largely a matter of trial and error.

Haralick and Anderson (1971) give Fortran listings of a very complex feature extraction algorithm, based on what they call spatial grey tone dependence matrices. These matrices, as the name implies, are dependent on the spatial relationship of the grey tones.

These are constructed as follows. For a range of grey levels of 1 to q, a matrix of size q x q is constructed. The element in the m,n position is the total number of times grey levels of value m and n occur together. These matrices can be constructed for all neighbouring points, ranging from adjacent to any distance apart, and the points can be related in any direction. Each matrix is associated with one distance and one angle. For example the "distance 1, horizontal" matrix contains the number of times grey levels m and n occur next to each other in a horizontal direction.

The features are extracted from these matrices. Haralick and Anderson (1971) give a list of 16 such features that can be extracted such as angular second moment and correlation.

The above work is illustrated by using 54 digitised areas of 64 x 64 pixels representing ⅛" x ⅛" on 1:20,000 scale photography. There were six examples from each of nine classes: fifty three were used as training, one as test; each sample had a turn at being the test one.

Three important points arise from Haralick and Andersons work:

A) Most cases use some general mathematical transform which assigns numbers to the result, i.e. many numbers (photographic density) are reduced to a few numbers (the features). The aim should be (as in the case of Haralick and Anderson) to try and understand the structure of the texture. Hence the testing on only one sample is not so impractical as it may seem.

B) There is a prime need to select suitable categories, bearing in mind the size of the image block and its pixel size. A texture may be required which is finer than the pixel spacing: or the block may be significantly smaller than the object.

C) It is important, in extracting spatial/textural features to realise they are orientation dependent. For consistent work the feature must be independent of orientation. For example rows of crops, however oriented in the image, should produce the same feature. Also important in conjunction with this is normalisation of the grey levels. Often the feature is made invariant by taking the mean and range of the feature over a number of orientations of the image block.

### 2.3.4 Use of the Fourier Transform

This is another useful statistical property. The Fourier Transform of an image produces a frequency spectrum. A frequency spectrum is a plot of the intensity or amplitude along a frequency scale, such as pixels per mm, that can be related to actual ground size. The high frequencies give information on edge, the low frequencies on contrast. Fourier Transforms are expensive in computer time but useful algorithms have been developed to make them worthwhile: a point dealt with later.

Sometimes non-computer oriented research can be implemented when searching for suitable features. When dealing with optically produced Fourier Transforms, it is probably just as easy to produce them digitally rather than spend time optically aligning a system. When the required feature is selected a rapid optical system can be implemented.

For example Nyberg and Orhaug (1971) describe an optical system that produces a Wiener spectrum.

Density of transparency = DA (xy)
after digitising D (xy) = Co DA (xy)
the Fourier Transform

$$D_2 (uv) = C_1 \iint dxdy\ DA (xy) \exp\left[ -j \frac{2\pi}{\lambda F} (xu + vy)\right]$$

cancelling phase and leaving the intensity

$$I(uv) = C_2 D_2 (uv) . D_2^*(uv)$$

This spectrum contains little useful information on the pattern DA (xy), but useful measures of the amount and direction of edge may be obtained.

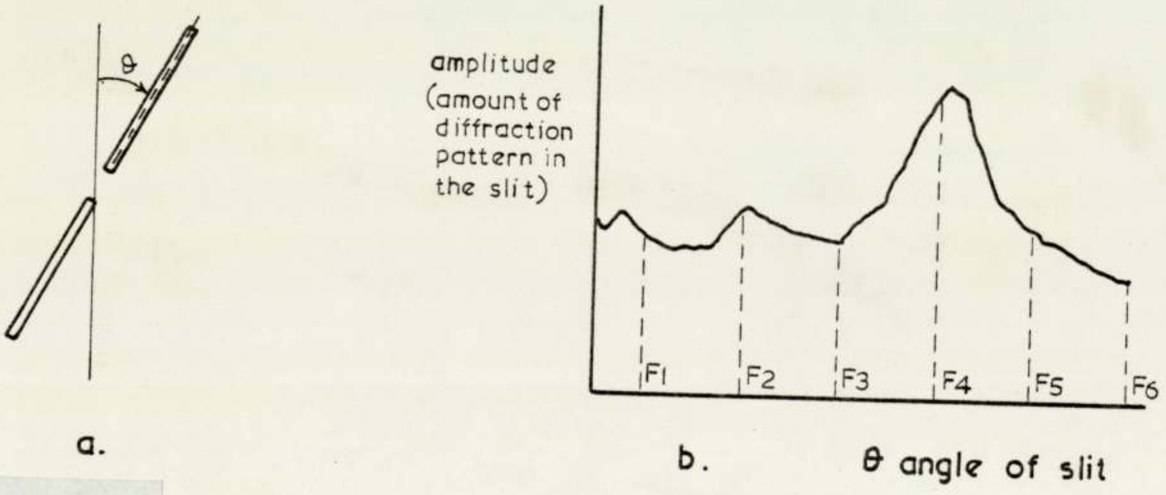
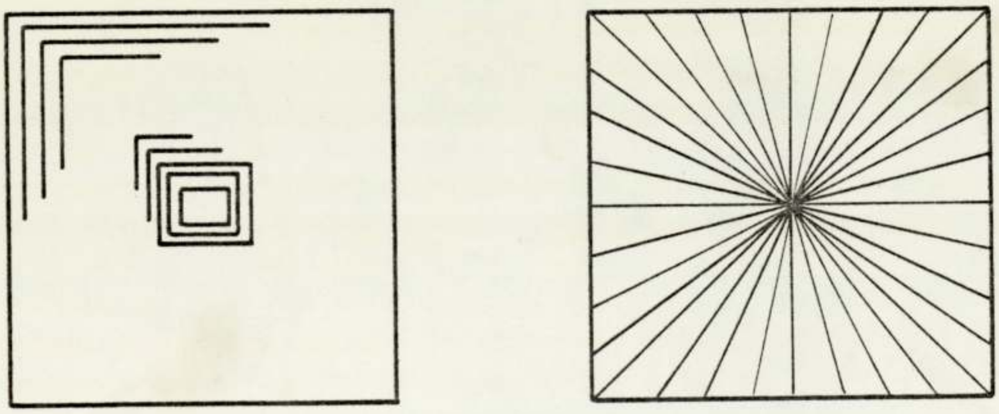



Figure 7. Feature extraction from a diffraction pattern
a. slit rotated about pattern
b. trace produced by slit and feature points $F_1$ to $F_6$



31 rings    32 wedges

Figure 8. Wedge and ring sampling of 2-D fourier transforms

Jensen (1973) also describes an optical system producing a diffraction pattern that could be implemented digitally. He makes some useful comparisons between digital and non digital methods and says, for example, that scanning the image requires N bits where:

$$N = [\,2\sqrt{2}\ ko\,]^2 \log_2 GA$$

where ko is the limiting resolution in line pairs per mm

G the number of grey levels

and A is the image area

From this digitally produced spectrum it is necessary to obtain a feature. Following the example of Nyberg et al (1971) a slit with the centre bit missing,to cut out low frequencies,can be rotated about the spectrum (Fig. 7). A plot can be produced of $\theta$ vs amplitude which is used as the feature. Alternatively Gramenopoulos (1973) extracts four spatial features from measurements in four sectors of the diffraction pattern.

Thus the stages here are to convert the image to another set of numbers, reduce these to a graph and from this extract some useful points. The usefulness of this lies in the information it can give on the line structure of the image. In structural geology the morphogenic importance of structural elements such as fluted morraine, fractures or glacial striations can be investigated.

Hornung and Smith (1973) describe a completely digital approach to Fourier Transforms. They produce digitally the diffraction patterns and sample these using two techniques. First using a set of 31, annular rings then a set of 32 wedges (Fig. 8). The features used are taken from a plot of ring or wedge number vs amplitude.of the diffraction pattern in that ring or wedge. The methods of use and implementation are discussed but no actual detailed applications presented.

Yet another approach using Fourier Transforms has been taken by Ramapriyan (1972), who uses the Discrete Fourier Transform (DFT) calculated for a number of angles of the image block. The features extracted are those such as the maximum distance between the DFT magnitudes of the rotations. This can be interpreted as the degree of asymmetry in the image.

Six classes were used in this case: water, grass, trees, and three classes for tomatoes.

It is extremely difficult to see how the asymmetry of a DFT relates to visually interpretable aspects of the image. At present this should be the limit of mathematical complexity to which one needs to go. More understanding is required in the area of image structure and recognition.

## 2.4 A note on the Fourier Transform

The Fourier Transform occurs quite frequently so a brief note on it is relevant. In addition to the work already mentioned Anuta (1970) gives a good example and explanation of its use in registering bands of imagery.

Conventionally it takes a long time (hours) to compute a two dimensional series of transforms for a typical aerial photograph. Using the fast Fourier Transform algorithm it is possible to significantly reduce the time

Doing this conventionally for one dimension of an M x M pixel image requires $M^2$ complex operations. Cooley & Tukey (1965) found that if M is a multiple of 2 ($M = 2^r$) then it was possible to do the transform in $2M \log_2 M$ operations.

Since then other radix transforms have been produced, notably those by Singleton (1968). Singleton (1967) gives methods where limited computer core is available. Hunt (1972) discusses the problems of handling transforms in general. Andrews (1968) explains this further. Hunt (1971) discusses in detail ways to handle and implement transforms of all sizes, and also points out ways to optimize the transforms.

## 2.5 Region Analysis

Whilst regional analysis cannot be regarded as a necessary prerequisite to feature extraction, the author would, for reasons outlined below, advise its use. There are two main ways to extract the features from the image: either scan a block across the image taking the features from this block or isolate an entire object and extract features. The block scanned can range in size and shape from a pixel upwards.

The disadvantages of using an image block are:

1) the object could have texture that is not picked up if too small a block is used.
2) if the block is too big the object will have too much background resulting in a confused feature.
3) the block could lie across a boundary giving mixed features.
4) only a rough outline of the object is achieved.

The advantages of an image block are:

1) the statistics of feature extraction and classification can be based on a fixed array of points.

2) the implementation of the processing is easier: it is necessary to specify only the size of image and size of block.

3) the processing speed can be very fast.

If an entire object is isolated then all the points in the analysis come from a single object and there is the additional information on boundary length and shape. The use of this is illustrated in Preston (1974b).

Region finding occurs in two different parts of the total analysis chain.

a) before feature extraction, to isolate objects from which features can be extracted.

b) in the feature extraction phase where features such as boundary length/area can be used.

Often region analysis is associated with classification. Either the regions or boundaries are a natural result of classification, or the regions found are regarded as being the classification.

Enhancement or pre-processing of the image is often needed before region isolation is performed. Pre-processing is detailed in such documents as ESRO (1973) and Plessey (1973) and will not be discussed in this thesis. The purpose of pre-processing is to reduce the number or range of pixels in the image. This enables the objects to be distinguished, but the detail, which may not be needed, is lost.

There are three main approaches:

a) the analysis area is moved a small amount at a time and a note is made where the classification changes. Subsequently the boundary can be refined if needed.

b) the statistics over an area are computed and a note is made where it changes.

c) some measure is used to build regions in all directions from some initial starting points - a hole filling operation.

The best approach to use in any given situation depends on the object being sought, hence the need for a research system. A user can digitize some imagery, then add some suitably chosen algorithms to the computer system. The user can then interact with the computer to compare and adjust each algorithm to find those most suitable for the given class or imagery.

### 2.5.1 Some suitable algorithms

Fisher et al (1973) describe an object isolation algorithm based on a Unimodal tree algorithm.

Robertson (1973) and Robertson et al (1973) describe an image partitioning algorithm that works recursively. Known as RIMPAR it subdivides blocks of the image until the block under consideration is either too small or reaches some predetermined statistical regularity.

Klausner and Karmeli (1974) describe the use of a K-s filter in segmenting and detecting objects in a picture. The image blocks are grouped together, using a statistical test for similarity, into fragments which should correspond to the objects in the image.

## 2.6 Operational systems

There are a number of centres in the U.S.A. concerned with the automated analysis of remote sensed data. Most are university based and are well documented in publications - such as Plessey (1973).

Many of them use variations of the LARSYSAA software system developed by the University of Purdue, and tend, therefore, to concentrate on spectral analysis of multispectral scanner tapes.

The University of Kansas KANDIDATS analysis system can operate with data from the IDECS enhancement system that has a photographic input.

An example of the data flow problem can be given. The NASA Earth Resources Laboratory (ERL) Data Analysis System (DAS) enables data to be processed using the LARSYS system. ERL can handle 4 band imagery and process it as if it were multispectral scanner (MSS) data or it can handle 24 channel MSS tapes.

The original tapes are first reformatted to DAS format. DAS is then used on one computer to select the best channels and prepare a training area tape. All tapes are then reformatted and merged to suit the LARSYSAA system. The tapes are classified on another computer producing a map tape for printing. Classification of 8 classes from 5 channel data containing 30,000 lines of 700 pixels takes 2,200 minutes of computer time, plus weeks of handling time.

As a further illustration of the limitations of digital spectral processing Kriegler et al (1973) give the following example. An airborne scanner will gather data from a 20 to 30 mile flight line in about 15 minutes. This data will require about 15,000 minutes of processing or six 40 hour weeks. Even then there is no guarantee that the variabilities along the flight line will not result in significant errors. Although in the same article Kriegler describes a digital parallel processor, claimed to classify in near real time and giving about 8 classes.

One problem in the development of hardware and software in the application of photographic remote sensing to land studies, is to identify the user's need. A land survey that is restricted to eight pre-determined classes only, will most likely be of limited value. This is particularly so where spectral differences alone are used to separate these classes.

Methods relying on spectral signatures produce reasonable output in agricultural areas but in non-agricultural areas the image is very noisy and unclear, with no location features. In these cases it is almost impossible to draw a reasonable boundary around a given class, or to know where any individual image point is.

## 2.7 Summary

This chapter has illustrated the two main classification methods used to date, namely Supervised (maximum likelihood) and Unsupervised (clustering). These classify the image, or organise the data points, into similar categories based on some criterion or feature. The main feature used has been the spectral signature, although others using textural or spatial features have been suggested. This spectral signature based classification has not 'recognised' anything in the image (in the way humans do), it has merely organised the data using mathematics.

This chapter begins to show a user how to understand the structure of his imagery so that he can approach an automated system with more understanding of what could happen when using more than the spectral signature.

If spectral values are the dominant interest, then a pinhole camera would be an adequate sensor.

# CHAPTER 3

## HARDWARE

# CHAPTER 3

# HARDWARE

## 3.1 Preamble

In terms of the hardware used to analyse photographs there are two main chains of processing:-

Chain (A) Camera - Photograph - Digitizer - Computer Processor - Display

Chain (B) Camera - Photograph - Electro Optical Device or Hardware Processor - Display

Within each of these chains are two sub-chains, one for the real analysis work and the other for enhancement work. It would have been just as easy to split the hardware into analysis enhancement main chains but the above two chains are proposed to isolate the digital computer analysis.

In chain B the enhancement device is represented by a range of hardware, from simple optical recombination viewers to complex electronic colour enhancers. The analysis work of this chain can be done by an optical Fourier Transform device, but as yet these are not far advanced towards automation. There are also hardware classifiers such as Plesseys FTCI, which in ⅛ second can classify 250,000 points in each of five channels into ten classes. The disadvantage at present is the 240 potentiometers that have to be set, but it is hoped in the future to have these replaced by a digital computer.

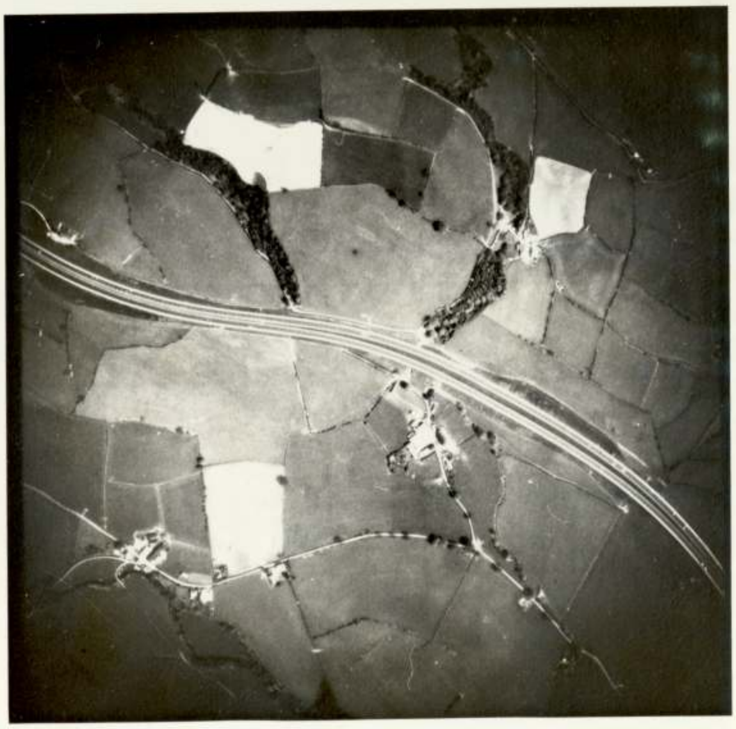
The work reported in this thesis, however, is mainly concerned with the workings of chain A. In this chain the enhancement is often carried out using a T.V. camera or other digitizer, plus a 'black box', the computer often being used

Band I

Band 4

Figure 9a. Multiband photographs illustrating the differences that can occur between bands 1 (blue) and 4 (infra-red). (Electronically dodged negative)

Band 2



Band 3

Figure 9b. Multiband photographs illustrating the similarity between bands 3 (red) and band 2 (green) of an undodged negative. Note the difference in the corners compared to Fig.9a.

just as a control device.

The analysis side of the chain uses digital data from the digitized photo. The data is processed by a computer to give an analysis of the photo in terms requested by the operator. This automated approach takes some burden off the interpreter leaving him free to work on those parts of the image that the computer fails to analyse.

The following section reviews briefly the range of systems on the market. From this is developed the digital automated system that allows more than simple spectral analysis and that is best suited to the needs of remote sensing research and operational work.

### 3.2 Cameras and Photographs

The types of cameras involved in this work produce in either black and white or colour a wide range of images from 9" x 9" to 70mm x 70mm.

The conventional aerial camera takes one photo at a time and is loaded with one of the four main types of films - panchromatic, infra-red, colour or infra-red colour.

Cameras can be mounted in groups, each one with a different film in it, but each taking a photo of the same scene at the same time (Fig. 9). Sometimes the black and white film is split by filters into two or more bands. This is the system used by specially built multispectral arrays that have up to 9 lenses on one camera body, producing filtered images on one piece of film. The development of scanners utilised the further splitting of the bands of the spectrum. Scanners can operate outside the visible band and use as many

Figure 10. Four-band multispectral camera.

as 24 bands within their spectral range. The output from these is an analogue signal on magnetic tape. For reasons already outlined the use of scanners and their data could come from a scanner or photo. However, the system developed should be flexible enough to analyse a wide range of films.

Single band imagery is a special case of multiband imagery (i.e. the number of bands equals one), and colour is just 3 bands in the same image. So developing a system that can analyse multiband imagery will automatically cover all types of imagery, leaving only the input as the major requirement in flexibility.

A brief description of two camera systems commonly used in the U.K. will give an idea of the types of photography that need to be analysed. Indeed it was the advent of multispectral imagery that substantially increased the need for automated analysis.

i) The $I^2S$ Camera, which was used to acquire the imagery for this work, consists of four lenses, of focal length 100mm, on one body (Fig. 10), each lens forming an image on the same roll of film. Each frame is 250mm x 250mm with four 95mm x 95mm images on it. The camera is supplied with four broad band filters, by no means proven to be ideally selected. This camera can be loaded with one type of film only, usually an infra red film, for all four bands.

ii) The Fairey Survey camera array - This is composed of four cameras mounted together in optical alignment. The use of separate cameras enables a different film to be used in each camera. Fairey s use four Vinten F95 cameras with 102mm focal length lenses.

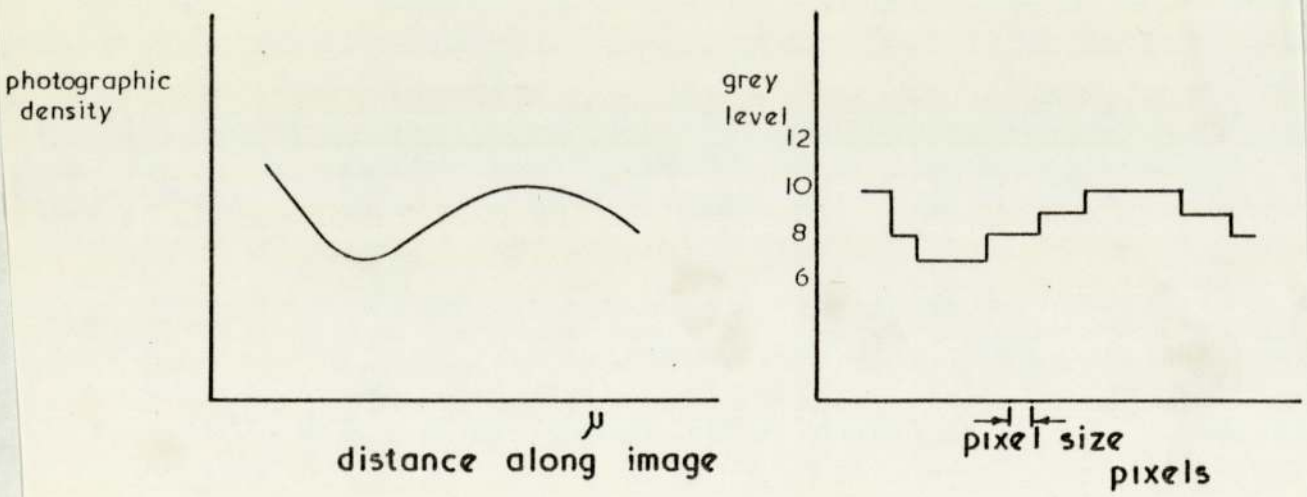



Figure 11. Digitisation of a continuous density profile to produce one line of pixels. The left graph shows the continuous grey level variation along a typical scan line. The right graph shows the result of assigning 1 of 12 discrete grey levels at discrete intervals, called pixels, along the line.

These photos have to be converted into some form that enables them to be processed or analysed. This conversion is done by digitizing the samples. This converts the image into a set of numbers, the numbers representing the photographic density or brightness of points of the image.

## 3.3 Digitisation

This is part of Chain A. It is necessary in both enhancement and analysis work, though more so in analysis where the computer may have to consider a portion of the image to extract some information. It works as follows: the grey level range is divided into equal intervals, say, 256. The grey level of a small area of the image can be measured optically by a machine called a microdensitometer. The area is given the number corresponding to its grey level (Fig. 11).

T.V. cameras digitize by measuring scene(image) brightness of small areas which is not quite the same as image density.

There are several varieties of instruments used for digitizing. Of the optical mechanical type are those made by Optronics, D.W. Mann, Joyce Loebl, Photometric Data Systems, Photometrics Inc., and Photo Digitizing Systems. These digitizers are either flat bed or drum microdensitometers. The film is moved past a light beam to measure density and digitize it. The machines can have a large data rate, so data storage or computer interface for digital data is required. Other microdensitometers are made but are not so suitable for air photo digitizing.

Flat bed microdensitometers operate at about 5,000 points per second. They can, because of their stable construction, digitize down to units as small as 1 micron interval. Drum microdensitometers need flexible film and generally have limited drum size. They can digitize at about 20,000 points per second with a 25 micron interval.

Other devices use a T.V. camera type of system for digitizing, e.g. EMR Schlumberger produce the ODD, for direct real time input to computer or storage on magnetic tape. T.V. cameras can digitize the picture at a rate of 500,000 points per second, whereas microdensitometers digitize at about 20,000 points per second maximum. However, T.V. cameras can have numerous radiometric and geometric distortions and a lower resolution. T.V. cameras are generally used in enhancement work where a real time image is needed. The output signal is for example in this case quantized and, depending on its grey level, assigned a colour by the computer. The colour signal is displayed on a T.V. monitor as a colour enhanced image for visual interpretation.

### 3.3.1 Microdensitometers

By referring to Table 1 it is possible to compare the various instruments which were investigated during the period 1972/74.

The EDP scanning microscope is limited to 70mm format and also has a spiral scanning motion, which would make computing from the data very tricky.

The PD 1010A is a well developed digitizer capable of handling images up to 10" x 10" and storing the digital data. It is a flat bed machine with fixed size scanning slits.

D.W. Manns' flatbed machine is a high precision, high cost instrument, limited to 4½" x 10" films so it will not accept the big format aerial photos. Bulk digital recording facilities can be made available.

The Optronics and Joyce Loebl systems are very similar. They both provide drum and flatbed instruments specially designed for digitizing and recording bulk digital data from large format films. The computers associated with them, especially the Joyce Loebl Mk IV, allow automatic selection of scanning controls.

One problem with these microdensitometers is the time taken to digitize. Flatbed instruments tend to be slow, about 5,000 points per second, but it is possible to have a continuous reel of film. Drum scanners are faster (about 5x) but the film has to be loaded for each frame. Even with faster T.V. scanners a limit is usually reached because of the speed of transfer to the bulk storage (magnetic tape). Another problem is the lack of a visual display of the image. One can argue that an automated system does not need one for this stage of the process. If a check is needed there are film writers which give in a very short time a print on photographic material.

3.3.2 T.V. digitizers

The optical data digitizer (ODD) is a T.V. camera with a minicomputer controller. This can image any scene and digitize any selected area in a field of 4096 x 4096 points into say 2048 x 2048 resolvable data points. T.V. cameras tend to drift a little so one resolution element from one scan may represent a different point of the scene in the next scan. This can cause problems with on-line processing if the picture elements are not constant. Storing on bulk medium considerably slows down the process and the stored image may have suffered distortions from image drift.

The PDS 200 is a camera digitizer that converts the imaged scene into 1000 x 1000 elements. The control computer digitizes the areas of interest for on-line work. It does not store the digitized image, though this option is available.

Once the image has been digitized it can be fed to a computer and analysed. If the computer fails to analyse the image, then an option should be available to put the enhanced image on a T.V. screen for human interpretation. So the enhancement systems will be briefly reviewed before discussing the analysis systems.

## 3.4 Enhancement systems

Enhanced images need to be displayed, preferably on a colour monitor, so that various combinations of colour can be tried for the best effect. This necessitates on-line work, i.e. a T.V. camera looking at the image or scan conversion storage tube, to display digital data from the computer.

Digitising in this respect, enhancement can take several forms, including colour coding, edge enhancing and contouring. All systems with a computer attached can be programmed to enhance, but only the systems specifically designed for enhancement work will be considered in this section.

The Spatial Data System has the capability of colour coding, edge enhancing and other simple processes. It can colour code an image into as many as 32 colour levels based on the brightness or density of the image perceived by a T.V. camera. A similar system is produced by $I^2S$, this is independent of their multispectral optical visual viewer. A more detailed discussion of the $I^2S$ system can be found in the appendix.

Daedalus produce a colour enhancer that works with data from their own scanner, or from ERTS tapes only, and even then is best used in the thermal IR band.

Interpretation Systems Inc., produce a black box called the VP-8 which will produce colour displays or 3-D representations of the image. However, it requires input and output devices from some other source, though some T.V. cameras and displays are recommended.

Finally, there is Princetown Electronic Products, which produce a Lithocon (R) storage tube. This can be used for a wide range of operations such as storing images on top of each other or side by side, or even to some extent as an enhancer. It can handle digital or analogue input at almost any rate and display the stored image on a T.V. screen.

The use of a T.V. camera is best suited for enhancement work where the aim is to make one object more visible to the human interpreter by enhancing it relative to its background. To this effect the radiometric distortions are not too important, whereas in computer analysis an accurate density level is important: for this reason densitometers are best for computer input.

For an interesting comparison see White et al (1973).

### 3.5 Analysis systems - General

There are two main ways to handle the data from the image 1) automatically via a hardwired unit that performs a given operation at the flick of a switch (chain B), or 2) through a programmable computer (chain A).

The chain B approach has been taken by Imanco with their Quantimet 720. This is provided with a set of plug in modules that enable it to perform a wide range of functions, even to a limited extent pattern recognition. However, the modules are limited in their scope when applied to aerial photography, the input size is limited, and there is no storage facility.

Another similar image 'analysis' device is the Histotrak produced by Ealing Beck. This is essentially for 'analysis' of biological images, and the analysis as such is area perimeter measurement and cell counts. However, despite its limited image size (microscope size) it may find a suitable application in work involving aerial photographs.

All the above systems, which are adequate for a lot of uses, are really measurement systems. But the aim of this work is to develop an analysis system, i.e. a system capable of looking automatically at an image and making decisions about the nature of the image.

Photometric Data Systems, Optronics and Joyce Loebl produce densitometer inputs suitable for aerial photographs. These systems are supplied with a computer and bulk storage medium that would enable analysis work to be carried out.

Computing Devices Company produce IPS II, which uses their computer and tape drive together with other manufacturers' input/output devices to process mainly satellite data. Processing here means high density instrument tape to coloured viewing screen or CCT to T.V. monitor etc., but it has a computer and, therefore, analysis capability.

To support these systems it is necessary to determine which analysis routines are common to many needs, and which can be supplied as basic building blocks. It would also be useful to identify other analysis routines that may be more user specific. At present each user has to build his own basic system and develop routines for a specific use. A way of approaching this problem is introduced in chapter 4.

3.5.1 Useful Analysis Systems

The Bendix system will produce a classification map based on spectral signature, but the input is limited to ERTS tapes and scanner data. The analysis is carried out by a combination of special purpose hardware and digital computer which can produce a vast amount of data.

The General Electric Image 100 is a very flexible system, consisting of a T.V. camera or ERTS tape input, computer and colour CRT display. The computer, however, contains a large number of image manipulation and analysis routines.

A new system on the market is OVAAC8 operated by Earth Observation Business Group. Their system is not for sale but offered as a service to analyse imagery. But more than just straight image analysis, they point the way to the future in supporting the work with a team of experts in the data collection and the user fields. The classification, however, is still spectral only and limited to about ten classes for coloured output. However, using a collection of programmable modules addressed by the computer a 4 channel ERTS image can be classed into 54 themes in about 3 minutes (cf FTC 1 on the first page of this chapter).

In the context of European work the need for analysis of ERTS tapes or scanner data is very limited so these systems are of little use. What is needed is a system that accepts photos as basic input, and can produce an analysis based on more than the spectral signature.

3.6 Other approaches

These are the chain B systems, based on optical or electro optical principles, which are mentioned here to show there are other approaches.

On the enhancement side, $I^2S$ and Fairey Surveys produce optical machines that will reconstitute the multiple image multispectral photos into a colour enhanced image which can then be visually interpreted.

For analysis Rank industries produce a machine called the Image 100. This produces the Fourier Transform of the image which could reveal a certain amount of information about the structure of the image. The Fourier Transform is not yet analysed automatically as it is produced. There are systems, notably the Terrain Classification System of Bendix, that classify an image in real time. The classification is based on texture comparisons to test samples by electro optical means.

3.7 Display

This is the most neglected of all stages in the automatic data processing of aerial photographs, yet it is as important as the other stages. The results of the analysis will usually be required as a hard copy. Two types of output are generally required - map and statistical. Statistical data can be printed on a conventional line printer.

The map type output can be displayed on a T.V. screen, but there is then the problem of obtaining hard copy. At present much work is output on a line printer in the form of a digital map, a very cumbersome method. The same output can be placed on a film writer, or the display screen can be photographed, though in neither case is a very satisfactory map produced. For hard copy coloured output the display screen can be photographed. It is possible to produce a number of black and white separation negatives and combine them in printing into colour composites. Unfortunately both these last two processes for colour, and the ones mentioned for black and white image, produce a large number of small pieces of the final map. These have then to be assembled into the final map required.

One need is a colour film writer able to accept video signals from a T.V. screen or digital data from the computer, and a number of firms - Joyce Loebl and Optronics in particular - are developing colour film writers.

Another need is a line drawn map produced on a graph-plotter or film writer, and this requires the development of suitable routines to change a block map to a line map.

Table 1 reveals that very few analysis systems are available. Many include a computer in their systems and have therefore a potential for analysis, but these systems are often limited in input/output, or processing throughput ability. Table 2 gives a list of the systems produced by each manufacturer. By cross reference between tables 1 and 2 it is possible to determine which manufacturers offer systems that meet the requirements (as described in 3.8) of an images analysis system.

## 3.8 Design considerations for an Image Analysis system

Any such system has two main functions; those of (i) handling or manipulating the image and (ii) analysing the image.

A. The general system functions are:

1) converting image to computer readable form
2) recording of processed images
3) real time display of images and other data
4) input of non-image information related to the image
5) storage and transfer of digitized image

B. The image manipulation functions are:

1) overlay and registration of images
2) selection of waveband subsets
3) selection of area subsets
4) geometric corrections
5) radiometric corrections

C. Typical analysis functions are:

1) ratio mapping
2) clustering
3) Gaussian decision rules
4) edge detecting and boundary finding
5) texture operation
6) general feature extracting

In the context of this research, item A.1 refers to digitisation. This involves the three important design functions (Lillestrand (1974)) covering input, processing and output.

| | |
|---|---|
| Input: | rate of digitisation of imagery |
| Processing: | complexity of image transform |
| Output: | nature of output |

Digitisation requires a consideration of the sample size, the number of digitized grey levels, memory requirements, storage medium and instrument digitizing rate. Digitizers can be video cameras or microdensitometers. Video cameras are fast, typically produce a 2000 x 2000 point raster, use up to 32 grey levels and are radiometrically and geometrically accurate to 5%. Microdensitometers are slow, typically produce a 18000 x 18000 point raster, use up to 1024 grey levels and are geometrically and radiometrically very accurate.

For comparison all transforms can be calculated in terms of the number of equivalent adds per pixel for the transform. For example, simple pattern recognition requires of the order of 100 adds per pixel. This gives some idea of the time of processing involved. The coarseness of digitisation will be a trade off between size of core for the image, and the programme. Processing the whole of a coarse picture may not give the same result as processing separate parts of a finer picture.

Output can be real time to microfilm plotter or storage tube display, or off line to magnetic tape for later printing by a film writer, graph plotter, or other hard copy device.

### 3.9 Hardware requirements

There is an obvious need for two different types of system 1) a digital software system and 2) a modular hardware system.

The purpose of the digital system is to develop the analysis routines and thoroughly examine their potential. It is basically a research system to determine the best approach to analysis in an operational system, which may be a hardware module, micro-programmable, software or even an electro optical approach.

The modular hardware system uses the routines developed and builds a hardware module to carry it out. For operational work this is much faster in throughput, as the modules can be under the control of a digital computer. Any problems can be put, in enhanced mode if needed, onto a T.V. screen.

The hardware requirements common to research or operational systems are:

Input - microdensitometer digitiser, drum or flatbed depending on application

Output - film writer

Display - storage tube/scan converter to T.V. screen

Computer - for development and operational systems

Modules - hardware analysis for operational work in real time

Facilities can be added to aid operator interaction, e.g. T.V. camera for quick look work, visual display for interaction with the computer, or extra storage facilities like magnetic drums or discs.

3.10 Summary

The main aim of this chapter on hardware is to make the reader aware of the difference between enhancement and analysis systems. Many systems on the market claim to be image analysis systems yet all they do is present the user with an enhanced version of the original. It still requires the user to decipher this image. Often the system provides simple functions like measuring the area of an enhanced colour. This is still not analysis; it will not help the user to interpret the image.

The systems that do offer an analysis function tend to be big, expensive, limited to spectral processing and therefore to classifications that can be achieved on spectral parameters. Input is often limited to ERTS or multispectral scanner tapes, or crude T.V. camera digitizers. Output is a colour coded or character coded 'recognition' map that has few locational features to enable a user to find the position of a given spot.

The components of a system are given which are suited to the proper and thorough investigation of the image structure and analysis problem.

Table 1 Comparison of Hardware

| Instrument | Digitizer | Enhancement | Analysis | Real time Visual display | Computer | Input | Output |
|---|---|---|---|---|---|---|---|
| 1 GE100 | TV camera 512 x 512 | Programmable | wide range | colour TV | included | max.9.5" x 9.5" ERTS tapes | LP map Photo CRT |
| 2 IPS II | optronics | Programmable | - | colour TV | included | 9" x 9" ERTS tapes | optronics |
| 3 Bendix | - | - | Spectral | colour TV | included | ERTS or m/s tapes | colour photo by overlays |
| 4 IA300 | - | - | optical Fourier | TV monitor | - | 20 mm.dia. on 82 x 100 mm. photo | 35 mm. camera |
| 5 PDS 200 | 500 line TV camera | - | - | b/w TV monitor | included | any scene | TV monitor |
| 6 Datacolor 703 | 500 line TV camera | main function | measurement | colour TV | - | 9" x 12" photo | TV photograph |
| 7 Optronics P1700 mk II | drum scanner | - | - | - | interface possible | 12cm. x 17cm.) ) | - mag.tape |
| 53400 mk IV | flat bed | - | - | - | " | 25cm. x 25cm.) | - |
| 8 PD 1010 | flat bed | - | - | optical of scanning area | included for control | 10" x 10" | mag tape |

Table 1 Comparison of Hardware

| Instrument | Digitizer | Enhancement | Analysis | Real time Visual display | Computer | Input | Output |
|---|---|---|---|---|---|---|---|
| 9 EDP | flat bed | - | - | facsimile output | interface possible | 70mm. film | circular facsimile |
| 10 PEP 400 | - | of grey levels | - | additional TV monitor | - | any digital or analogue data | hard copy device available |
| 11 VP 8 | - | main function | - | - | - | needs TV camera | needs TV monitor |
| 12 Quantimet 720 | 650000 point TV camera | yes | fixed module measurement | TV monitor | hardwired logic modules | 70mm. | teletype |
| 13 ODD | TV camera | - | - | - | required as controller | any scene | - |
| 14 Mann 1140 | high precision flat bed | - | - | - | - | 4½" x 10" | data to mag tape |
| 15 Joyce Loebl Mk IV | flat bed | - | - | optical of scanning area | included for control | 10" x 10" | digital tape |
| 16 Scandig | drum | - | - | - | interface available | 5" x 10" | digital tape |

## Table 2 Manufacturers of Systems mentioned

### General Electric

GE 100, complete software and hardware analysis system

ERTS, processing and analysis centre for customers

### Control Data Canada

IPS II, data handling system

### Bendix

ERTS processor, software and special purpose hardware spectral analysis, also for their own multispectral scanner

ERTS analysis centre for customers

### Rank

Image Analyser 3000, optical Fourier transform device

### Photo Digitizing Systems

PDS 200 T.V. digitizer with computer

### Spatial Data

Data colour electronic enhancement system

### Optronics International Inc.

Wide range of drum and flatbed digitizers with computers

### Photometric Data Systems (Perkin Elmer)

PD 1010 Flatbed digitizer with bulk storage and photo playback option

### Photo Metrics Inc.

EDP Scanning Microscope

### Princetown Electronic Products

PEP 400 Lithocon storage tube - many uses in display and enhancement

Interpretation Systems Inc.

VP Image analyser, black box enhancer with no input/output supplied

Image Analysing Computers (Imanco)

Quantimet 720 modular system for measurements on the image, T.V. camera input but equivalent to 0.5 million point digitizer.

EMR Schlumberger

ODD T.V. camera type digitizer, computer controllable image field.

D.W. Mann

1140 high accuracy flatbed digitizer

Ealing Beck

Histotrak - image measurement device

Earth Observation Business Corp.

OVAAC8 - complete image analysis service and large support staff

Joyce Loebl Ltd.,

Mk 1V digitizer flatbed computer control

Scandig drum digitizer computer control

Film writer

# CHAPTER 4

# PICTURE PROCESSING

4.1 Preamble

4.2 Theory of picture processing

4.3 The features

4.3.1 Statistical features

4.3.2 Textural features

4.3.3 Spatial structure features

4.3.4 Shape features

4.3.5 Relational features

4.3.6 Other features

# CHAPTER 4

# PICTURE PROCESSING

## 4.1 Preamble

The main approaches taken by software in trying to automate data processing of imagery have been explained in the previous chapters. The basic stages used in image processing are;

1) Digitisation
2) Preprocessing
3) Feature extraction
4) Classification or image description
5) Display or hard copy.

Digitisation has been dealt with briefly in the chapter on hardware, and display has also been briefly mentioned in the same chapter. Preprocessing is outside the scope of the thesis. Simple feature extraction and classification have been explained in chapter 3.

There is at present no practical theoretical guidance to feature selection (Bremermann 1970). However, using the system developed in this thesis a user can select a structure of features best suited to his application. Having done this the selected algorithms can be assembled into an efficient operational system. Thus this chapter leads on from the simple spectral classification approach to a more general image description and analysis approach.

It is possible to envisage a bureau service to which imagery can be brought. Users could then select features useful for their application and assemble these into an operational system.

## 4.2 Theory of picture processing

Once all the features have been acquired there is the problem of fitting them together into a useful program of analysis.

There are two basic systems which can be described as closed or open ended systems.

The closed type is that described by Bajcsy and Tavakoli (1973). They use a world model to restrict the program, i.e. they assume it is known what the images could possibly contain, and how to describe the objects. They use a conceptual identification of the objects with the concepts having meaning in the 3-D world. For example, if the concepts are rivers, lakes and bridges, low level operators (features) describe the concepts in meaningful ways. A river is identified as:- grey value same as water, texture homogeneous, boundary open, contrast great, spatial relations connected to lake, below bridge, surrounded by land. The grey value, homogeneity, contrast, can be set values during training. The low level operators are controlled by a high level (FORTRAN) programme. This system can recognise objects only that belong to its known world.

The open system is the type developed in this thesis. The user can select from a large pool or library of operators (feature extracting algorithms). The selected operators can be applied to the image to assess the operators' ability to discriminate and aid recognition in the particular type of image. This is, therefore, a user interactive system best suited for research into image structure. Once the structure has been found in terms of the available operators a closed and more efficient system can easily be connected to run in an operational mode.

However, even in this open system it is essential to develop things in the correct concept. Just extracting numbers is not very useful, the aim is to relate the 2-D image to the 3-D world. The texture should be described as rough in addition to 0.7 per unit area. Once again it is advisable to remember the importance of scale, rough at one scale may be smooth at another scale.

In looking more closely at two related options for recognition, a distinction will be made by calling them 'picture description' and 'picture grammar'. In both cases the object is described by features that have some conceptual meaning. Picture description describes all objects in the picture. It will apply each operator to the objects and depending on the value will produce some conceptual description in terms of the features. Here there is no need for a trash class as all objects are described.

The output produced by the application of the features could be

| | Feature Value | Feature |
|---|---|---|
| OBJECT 1 | SMOOTH | TEXTURE |
| | GREEN | COLOUR |
| | NO | LINEAR FEATURES |

| | Feature Value | Feature |
|---|---|---|
| OBJECT 2 | MEDIUM | TEXTURE |
| | BROWN | COLOUR |
| | STRONG | LINEAR FEATURES |

However, this is limited in its usefulness. The descriptions are more useful if they can be allocated a class membership. Any unallocated description generated during recognition will cause the object to be assigned to the undefined class. This structuring of the features is described as a picture grammar.

The more formal description of Evans (1968 and 1969) is useful here. The investigator chooses some broad class of patterns such as the class of all line drawings (or vegetation). He then chooses a set of primitives (or features) and relations between primitives. The primitives could be line segments and curves of various sizes and orientations (or colour, texture). The relations could be 'next to', 'above' (or union intersection). The primitive relations specify various ways in which the primitives can be concatented to form objects (or classes). A formalism can be specified which defines how these primitive relations can be used to link primitives into objects, this is the grammar.

Two things are required:

1) a processor to extract primitives (this is one function of the system developed in this thesis).

2) a parser, which given the primitives and the grammar does one of three things:

   a) produces a description of the pattern in terms of its composition (Picture description)

b) classifies the pattern into one of the known classes using the grammar (Picture grammar)

c) if no class exists, either goes to a) or sets up the formalism for a new class.

This second option b) is very much in the hands of the user.

The complete system should be capable of accepting new primitives or new relations without a change in the grammar. At present the grammar is still 'written' by the user and the system developed is used as a processor to extract the primitives or features.

As an example in grammar construction let us follow the idea of George F. (1970).

Formally classes are named A,B,C,.......
these are known before hand.
properties are named o,p,q.....
the properties of the classes are known.
Individuals of class A are $\alpha_1$ $\alpha_2$ $\alpha_3$
" " " B are $\beta_1$ $\beta_2$ $\beta_3$
the relations are $\cap$ intersection
$\cup$ union
$\leftrightarrow$ connected to
$>$ larger than

For example consider A the class of all vegetation. Vegetation is known to have the properties

o = green

p = brown

q = smooth

r = rough

then an individual of the class could be

$$\alpha_1 = (o \Omega q)$$

this means that $\alpha_1$ has the property of being green and smooth textured. It is conceptually described as grass.

This much the interpreter will be able to do himself. At present then it is the interpreter who constructs the grammar and the relations, and not an automatic parser.

However, the problem remains of how to define rough, smooth, green, etc., and it is in this situation that the system outlined here has some application. By applying various operators to the image, numerical values can be set to the features that describe the properties of the classes.

To investigate the structure of the image and the relationship of the features the user needs to follow these steps:-

1) The classes and class members should be defined.
2) The conceptual properties describing each class and distinguishing between each class should be defined.
3) The system can then be used to select the best features to delineate the properties.
4) A classifier or picture grammar can then be constructed to produce the required classification from the features.

It may turn out that no feature combination is adequate to distinguish between some classes or class members. In this case the class member will have to be amalgamated or deleted from the analysis.

On the other hand it may happen that a particular feature, say spectral value, may enable 'green' to be divided into two clear shades. In which case it is possible to expand the class members.

What usually happens is that classes or class members have the same conceptual properties but are delineated by different values of the associated features. This is the strength and simplicity of the supervised and unsupervised classification based on spectral value. Indeed in more complex recognition structures, simple decision rules or thresholding can decide which conceptual property a certain value of feature represents.

For example Haralick and Anderson (1971) describe the use of a dictomous key classifier where a decision is made at each hierarchical level based on the value of a certain feature. These features and their values are chosen by the use of training sets of data.

The way the features are found can be very important. If the decision is between woods and grass then a small regular block of pixels with a texture feature will be adequate. If on the other hand the class water contains the class members lake and river, a boundary finder would be required. This traces around all areas of water and notes if the boundaries are open or closed. In this instance a small fixed block of pixels may not be much use.

To place a grammar to the class members in order that they might be recognised, consider the properties:

o = black

p = boundary

q = closed

r = open

and the relations

* surrounded by

<-> next to

Ω intersection

then the concept lake = (o*(pΩq))

and the concept river = ((pΩr)<-> o <-> (pΩr))

Even this may call a lake a river if the lake is cut off by the edge of the picture or pixel block.

The conceptual properties could be found to be related to features using the system such that

black = density feature 1.5D

boundary = edge feature with black on one side.

closed = feature that measures the distance between the ends of the boundary, feature value very small or zero.

open = large feature value for the distance between the ends of the boundaries.

## 4.3 <u>The features</u>

All the features given in this section can be applied to the objects in the imagery, and a classifier or recognition structure built from the results. But to apply operators (feature selecting algorithms) at random is a bit futile, and a rational approach is necessary.

First, as previously mentioned, the user can break down the conceptual description of the classes into their properties. Secondly operators must be sought which describe these properties, thirdly the systems should be used to test suitable operators.

There also remains the problem of the user identifying his real needs from such a system. A lead to the solution of this is given by Brick (1969) who poses some general questions all users should answer before utilising the systems computer. These questions help the user to highlight his real problem area.

Questions such as:

i) Is there an obvious approach? Has the problem, its analogue or homologue, been solved in some other field or aspect of the users' field?

ii) Are the pattern classes defined, undefined or to be teleologically devised?

iii) What a priori assumptions should be made?

iv) Which features need enhancement in preprocessing?

Ideally as the system is computer based it would be most suitable to have an interactive terminal where the user could answer these questions and learn where to find solutions to his problems.

From the results of this initial dialogue the user will have some idea of which algorithms to try. As an aid a number of operators or feature selecting algorithms will now be given.

For convenience the features are given under the following headings:

A. Statistical features

B. Textural features

C. Spatial structure features

D. Shape features

E. Relational features

F. Other features

There are several ways features can be extracted. From a regular area of the image sampled at constant intervals, or from isolated object itself. The latter case reveals information about shape and boundary.

Remember that each point represents a certain area on the ground so a feature using an 8 x 8 square at one scale may not work at another scale, because the object may now be totally contained within four resolution elements.

4.3.1 Statistical features.

(i) Herzog and Rathja (1973) describe a number of features. For an n x m set of points $A_{ij}$ $i = 1.....n$ $j = 1.....m$ intensity $I_k$ $k = 1....p$ p density levels

(1) the mean $\mu = \frac{1}{(n \times m) - 1)} \sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij}$

the deviation $\sigma^2 = \frac{1}{(n \times m) - 1)} \sum_{i=1}^{n} \sum_{j=1}^{m} (A_{ij} - \mu)^2$

the feature vector is $F_s = \begin{vmatrix} \mu \\ \sigma \end{vmatrix}$

(2) construct a distribution function

$n(I_k)$ number of data points of intensity $I_k$

(3) construct a probability function

$$p\ (I_k) = \frac{n(I_k)}{n \times m} \quad \text{probability of intensity } I_k$$

(4) the Entropy of the data array (amount of information)

$$\rho = \frac{-1}{(n \times m)} \sum_{k=1}^{\rho} n(I_k)\ \mathrm{Log}_2\ (p\ (I_k))$$

the feature vector is $F_I = |\rho|$

the higher the entropy the greater the disorder in the data array.

(ii) Statistical measurement feature.

Cheng and Ledley (1968) describe a number of measurements that can be made and assembled into a multi-value feature. Each element of the feature vector is one value from the following list. This vector can be used in classification in exactly the same way as the spectral signature.

Elements of statistical vector.

1) Mean grey level

2) Grey level variance

3) )

4) )

5 )

6 ) - Relative frequency of

7 ) grey levels

8 )

9 )

10 )

11) Information in x direction (along lines)

12) Information in y direction (down pixel columns)

13) Area of the object that has a grey level equal to the mean

14) Area of the object that has a grey level within one variance.

15) Area of the object that has a grey level within two variance.

(iii) Statistical measure of texture.

Consider picture functions of the form Aij i,j = 1,2,3...256 and the sample point having a density in the range 1-64. A completely random picture is one that satisfies the requirement that the grey level values be statistically independent, i.e. they are completely disordered (see entropy earlier on in this section) e.g. (p(x/y) = p(x). Characteristic deviations from randomness might be indicative of a specific texture.

Sutton and Hall (1971 and 1972) have used a number of measures of texture of the general form

$$M = \sum_i \sum_j \sum_k \sum_l \left| Aij - Ak,l \right|$$

Specific cases are

Gradient

$$G = \sum_i \sum_j \left| A(ij) - A(i+1,j) \right|$$

$$F_G = \left| G \right|$$

Radial measure M(r)

$$M(r) = \sum\sum \left| A(ij) - A(i+r,j) \right| + \left| A(ij) - A(i-r,j) \right| + \left| A(ij - A(ij+r) \right| + \left| A(ij) - A(ij-r) \right|$$

the feature vector consists of a subset or set of the values of M(r) at specific distances $\begin{pmatrix} \\ M(r) \\ \\ \end{pmatrix}$

$$F_R = \begin{vmatrix} M(1) \\ M(2) \\ M(3) \\ \vdots \end{vmatrix} = \begin{vmatrix} \begin{pmatrix} \\ M(r) \\ \\ \end{pmatrix} \end{vmatrix}$$

Differentiation of vertical or horizontal patterns can be achieved by using part of the summation in the modulus at various valves of r.

iv) Sequency statistics.

For information on the spatial sequency or statistical occurance of sequences of grey tone a Walsh function can be used. Using this function in a 2-D way results in the equivalent of the conventional power spectral density. For a detailed explanation of these transforms see H.C. Andrews (1970).

For an array of data points A

$$H = W^T AW$$

where W =

| | | | | | | | | sequency |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 1 | 1 | 1 | 1 | -1 | -1 | -1 | -1 | 1 |
| 1 | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 2 |
| 1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | 3 |
| 1 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 4 |
| 1 | -1 | -1 | 1 | -1 | 1 | 1 | -1 | 5 |
| 1 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 6 |
| 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 7 |

The features are Hi, where Hi is formed from the sum of the squares of certain regions of the matrix H. Each Hi contains information concerning the spatial sequency i in the data array.

The feature vector is

$$Fw = \begin{vmatrix} Ho \\ Hi \\ H2 \\ \cdot \\ \cdot \\ \cdot \\ Hn \end{vmatrix}$$

### 4.3.2 Textural features

i) Textural features (Herzog and Rathja 1973)

The distribution of change of grey levels of adjacent cells can be used as a measure of texture.

Divide the range of magnitude of grey level change into $\ell$ ranges.

Then find d(i) $(i = 1, \ldots, \ell)$ where d(i) is the number of adjacent cells having a magnitude change in the range i. This is taken a stage further in the spatial grey tone dependence matrices of Haralick and Anderson (1971).

The feature vector Fd is

$$Fd = \begin{vmatrix} di \\ \cdot \\ \cdot \\ d\ell \end{vmatrix}$$

A further measure of texture can be obtained by adding the weighted feature vector Fd. The weighting will show up and influence a particular magnitude change:

$$d = d_1 + 2d_2 + 3d_3 + 4d_4 + 5d_5$$

$$FT = |d|$$

Possible variations are:

(a) to consider the magnitude change in specific directions.

(b) to increase the distance over which the magnitude change is considered.

(c) to allow changeable weights.

ii) Textural features of detail.

For information on texture a detail filter can be used (Taylor 1972). This must be used with care since it is sensitive to spatial frequency and intensity level.

Using a 3 x 3 grid operator each point can be either +ve or -ve. This results in $2^9 - 2$ possible arrangements of +ve and -ve. Each arrangement of operator when applied to the data points will result in a different output of the filter. These outputs can be used as a measure of texture. The filter has to be weighted so that the output from a uniform set of data is zero.

$$\begin{matrix} V_1 & V_2 & V_3 \\ V_4 & V_5 & V_6 \\ V_7 & V_8 & V_9 \end{matrix}$$

If the above is the set of data points, and the filter used is (a) or its inverse (b)

$$\text{(a)} \begin{matrix} -1 & -1 & -1 \\ +1 & +1 & +1 \\ -1 & -1 & -1 \end{matrix} \qquad \text{(b)} \begin{matrix} +1 & +1 & +1 \\ -1 & -1 & -1 \\ +1 & +1 & +1 \end{matrix}$$

then the output is

$$\phi = \tfrac{1}{3}(V_4 + V_5 + V_6) - \frac{1}{6}(V_1 + V_2 + V_3 + V_7 + V_8 + V_9)$$

if the maximum value of V is Vm

then $\phi$ can vary between -Vm and +Vm

It is more convenient to have a positive output proportional to the amount of detail detected. This is obtained by taking the modulus of the detail filter or the inverse filter (b).

Generally V will vary Vh to Vl and the maximum output will be

$$\phi = \tfrac{1}{3}\,(Vl+Vl+Vl) - \frac{1}{6}\,(Vh+Vh+Vh+Vh+Vh+Vh)$$

$$\phi = Vl - Vh = V$$

this is just a measure of the contrast, and is independent of the actual levels.

Each detail filter is 'tuned' to a particular spatial frequency and angle.

Some filters and their inverse are listed here.

$$DF_1 = \begin{array}{ccc} - & - & - \\ + & + & + \\ - & - & - \end{array} \qquad \begin{array}{ccc} + & + & + \\ - & - & - \\ + & + & + \end{array}$$

$$DF_2 = \begin{array}{ccc} - & + & - \\ - & + & - \\ - & + & - \end{array} \qquad \begin{array}{ccc} + & - & + \\ + & - & + \\ + & - & + \end{array}$$

$$DF_3 = \begin{array}{ccc} - & - & - \\ - & + & - \\ - & - & - \end{array} \qquad \begin{array}{ccc} + & + & + \\ + & - & + \\ + & + & + \end{array}$$

$$DF_4 = \begin{array}{ccc} - & - & + \\ - & + & - \\ + & - & - \end{array} \qquad \begin{array}{ccc} + & + & - \\ + & - & + \\ - & + & + \end{array}$$

The feature vector is

$$FDF = \begin{vmatrix} DF_1 \\ DF_2 \\ . \\ . \\ DF_N \end{vmatrix}$$

4.3.3 Spatial structure features.

i) Features based on power spectra.

To investigate the spatial structure one can obtain the power spectrum and extract features from this. For example one method based on work by Preston and Davies (1972) is useful in that the spectrum, and therefore the features, can be obtained in terms of absolute ground measure. This allows comparisons with other areas. Also the method involves standardising the density values and smoothing the data set. So a really useful set of features can be obtained.

As given these features refer to one dimension only but data lines can be taken at various angles across the image and the resulting spectra used separately or averaged to find a mean vector. The different spacings of points and the various angles are catered for in the algorithm. Averaging will reduce rotation dependence of the object.

The structure of the power spectrum is characterised by the set of numbers of the discrete FT of the autocovariance function (ACVF) of the data set.

$$\text{ACVF}(J) = \frac{1}{N} \sum_{i=1}^{i=N-j} (y(i+j)-\bar{y})\,(y(i)-\bar{y})$$

where

ACVF (J) = discrete autocovariance function for the data function at lag j.

N = number of equally spaced data points.

j = lag value for autocovariance function

y(i) = value of the function

$\bar{y}(i)$ = arithmetic mean of yi over the complete <u>line</u>

For standardisation

$$y(i) = \frac{T(i) - \bar{T}}{\sigma}$$

where Ti = optical density of data point

$\bar{T}$ = mean over the <u>entire</u> data set

$\sigma$ = standard deviation

The discrete power spectrum is $\left( S(k) \right)$

$$S(k) = 2\Delta\left( ACVF(O) + 2\sum_{j=1}^{j=m-1} ACVF(j)\, W(j) \cos \frac{\pi jk}{F} \right)$$

where

$\Delta$ = spacing between successive data points either on film or on ground.

ACVF(O), ACVF(j) = value of ACVF from first equation

W(j) = ACVF smoothing function or lag window whose function form can vary to suit the application.

M = maximum lag or truncation point

F = integer multiple of M to permit interpolation of more spectrum points.

F = M, 2M, 3M etc.,

the Parzan lag window is useful for W(j)

$$W(j) = 1 - \frac{6j^2}{M_2} \left(1 - \frac{j}{M}\right) \quad O \leq j \leq \frac{M}{2}$$

$$W(j) = 2 \left(1 - \frac{j}{M}\right)^3 \quad \frac{M}{2} \leq j \leq M$$

to obtain spatial frequency for index k

$$fK = \frac{1}{2} \quad \frac{k}{F}$$

This allows standardisation to true object size.

The set or subset (S(k)) is used as the feature vector

$$FACVF = \left| \begin{pmatrix} S(k) \end{pmatrix} \right|$$

ii) Spatial structure features based on Fourier Transform.

Hornung and Smith (1973) use features extracted from Fourier analysis of image blocks. As mentioned elsewhere in this thesis the Fast Fourier Transform can be used to compute the 2-D power spectrum. Or the power spectrum can be obtained optically then digitised (Preston & Davis 1972 page 231). But due to the lack of dynamic range of film the latter method may lose some information. Typically a 64 x 64 image block is convenient to use.

The features used indicate distribution of energy in the Fourier plane. This energy is related to the spatial structure in the image. The features are obtained by using a square ring or wedge sampling of the power spectrum (Fig. 8): the feature being the energy contained within a wedge or ring. The final features can be a subset or combined subset (average of several adjacent samples) of the total set.

For a 64 x 64 image block one can use up to 31 rings or 32 wedges.

For n rings or m wedges

$$TW = \{Iwj\} \quad (j \varepsilon \,|1.....m|)$$

$$TR = \{IR_k\} \quad (k \varepsilon \,|1.....n|)$$

The complete feature vector is

$$FTWR = \begin{vmatrix} (Iwj) \\ (IRk) \end{vmatrix}$$

4.3.4 Shape features.

i) Shape filters.

Hawkins and Elerding (1967) describe a set of shape detecting filters similar to those of Taylor (1972). These filters again are in the form of masks. Each element of the mask is individually weighted and the shape of the mask is non-standard.

Some examples are

$$\begin{array}{ccc} -1 & +2 & -1 \\ -1 & +2 & -1 \\ -1 & +2 & -1 \\ -1 & +2 & -1 \end{array} \quad \Bigg| \quad \begin{array}{ccc|ccc} -1 & +2 & -1 & 0 & 0 & 0 \\ 0 & -1 & +2 & -1 & 0 & 0 \\ 0 & 0 & -1 & +2 & -1 & 0 \\ 0 & 0 & 0 & -1 & +2 & -1 \end{array}$$

Elements are weighted so that a uniform image results in zero output from the filter.

The filter sum Sp is formed for an n x m filter

$$Sp = \sum_{i=o}^{n} \sum_{j=o}^{m} W_{ij} I_{ij}$$

W is the filter element

I is the image point

Using a number of different shape filters $S_k$ $k = 1.....p$ gives a feature vector

$$Fs = \begin{vmatrix} S1 \\ S2 \\ \cdot \\ \cdot \\ Sp \end{vmatrix}$$

ii) Shape descriptors.

Cheng and Ledley (1968) also give a number of shape measures that can be applied to isolated objects.

a) Area of object
b) Height of circumscribed rectangle
c) Width of circumscribed rectangle
d) Length of ellipse of equivalent area of object
e) Thickness of ellipse of equivalent area of object
f) Aspect ratio of equivalent ellipse
g) Perimeter of object
h) Shape complexity $(\text{perimeter})^2/\text{area}$

i) 'Serpentine length' length of equivalent rectangle having same area and perimeter

j) Serpentine width

k) Aspect ratio of serpentine equivalent rectangle

l) Horizontal intercept count

m) Verticle intercept count

n) Compactness - ratio of actual area to area of circumscribed rectangle

o) Hollowness - ratio of intercept counts to height and width.

4.3.5 Relational features.

Barrow and Popplestone (1971) describe a number of measurements that can be used as features describing the shape and relation of the object. These are based on information from the object as a whole. Hence an initial object isolation algorithm is needed.

a) **Compactness**

$$c = \frac{4 \quad \times \text{area}}{\text{Perimeter}}$$

$$Fc = |c|$$

this varies from 1 (circular) to 0 (very irregular)

b) Shape - derived by sampling the components derived from a Fourier analysis of the $S - \psi$ equation of the region boundary. Any curve may be represented in $S - \psi$ co-ordinates, where $\psi$ is the angle the tangent to the curve makes with the x axis, and S is the length along the curve between the point and an arbitrary zero.

$$\text{Consider } \phi(S) = \psi(S) - 2\pi \frac{S}{So}$$

where So is the circumference of the curve.

This repeats cyclically $\phi(0 + S) = \phi(So + S)$ and can be Fourier analysed. The shape properties are the RMS amplitude of n components of $\emptyset(S)$.

$Fj\,\emptyset(S) \quad j = 1.......n$

The feature vector is

$$FSH = \begin{vmatrix} F1\ \emptyset \\ F2\ \emptyset \\ \cdot \\ \cdot \\ Fn\ \emptyset \end{vmatrix}$$

c) Bigger - the relation between two regions A and B

$$b = \frac{\text{area } A}{\text{area } A + B}$$

this varies between O and 1

the feature vector is

$$Fb = |b|$$

d) Adjacent - is the fraction of the boundary of A that has a point of region B next to it or within some very small distance

$$A = \frac{\text{length } A \cap B}{\text{length } A}$$

$$FA = |A|$$

e) Distance - provides information about the relative position of the regions. It is equal to the distance between the centres of the regions (dr) divided by the geometric mean of the average radius of the two regions (avr)

$$avr = \frac{2 \times \text{Area}}{\text{perimeter}}$$

$$\text{distance } DI = \frac{dr}{avr}$$

$$FDI = |DI|$$

In connection with this measure by considering the arithmetic sign one can derive the relations 'above' 'below' and 'beside'.

4.3.6 Other features.

There have been other approaches to feature extraction in many fields of science. Some of these approaches may prove useful in Remote Sensing so some key references are given below that should prove useful.

i) Theoretical papers on feature detection mainly referring to character recognition but still valid methodologies for remote sensing.

In: IEE NPL Conference on Pattern Recognition July,1968 National Physical Laboratory Conference publication 42, Teddington, Middlesex.

A Strategy for the Design of Feature Detection Systems for Pattern Recognition, J.P.M. Thomas, pp.144-153.

A Method of Choosing Operators in Pattern Recognition, B.A. Wichman, pp. 191-196.

A Simplification of the Problem of Choosing Features, J.R. Ullmann, pp.197-206.

A Practical Technique for Feature Detection, R.H. Britt, pp.347-354.

ii) Application papers for feature extraction on non Remote Sensing Subjects, but valid for Remote Sensing Applications.

In: IEEE Conference Record of the Symposium on Feature Extraction and Selection in Pattern Recognition, Oct. 1970, 70C 51-C, Argonne National Lab., Illinois.

E.L. Hall et al, Measurement Selection Techniques applied to Digital Images, 78-89.

J.E. Green, Computer Methods for Erythrocyte Analysis 100-109.

Rosenfeld, A.R., Troy, E.B., Visual Texture Analysis pp.115-124.

Feature Extraction for General Visual Patterns, J.B. McFerran, pp. 125-134.

A General Purpose Programme for the Extraction of Physical Features from a Black and White Picture, Shelman, C.B., Hodges, D., pp.135-144.

# CHAPTER 5

## THE INTERACTIVE SOFTWARE SYSTEM (ISS)

PDP 11/40

Figure 12. General view of the computer.

# CHAPTER 5

# THE INTERACTIVE SOFTWARE SYSTEM

## 5.1 Preamble

In this chapter the term System refers to the computer and its operating software such as compilers. The set of programmes developed are called the Interactive Software System, or ISS.

Both hardware (machines) and software (programmes) parts of the System are typical minicomputer types. An attempt has been made to make this initial ISS as independent as possible of specialised equipment. In the European context, as well as the research context, an interactive minicomputer is preferable.

The components of the basic System (shown in Fig. 12) are:

DEC PDP 11/40 with 24K memory
Cartridge disk
7 track magnetic tape
Line printer
Card reader
Keyboard
GT40 graphics terminal with 8K PDP 11/05
Digitising facility (available external to the university)

The ISS will operate without the GT40, but as all output displays will have to go to the line printer this will slow the process down considerably. The digitising facility need not be in-house as in this case where, due to the co-operation through the IHD scheme, it was possible to use the digitization services of Joyce Loebl.


Figure 13. The GT40 graphics unit, showing the small computer (below the screen) used to store the image being displayed, and the light pen (right of screen) used to interact with the image.

Information can be stored or transfered from the magnetic tape (MT:), the System disk (SY: or DK:), the card reader (CR:) or the keyboard (KB:). The GT40 is normally a 'stand alone' device, but using a program developed and incorporated into the System software it can be used to display anything that would normally be printed on the keyboard or line printer. The keyboard itself is still used as the main interactive device by which the running of the ISS is controlled, but the characters appear on the GT40 screen and not on the keyboard paper. This allows a fast interactive facility.

The core of the GT40 (shown in Fig.13) is a PDP 11/05 (8k) which is split into a number of areas. The core is scanned every $\frac{1}{30}$ second and its contents displayed on the screen. The areas of core are split into

i) the Scroll, this allows up to 32 lines of 72 characters to be displayed

ii) the remainder, which is the book, is divided into four chapters called pictures, figures, tables and graphs respectively.

Using the Fortran routines in the Picture Book language, it is possible to construct figures, graphs and tables, each stored in its relevant chapter. The contents of these chapters can then be displayed on the screen.

Any scrolling will appear on top of the figures drawn, and it is this scroll section that is used in a monitor mode with the keyboard.

5.2 <u>Two approaches to the Interactive Software System</u>

The two ways to build the Interactive Software System are as a library based program or Overlay system.

5.2.1 The library based Interactive Software System

Using the DOS library facility LIBR it is possible to construct a user's own library similar to the standard Fortran library. The library is a collection of compiled subroutines organised into a single package. The subroutines in this library can be called by any program that has been 'linked' to the library.

Linking is the final stage in program preparation. After the main program containing the subroutine calls and the library have been compiled there are two object modules. These are not yet quite in a form that can be loaded into computer core and run. Linking creates a load module from a number of object modules. It is this that is loaded into core to run as a program.

Thus, after linking there is one load module on the disc that contains the main Fortran program and all the subroutines it calls. This program is executed by a DOS command that puts it into core and starts it running.

5.2.2 The overlay based Interactive Software System

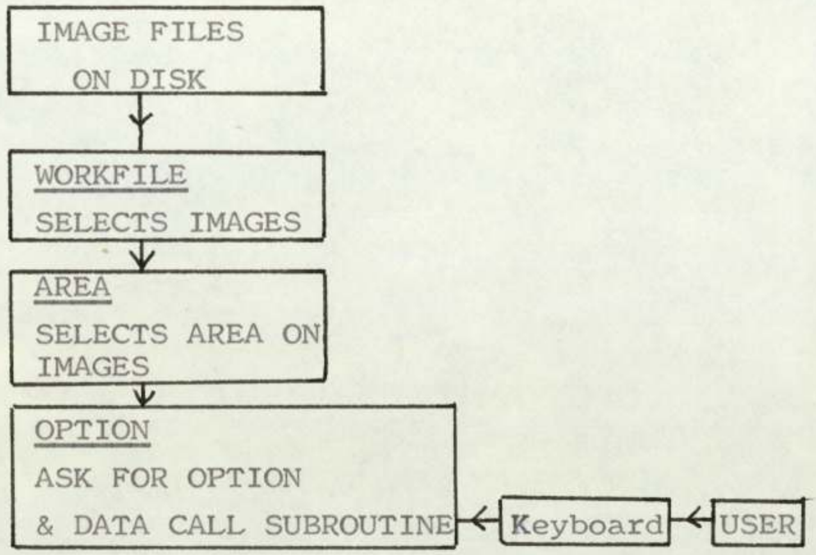
Once again there is the main Fortran program and all the separate subroutines. In this approach the subroutines are separate and each is individually linked to produce a separate load module. Similarly, the main program is created as a separate load module.

The computer core is split into two areas called the resident portion and the overlay portion. The main program resides permanently in the resident portion during the running of the ISS. Each time a subroutine is called it is loaded into the overlay portion and becomes in effect part of the program. When finished with it is overwritten

Figure 14.

Layout of the library Interactive Software System

main program



by the next overlay.

It is thus possible to have an unlimited number of overlays on the disk. Unlike the library approach, it does not require all the subroutines and main program to be in core together.

## 5.3 The library Interactive Software System.

For this study a library was built called IMAGE which contained the six subroutines:-

HPLOT
MAP
EDGE 1
CLUSTER
BOUNDARY
SPECTRAL PLOT

The operation of these is essentially the same as those described later on in the chapter.

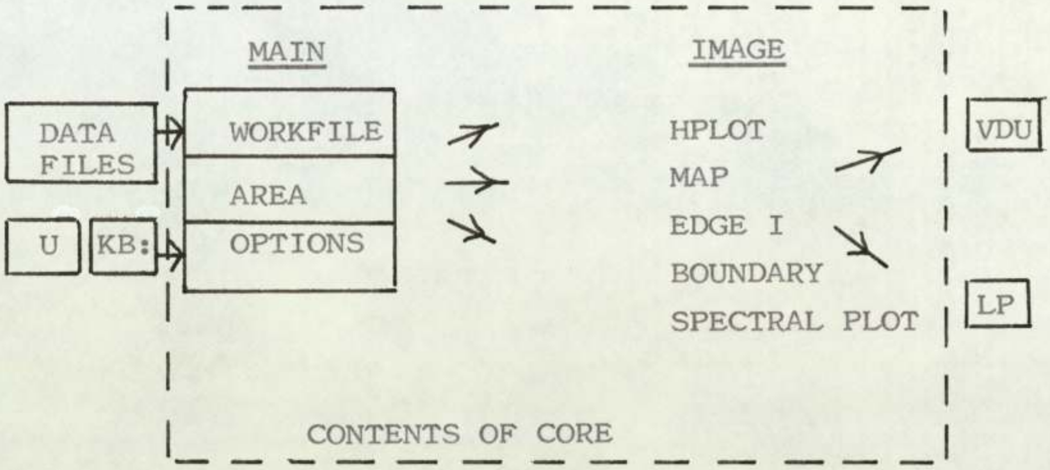
This library was linked to the main interactive program called MASTER.

The subroutines in IMAGE are purely subroutines and they contained no main segment or interactive sections.

MASTER contained all the interactive sections including those which asked for the subroutine parameters. MASTER was split into three sections called 'Workfile', 'Area' and 'Option' (see Fig. 14). Workfile interacted with the user to find out which of the images stored on the disk were going to be used. 'Area' interacted with the user to establish which area on the images was to be analysed. When selected the 'option' section also asked for all the data needed to carry out the algorithm and then called the subroutine.

Figure 15

Block diagram of the Library Interactive Software System 'Main' Program and 'Image' Library



The selected subroutine performed the calculation and output the result to the required device or stored it on a disk file. The flow of operations is shown in Figure 15. The entire program and subroutines have to be in the computer core, and this is where the limitation lies.

Initially, the main program was linked to only five of the subroutines, i.e. the program contained five options only and five corresponding subroutine calls: the missing one was CLUSTER. The problem with this type of system is encountered when trying to add a further option as can be illustrated. To add the option CLUSTER the main program had to have additional lines added (to interact with the user) to ask for information related to the option, such as 'How many clusters do you want?'. The main program had then to be recompiled, and the library had then to be rebuilt to incorporate the compiled version of CLUSTER.

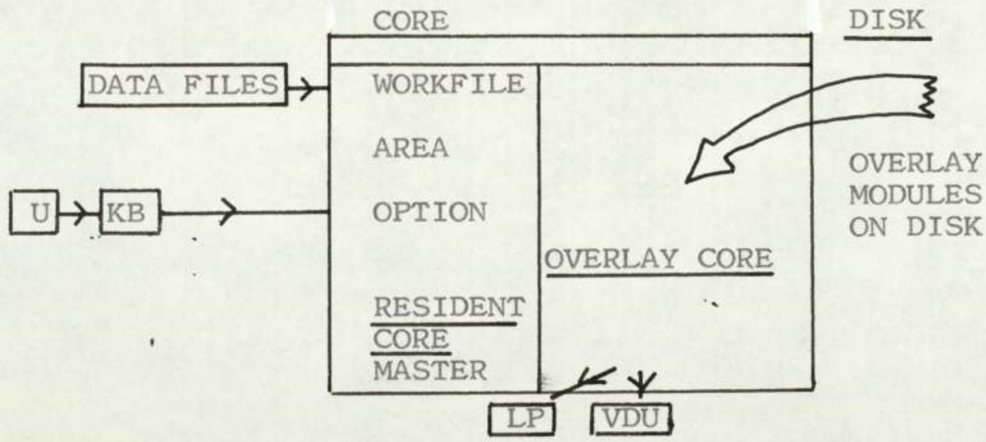
The library and main program had then to be relinked to form a new load module, but, unfortunately, this load module became too big for the available core. Hence the limit had been reached. For the size of computer available only a very limited number of options could be offered with this method. There is the additional disadvantage of the effort required to add subroutines.

## 5.4 The overlay Interactive Software System developed for this study

To overcome the limitations of the library system, an overlay system was initiated. Using this approach it can be made to appear as though there is unlimited core available.

Figure 16.

The overlay Interactive Software System



The main program is similar in structure to the library case. It contains the three sections 'Workfile', 'Area' and 'Option'. This time 'Option' displays a list of options; 12 in this case, and the user is asked to select one. On selection the relevant overlay is then called and loaded into the overlay portion of core (Fig. 16 ). Each overlay contains the interactive section needed to find the parameters of the subroutine, and the subroutine itself. On completion of the operation the subroutine sends the results to the required device or data file, and returns control back to the main program in the resident section.

This overcomes the limitation of core. In fact an overlay in core can call another overlay, in which case the called overlay overwrites the calling overlay. Communication between overlays and the main program is by common blocks or by storing results temporarily in a data file on disk.

The problem of adding extra programs is eased by this method: the overlays are called into core by a Fortran statement CALL LINK ('OVERLAY') in the option subroutine. The name of the overlay stored on disk is OVERLAY. Hence providing there is a load module called OVERLAY on disk, the option selected can be carried out. The overlay does not have to be linked to MASTER but uses a special symbol table created when MASTER is linked. This symbol table can be saved for use at a later date. If a new overlay is written subsequently, the saved symbol table can be used in the linking process. This will ensure that the new overlay is formed correctly and can be used by the master program. The main purpose of the symbol table is to ensure that input output and the common blocks between master and overlay are set up correctly. Also to ensure the overlay goes into the correct place in core. A CALL RETURN statement in the OVERLAY returns control back to the master subroutine.

Hence OPTION can contain statements such as CALL LINK ('NEWONE') and CALL LINK ('NEWTWO'), and NEWONE, NEWTWO listed as selectable options. Then if a user wants to add a new algorithm all he needs to do is write a program called NEWONE containing the algorithm and the interactive lines, then compile it and link it using the symbol table. Thus, if he adds a new option to say pick out all line structures in the image and calls it NEWONE, then when he selects NEWONE under control of the option section his program will be run. Including the relevant common block (see later) will ensure that information about the image is passed to his program.

Thus, there is no need to change MASTER or any of the other overlays to add extra algorithms.

Each overlay as needed is loaded into core and becomes part of the program in core. The interaction between user and the option selected now occurs in the overlay section and not in the 'Option' section of MASTER. The only interaction between user and MASTER involves WORKFILE, AREA and OPTION selection. The overlay, as do the subroutines of the library ISS, controls the output. The overlay ISS is easier to expand than the library ISS.

For the reasons of core saving and easy addition of extra programs, the overlay ISS is the preferred system.

The detailed operation of the overlay ISS is explained in two sections. Later in this chapter the operation is explained so that users can understand the running of it and the meanings of the questions the program asks. Chapter 6 explains in programer's terms the operation of the ISS.

In the first instance, however, it is worth noting a few general points on the running and organisation of the ISS.

## 5.5 Image data

The image (photograph) sampling used is M x n rectangular matrix on a 'x' cm by 'y' cm film. In this particular case four images from the four bands of one multispectral photograph were digitized. The images were digitized with a drum scanning microdensitometer that extracts data in a horizontal raster pattern. The digitizer fixes the y co-ordinate (line) and increments the x co-ordinate (pixels), digitizing a small area of the film density into a binary number. In this case the x and y increments were 200 microns with a sample spot 200 microns in diameter. The image size is 95 mm x 95 mm but to cover the edges a scan of about 500 x 500 points (i.e. 100 mm x 100 mm) was undertaken. The density was digitized to an 8 bit binary number corresponding to an integer in the range 0-255. This covered a range of D from 0 to 2D. At the end of the x scan the y is incremented (i.e. the next line is scanned).

The data is written onto magnetic tape so that the jth record is the same as the jth row or line of the image matrix. A collection of n such records is the image file. This form of data structure is known as sequential row access.

To obtain a more efficient working format the data is converted to its integer value and stored on a direct access (random) data file on the disk. This means that to get at an image line (file record) all that is needed is to specify the record number, and the line is immediately obtained. In a sequential file all the records would have to be passed over until the required one is reached.

Things are not as simple as the above paragraph might indicate. There is the problem of tape compatability between digitizer and computer.

The output of the Joyce Loebl Scandig is a 9 track magnetic tape, with the format in blocks of 1024 words, each word an 8 bit number representing the density at the scanned point.

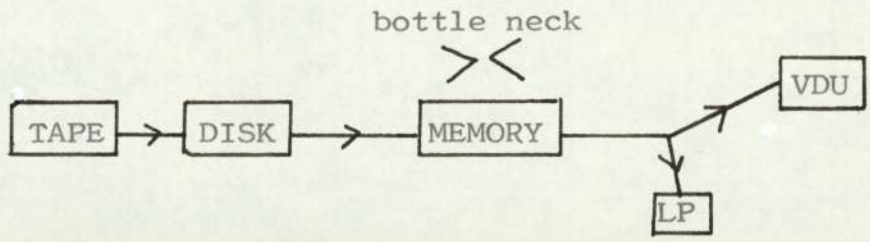
The DEC System requires 7 track tape written in DOS format with 256 words per block and a tape header for each file.

After approaching various centres for assistance, Harwell stated they could carry out the required operation. They were able to read and re-write the tape into a format that the System could handle. But this was still a binary tape that could not be used under program control.

A number of programs were used to convert this binary sequential access image file to a direct access integer image file.

Figure 17.

Data Flow bottleneck. The data capacity of each part of the System




Magnetic tape - 5 million data points

Cartridge disk - .75 million data points (or data + programs)

Memory - 16000 words for data and program

Display - 32 lines x 72 characters or 2000 dots

Line print - per page 60 lines of 132 characters

Keyboard - per page 60 lines of 72 characters

Using the DOS program FILDV9 blocks of the tape were dumped to a file on the disk. This gave a list of octal numbers for each block plus a lot of other extraneous information.

Using a program developed called PACK these octal dumps were decoded, converted to decimal and organised into lines of image points. As there were only 500 pixels per line, the 1024 word block on the 9 track tape were converted to two 256 word blocks. Two blocks of 256 words containing nothing were thrown away. It was the two blocks of octal that had to be organised to one image line of 500 integer grey levels: this could then be stored on the direct access file.

5.6 Data Reduction

The original 9 & 7 track tapes contained 4 images from a multispectral frame, each digitised to 500 x 500 points. As only a cartridge disk is used in the System four images of this size would not fit on the disk. The program PACK was used to reduce the complete image size to 125 x 125 points or part of the image to 250 or 500 points per line.

The results of processing one of these images can be displayed on the GT40 display unit or printed on a line printer. This involves a further reduction in data. It is possible if the time is available to print or display the entire image, but for checking on the processing it is sufficient to display a part of the image.

The data reduction chain is shown in Figure 17.

5.7 Operating guide to the preferred system

The preferred method of overlays offering 12 options was developed as an example. This is clearly better than the library systems 6. In addition two other options numbered 13, 14 and called NEWONE, NEWTWO are offered to allow extra programs to be added.

A further facility of being able to read and write a heading into the image files is provided. The heading replaces line 1 in the image file: this enables a track to be kept on the contents of the image file.

The system operates in the following way (For greater detail see the programer's guide).

FILDV9 and PACK are used to put the image from tape onto a direct access file.

The GT40 is activated as a monitor and the program MASTER is run.

The aim is to take the user through the complete program and overlays, explain what each part does and what answers to give.

When the program starts to run, the first output is

```
***** ALL INPUT IS INTEGER FREE FORMAT UNLESS *****
***** INDICATED BY F AS F FREE FORMAT OR Y, N *****
***** FOR YES, NO ANSWERS                     *****
***** ALL NUMBERS MUST END WITH A COMMA       *****
```

The answers to all questions will either be a number or Y, N for a decision making answer. The normal format is integer, unless indicated when it is F format. All free format numbers must be terminated by a comma

This is followed by

```
INPUT SELECTION
1  CHANGE WORKFILE
2  CHANGE AREA ON FILE
3  CHANGE OPTION
0  NO CHANGE
4  EXIT
```

Type in upto three selections

(answer) n1,n2,n3.

Initially the numbers input must be 1,2,3 after that any combination of upto 3 numbers is possible. The result of this causes one or more of the selections to be implemented.

i) <u>Selection 1 (Workfile)</u>

```
PLEASE ASSIGN IMAGE FILES TO AVAILABLE LOGIC NUMBERS
TYPE CO TO RETURN TO PROGRAM
AØØ5 ØØØØØØ
$
```

This creates a temporary exit from the program, indicated by the dollar sign ($), which enables the images stored in direct access disk files (with names such as RED.ONE) to be allocated a channel or logic number. A logic number is required for all input/output operations, data being sent to the device or file with a given logic number.

```
(answer)   $AS  IRED.ONE,1
           $AS  BLUE.ONE,2
           $AS  KB:,5
           $CO
```

This sets the image in the file named IRED.ONE to logic number 1. KB: is the keyboard terminal and 5 is the default number normally reserved for the line printer.

Assigning 5 to the keyboard causes all the output that would have gone to the line printer to go to the keyboard. If the GT40 is being used as the keyboard all output will be displayed on the screen.

HOW MANY FILES TO ASSIGN?

(answer) 2

This implies two files were assigned logic numbers. The next two questions supply information for the DEFINE FILE statement in the Fortran program. The following questions are asked for each assigned file

FILE NUMBER *****

(answer) 1

SIZE OF FILE ON DISK
# RECORDS ***, # SAMPLES PER RECORD ***

(answer) 125,128

This defines file number 1 (IRED.ONE) to be of size 125 records of 128 numbers (integers), i.e. the image is 125 lines each of 128 pixels.

ii) <u>Selection 2 (Area)</u>

DEFINE THE AREA TO BE OPERATED ON
RECORD START ***, # RECORDS **, SAMPLE START **,
# SAMPLES **

(answer) 6,114,6,114

This defines the area and location of the part of the image to work on: its top left hand corner is at line (record) 6, pixel (sample) 6, and its size is 114 lines by 114 pixels.

The image is stored in a direct access file where each record is one line of the digitized image.

Note that the area selected should be compatible with the output. The GT40 can display a line 72 pixels long and any number of lines. New lines are added to the bottom and lost off the top, creating a rolling display if more than 30 lines are requested. The line printer will display up to 128 pixels, and any number of lines. There is no restriction in writing to another disk file.

iii) Selection 3 (Option)

WHICH OPTION DO YOU WANT?

1 HISTOGRAM

2 EDGE DETECTION

3 SYMBOL MAP

4 BOUNDARY FINDING

5 SPECTRAL PLOT

6 CLUSTER ANALYSIS

7 IMAGE HANDLING

8 IMAGE QUANTIZING

9 FREQUENCY DISTRIBUTION

10 IMAGE SMOOTHING

11 FILTERING

12 HOMOGENEITY IMAGE

13 NEWONE

14 NEWTWO

(answer) 8

The answer selected responds by typing

OPTION CHOSEN
IMAGE QUANTIZING

The option asks its questions, does the processing and returns to the master program.

NEWONE and NEWTWO options are included so that additional programs can be incorporated as overlays without having to write extra lines into the master program.

This is followed by

TYPE R IF YOU WANT TO READ A HEADER
TYPE W TO WRITE A HEADER
CR FOR NO ACTION

This allows a header to be written into line one of the image processed, or the header to be read and printed to the output device. This allows track to be kept of the contents of the image file.

For the reply R

WHICH FILE HEADER DO YOU WANT TO READ?

(answer) 3

This will automatically read and print the header that is in file 3.

For the reply W

INPUT UPTO 80 CHARACTERS FROM UNIT 6 (keyboard)

(reply) IRED QUANTISED TO 10 LEVELS

WHICH FILE DO YOU WANT TO WRITE INTO?

(answer) 3

The above sentence is written into line 1 of the image in file 3.

When the reply is CR (carriage return) then the program loops back to the start and prints

INPUT SELECTION

## 5.8 Individual Options

This section gives the questions asked by each option and a brief explanation of the use of the option though a more detailed description is given in the programming section (chapter 6).

### 5.8.1 Option #1 histogram

This produces the histogram of the grey level distribution of an area of the image. Columns of the histogram are printed across the page.

OPTION SELECTED

HISTOGRAM

LOWER AND UPPER BOUNDS OF DATA F FORMAT

(answer) 0.0, 200.0,

This selects the range of grey levels to display in the histogram

NUMBER OF INTERVALS

(answer) 10

The range is split into the specified number of equal intervals.

INPUT IMAGE IN FILE

(answer) 3

This gives the image file as the file associated with logic number 3.

SCALE

(answer) 50

The columns of the histogram are scaled so that the widest column across the page is 50 characters. Each character represents the number of pixels having grey levels within that range.

The output is now sent either to lineprinter or keyboard.

### 5.8.2 Option # 2 Edge Detection

This is a simple operator working on a group of 2 x 2 pixels. The grey level discontinuity within this group is measured and this is taken as a measure of the 'edge' between the pixels.

OPTION CHOSEN

EDGE DETECTION

EDGE SIZE F FORMAT

(answer) 50.0

This is a threshold level. If the amount of 'edge' found is greater than this, then true edge is taken as having been found.

INPUT IMAGE IN FILE

(answer) 7

The image is now sent either to the line printer or the keyboard. A symbol is printed where an edge is found, no symbol if there is no edge.

### 5.8.3 Option # 3 Symbol Map

This produces an image like output, but as only characters can be printed by the peripherals available, the characters are used to represent the grey level of a pixel. As there are usually a large number of grey levels a range of grey levels can be assigned a character. Any number up to 9 contiguous or separate grey level ranges can be used. This gives the option of density slicing as well.

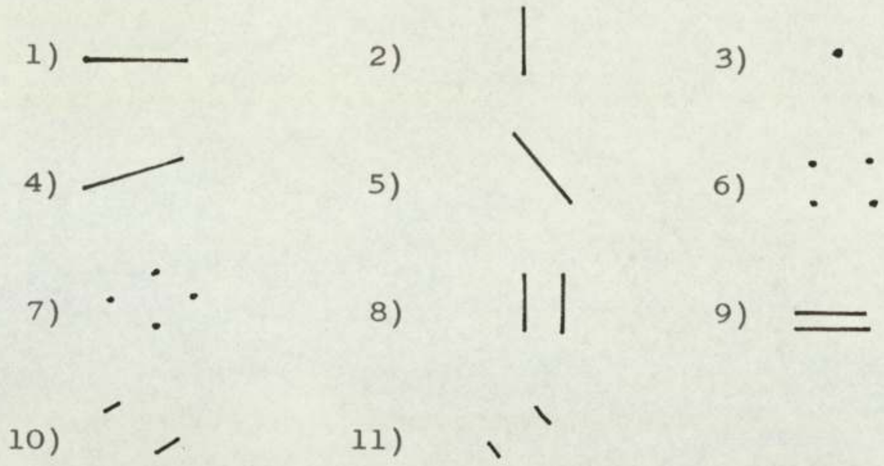
OPTION CHOSEN

SYMBOL MAP

SYMBOL TABLE? Y OR N

(answer) Y

Figure 18 Conceptual description of image filters.



Y or N means yes or no. The symbol table gives the range of grey levels each character represents, and the location of the mapped area in the image file.

NUMBER OF SYMBOLS MAX 9

(answer) 6

This defines the number of slices. There is a tenth character the blank, which is used to represent all pixels not falling within one of the defined ranges.

VARIABLE LEVELS Y OR N

(answer) N

No implies that all the slices are to be contiguous and of equal width. This is followed by

RANGE OF NUMBERS R1 R2 F FORMAT

(answer) 0.0,250.0

This selects the range of grey levels to be divided into the specified number of equal levels.

If the answer had been Y for Yes.

LOWER AND UPPER BOUND OF LEVEL N F FORMAT

(answer) 25.0,50.0

This is the individual range of grey for the slice N. This is printed for each level 1 to N.

Finally

INPUT IMAGE IN FILE

(answer) 2

The image is contained in file 2

The output is now sent to the line printer or keyboard.

### 5.8.4 Option # 4 Boundary Finding

This finds closed boundaries around all areas that have some defined similarity. This similarity is found by the program from a small sample area of pixels given as input data. The program then selects all pixels similar to the sample pixels. After this it constructs a closed boundary of points around the selected areas.

OPTION CHOSEN

BOUNDARY FINDING

SAMPLE AREA

START AT LINE **, START AT PIXEL **, # LINES **,

# PIXELS **

(answer) 6, 7, 8, 9

This selects a sample area with top left hand corner at line 6 pixel 7 and 8 lines by 9 pixels in size.

SCAN AREA

START AT LINE **, START AT PIXEL **, # LINES, # PIXELS **

(answer) 1,1,100,100

This defines the area of the image to be scanned for boundaries.

INPUT FILE **, SCRATCH FILE **

(answer) 3,7

The scratch file is used to store the result of the search for similar pixels. The value stored is the grey level in the same spatial location as in the input image.

DO YOU WANT THE TOTAL AREA PRINTED Y OR N?

(answer) N.

DO YOU WANT THE BOUNDARY PRINTED Y OR N?

(answer) Y.

These give the option of printing or not printing the pixels detected and the boundary around them as two separate outputs.

The pixels in the scratch file are searched to produce these outputs to the line printer or keyboard.

5.8.5 Option #5 Spectral Plot

This option works only if the graphics facility of the GT40 is available. It displays two co-ordinate axes, each axis representing the grey level from one image file. This requires the image files to be registered so that the spectral signature of a pixel can be plotted as a point in the co-ordinate system. It enables a visual check to be made on how well the image data is clustered. If there are more than two bands of multispectral imagery then the plots will have to be done in pairs.

The word SQUARE will appear on the screen. By pointing the light pen at it a square will appear superimposed on the dots. Down the side of the screen a menu will appear, and by pointing the light pen at the words of the menu the square can be made to change in size. The square will follow the light pen to change position. Pointing to the word SIZE causes the size and position of the square to be printed at the keyboard.

```
          OPTION CHOSEN
          SPECTRAL PLOT
          IMAGE CANNOT CONTAIN MORE THAN 900 PIXELS
          START LINE, START PIXEL,  LINES,  PIXELS
(answer)  20,1,4,100
```

Owing to core limitations on the GT40 no more than 900 pixels can be displayed without overwriting points already on the screen.

THIS PLOT REQUIRES DATA FROM TWO
FILES. DO YOU WANT TO CHANGE IMAGE
FILES Y OR N?

(answer) N

A reminder that two separate files containing the image from two bands is required. If the answer is Y then the input option FILE is called to set up new files.

X AXIS PLOT DATA IN BAND/FILE **

(answer) 1

Y AXIS PLOT DATA IN BAND/FILE **

(answer) 2

These define the files containing the two bands of imagery. The screen is now activated and displays the spectral plot.

5.8.6 Option # 6 Cluster Analysis

This is a very simple cluster analysis algorithm. Its main aims are to give a rough guide to the possibility of clustering the data. It is primarily designed to produce, from registered bands of imagery, a classification based on spectral signature.

The program makes one pass through the data set and makes an initial guess at the locations of the clusters. The data set is then passed through a given number of times to iteratively improve the guess. After each iteration the location of the clusters is printed.

It can operate with up to 10 clusters using up to 5 bands of registered imagery.

No actual classification map is produced.

OPTION CHOSEN

CLUSTER ANALYSIS

CLUSTER AREA START LINE, # LINES, START PIXEL, # PIXELS

(answer) 1,100,1,110

The area clustered will have its top left hand co-ordinate at line 1 pixel 1 and be 100 lines by 110 pixels in size.

HOW MANY CLUSTERS **

(answer) 6

HOW MANY DIMENSIONS **

(answer) 3

The word dimension refers to band of imagery. For each dimension the following question is asked

DIMENSION N IN FILE

(answer) 2

The file logic numbers may not be the same as the band numbers so N goes from 1 to the number of dimensions specified.

EACH DIMENSION IS STORED IN ONE IMAGE FILE

DO YOU WANT TO REASSIGN THE FILES Y OR N?

(answer) Y

If the answer is yes then the input option CHANGE WORKFILE in master is called.

HOW MANY ITERATIONS

(answer) 4

The initial estimate will be refined with four passes through the data set.

The program will now run printing out the results of each iteration to the line printer.

5.8.7 Option #7 Image Handling.

Two sub options are offered here. These are image moving or image subtraction.

Image moving moves one image relative to another to enable them to be registered. The move can be done only in a combination of horizontal and vertical steps; rotation is not possible. The image to be moved is in say file A. The result of the move is stored in file B. It must be put into a different file to prevent overwriting the original image before it is read.

Image subtraction subtracts one image from another and can if needed store the result back in one of the original image files with no fear of losing the image before it is read.

OPTION CHOSEN

IMAGE HANDLING

THE IMAGE HANDLING OPERATIONS ARE

1 IMAGE SUBTRACTION

2 IMAGE TRANSLATION

WHICH ONE DO YOU WANT

(answer) 1

If operation 1 is chosen then

IMAGE SUBTRACTION REQUIRES UP TO THREE DIFFERENT IMAGE FILES

DO YOU WANT TO ASSIGN MORE FILES Y OR N?

(answer) Y

If the answer is yes then the input option CHANGE WORKFILE in the master program is called to assign new files.

IMAGES IN FILES ** AND **, RESULT IN FILE **

(answer) 1,2,7

The images in files 1 and 2 are subtracted and stored in file 7

The operation is now carried out and when finished control is passed back to MASTER.

If operation 2 was selected

THE IMAGE TO BE MOVED IS IN FILE **

THE RESULT IN FILE **

(answer) 1,7

The image in file 1 is moved by an amount to be defined and stored in its new position in file 7.

IMAGE TO BE MOVED L LINES BY IC COLUMNS

+L TO MOVE UP -L TO MOVE DOWN

+IC TO MOVE RIGHT -IC TO MOVE LEFT

(answer) -5, 6

The image is moved 5 lines down and 6 pixels to the right. The operation is now carried out, data being transferred between direct access files. On compltion, control is returned to MASTER.

5.8.8 Option# 8 Image Quantising
Option #9 Frequency Distribution

Both these options call the same overlay containing 3 subroutines which can do the following.

Find the grey level frequency distribution of the image and print it if required.

Find the normalised frequency distribution (CFD) of the image grey levels and print it.

From the CFD calculate and print the equal probability levels. These are new grey levels that allow the image to be standardized to some degree.

Reformat the image to a new image file so that the grey levels are requantised to the new levels. The image now has a grey level distribution where each new grey level is equally probable.

OPTION CHOSEN or OPTION CHOSEN

FREQUENCY DISTRIBUTION IMAGE QUANTISING

PICTURE FILE **

(answer) 2

HOW MANY GREY LEVELS IN THE INPUT IMAGE **?

(answer) 256

The image in file 2 contains grey levels in the range 0-255

QUANTISING LEVELS **

(answer) 10

The image is to be reformatted to 10 equally probable levels.

DO YOU WANT A FREQUENCY DISTRIBUTION OF THIS IMAGE PRINTED Y OR N?

(answer) Y

If the answer is yes

WHICH DISTRIBUTION

1 FREQUENCY

2 NORMALISED FREQUENCY

3 CUMULATIVE FREQUENCY

(answer) 3

The one selected is then printed to the lineprinter or keyboard. The question after this, and also after a no answer to the question before, is

DO YOU WANT THE EQUAL PROBABILITY LEVELS

PRINTED Y OR N?

(answer) Y

For a yes answer the levels are printed together with the minimum grey level. The new equally probable levels are from minimum to level 1, level 1 to level 2, level 2 to level 3 etc.

DO YOU WANT TO QUANTISE AN IMAGE Y OR N ?

(answer) N

For a no answer control is handed back to MASTER

For a yes answer -

IN WHICH FILE DO YOU WANT TO PUT THE QUANTISED

IMAGE **?

(answer) 3

The image in the original file is now requantised according to the equally probable levels and put into a new file. It is possible to rewrite it straight back into the old file.

5.8.9 Option # 10 Image Smoothing

This applies a filter with a varying number of terms to smooth the image,and to some extent enhance it, and also helps to reduce the noise. The new smoothed value of a pixel is calculated from its 4, 6, or 20 neighbours along the same line. These pixels are the 2,3,10 pixels either side of the smoothed pixel.

Only one line at a time is smoothed, so this gives the possibility of writing the smoothed image back into the original file.

OPTION CHOSEN

IMAGE SMOOTHING

DO YOU WANT 5, 7, OR 21 TERMS?

(answer) 5

Any answer other than 5, 7 or 21 will give by default the 21 term filter.

IMAGE IN FILE **, OUTPUT TO FILE **,

(answer) 2,7

The option is now processed writing the smoothed image into a new direct access image file.

5.8.10 Option #11 Image Filtering

This offers a collection of eleven 3 x 3 operators that can be applied to each point of the image. The result of applying the filter is a measure of a certain type of detail or texture in that image block. The filters will detect and isolate, for example, horizontal edges or diagonal edges or certain type of texture. This is achieved by giving the elements of each 3 x 3 filter a different weight.

The filters can be conceptually described by lines and shapes as shown in figure 18.

OPTION CHOSEN

FILTER

INPUT IMAGE IN FILE **, OUTPUT TO FILE **

(answer) 3,7

THE FILTERS ARE NUMBERED FROM 1 TO 11

WHICH ONE DO YOU WANT?

(answer) 6

The filter selected is now applied to the image and the result written to the output image file.

DO YOU WANT TO TRY ANOTHER FILTER Y OR N?

(answer) Y

This allows the option to be repeated without going back through the master program.

5.8.11 Option 12 Homogeneity Image

This is really a type of edge detection process. The homogeneity of small areas of the image is calculated and an edge weighting applied to the homogeneity function. The homogeneity of an area of the image is a measure of the degree of sameness in the image. Thus, non-homogeneous areas could contain edges. This should be highlighted by applying a suitable weight when calculating a special edge-homogeneity value from grey tone dependence matrices, calculated by the program from the image blocks.

A small image block of selectable size can be scanned at any interval across the image to measure this value. The image generated is the edge-homogeneity image whose value related to the value of the edge-homogeneity.

This is an attempt at investigating image structure.

OPTION CHOSEN
HOMOGENEITY IMAGE

DO YOU WANT TO QUANTISE THE IMAGE Y OR N?

(answer) N

The image for this algorithm should be reasonably standardized. This can be achieved using the quantizing option. If the image has not been quantized this question will allow the quantizing overlay to be called and executed. After quantizing, to avoid re-displaying the option list, continue pressing CR until you get back here.

QUANTIZED IMAGE IN FILE ***, SCRATCH FILE ***

(answer) 3, 7

The image in file 3 will be converted to its edge-homogeneity image in file 7.

SIZE OF SCAN BLOCK LINES, PIXELS

(answer) 5, 5,

DISPLACEMENT OF SCAN BLOCK LINES, PIXELS

(answer) 1, 1,

An image block of 5 x 5 will be used to calculate the edge-homogeneity value at points 1 x 1 apart.

HOW MANY GREY LEVELS IN THE IMAGE?

(answer) 20,

The maximum number of grey levels is 20 in the quantised image.

The program will now run.

# CHAPTER 6

# THE INTERACTIVE SOFTWARE SYSTEM

# PROGRAM DETAILS

# CHAPTER 6

# THE INTERACTIVE SOFTWARE SYSTEM (ISS)

## 6.1 Preamble

This chapter describes the more technical aspects of the ISS.

It is covered in two main sections. The first (6.2, 6.3) deals with how to get the system running, and how to extend or alter the system. This is mainly concerned with the use of the programming languages in manipulating the programs.

The second section (6.4) describes the programs in detail. These are given in the form of a detailed program write-up, program summary and program notes describing the program.

## 6.2 Creation of the Interactive Software System

The ISS developed in this thesis consists of one main controlling program called MSTR, plus 11 overlay programs giving the 12 options described in the previous chapter.

Putting all the Fortran programs on a disk using PIP gives 12 program files with names such as PROG. FTN. Each Fortran program contains a main section plus subroutines, and the necessary common statements that are used to pass data between MSTR and the overlays.

These Fortran programs are compiled using the DOS command

```
$R FORTRAN
# PROG.OBJ, LP:<PROG.FTN
```

This results in 12 object modules, one of which is MSTR, the other 11 are the overlays.

The next stage is called 'Linking', this links all the functions in the Fortran library to their place in the program. These functions not only mean those such as FLOAT or IFIX, but also all the input/output and other system housekeeping routines. If any input/output mode is used in one of the overlays and not in MSTR then the required input/output handlers have to be forced into MSTR in the linking. This can be done either by including dummy input/output statements in MSTR or by linking MSTR to a MACRO (machine language) subroutine containing the required input/output handlers.

The MSTR program when run is held in a section of core called the resident main area. Each overlay when called is held in a section of core below this, known as the overlay area. To ensure the overlay is always put in the correct place in core, a symbol table (RES.STB) is created at link time. This contains the addresses of the function calls, the 'call link' statements and location of the MSTR program. If at some later stage it is decided to change an overlay, it can be relocated to the correct place in core by using the saved symbol table.

To link the object modules

```
$ R V11A
#   MSTR,,RES.STB <MSTR/CC/OV:11, FORCE, FTNLIB/L/E
     a   b c       d  e f          g       h
```

This indicates

(a) is the resident main program
(b) is the load map which is usually not needed
(c) is the symbol table to be saved for further use
(d) is the object module
(e) indicates concatention (subroutines present)
(f) is the switch saying there will be 11 overlay modules to follow, all to be linked individually but such that they do not use the same core

as MSTR

(g) is the subroutine to force the loading of input/output not used in MSTR

(h) the Fortran library

This instruction is immediately followed by the 11 overlay links

```
# MAP  MAP/CC, FTNLIB/L/E
# SPECT <SPECT/CC, DLIB.LIB/L, FTNLIB/L/E
              etc.,
```

There is no need to include RES.STB in these links if this is done at the same time as MSTR is linked.

If, however, one of the overlays is changed, or it is decided to add another program, called say NEWONE, then when the new object module has been created

```
# R  V11A
# NEWONE <RES.STB, NEWONE/CC, FTNLIB/L/E
```

The system is now ready and is stored on disk as 12 separate load modules. These are MSTR plus the 11 overlays which MSTR can call upon.

## 6.3 Getting MSTR running

First prepare the computer to run the program MSTR.

For the 11/40 system possessed this involves the following:

1) Set 173100 on the switch register and press load address
2) Set 177406 on the switch register, set halt up and press start
3) Enter the date and time as requested
4) If it is intended to use the GT40 as the keyboard display then do 5 otherwise go to 10

5) Reply no to the dialogue question

6) Load user number and log in

7) Set 16600 on the GT40 register, load address set halt up and press start

8) $ R LOAD GT

# BOOK BIN[1,1]
Then kill this using CNTRL/C

9) $ R CILUS

# GTMON [5,5] /BO

10) Reply yes to the dialogue
Answer the dialogue questions

11) Load user number and login

12) $ RU MSTR
and the ISS is now running

## 6.4 Program write-ups

Unless otherwise stated the following apply for all the programs:

Source: Remote Sensing Unit
University of Aston
Birmingham B4 7ET

Computer: PDP 11/40

Core: 24K 16 bit word

System: DOS V9-20

Language: Fortran lV

Disk: 256 word blocks used to store all programs

Each program is presented in two parts i) A program summary giving a brief review of the program, ii) the detailed write up, explaining the theory and operation of the program. The program listing, which includes comment statements to explain the steps in the program can be obtained from the previous mentioned source.

### 6.4.1 Subroutine Map

i) Program Summary

| | |
|---|---|
| Title | MAP |
| Storage | listing MAP.FTN 7 blocks<br>object module MAP.OBJ 15 blocks<br>load module MAP.LDA 7 blocks |
| Peripherals | line printer for output<br>disk for data file (direct access)<br>keyboard for interaction |
| Program length | 85 lines |
| Overlay structure | called as overlay 'MAP' from MSTR |
| Program structure | main interactive section<br>subroutine SYMMAP |
| Nature of problem | to display the results of image processing |
| Solution | Assign a character to each pixel to represent its grey level, or the grey level range in which the pixel falls |
| Limits | Output limited to lineprinter width, lines printed as program runs |

ii) Detailed Write Up

Up to 9 grey level ranges can be given a symbol for the map output. The order of symbols in the program is:

+ ( I / * - < = O

The image size and location within the image file is passed from MSTR in the common block /FDATA/ S, R, DS, DR.

S,R are the pixel and line numbers of the top left hand corner of the image respectively. DS, DR are respectively the number of pixels and lines in the image.

Additional information required for the mapping is asked for interactively by the main part of MAP. A call is then made to the subroutine SYMMAP.

CALL SYMMAP (RL,RU,RA,IFN,ITABLE)

RL and RU are arrays containing the upper and lower bounds of the RA grey level ranges. The ranges can either be assigned as a continuous set equally spaced between and maximum or minimum value, or each individual range can be given its own limits; this is decided at the interactive stage. The ranges specified must stradle the point value else it is not mapped. For example if the ranges are 0-2, 2-4, 4-6, etc., then pixel grey values of 2, 4 will not be mapped with a symbol.

Any pixel not having a grey level in the specified ranges is mapped as a blank. The detection of a pixel A(K) as belonging to a grey level range RU(J) to RL(J) is done by the statement

IF((RU(J) - A(K)) * (RL(J) - A(K))) 7,6,6 J = 1,2....RA

If this is negative then the pixel grey level A(K) must lie within the range RU(J) to RL(J).

IFN is the logic number of the image file.

ITABLE controls the printing of a symbol table giving the character assignments and location of the image.

6.4.2 Subroutine EDGE1

i) Program Summary

| | | | |
|---|---|---|---|
| Title | EDGE1 | | |
| Storage | listing | EDGE1.FTN | 4 blocks |
| | object module | EDGE1.OBJ | 9 blocks |
| | load module | EDGE1.LDA | 5 blocks |
| Peripherals | line printer for output | | |
| | disk for data file | | |
| | keyboard for interaction | | |

| | |
|---|---|
| Program length | 43 lines |
| Overlay structure | called as overlay 'EDGE1' from MSTR |
| Program structure | main interactive section<br>subroutine EDGE1 |
| Nature of Problem | To detect 'edges' or discontinuities in grey level |
| Solution | Measure the difference in grey level over a group of points and decide if it constitutes an edge |
| Limits | Output limited to width of line printer<br>Lines printed as program runs<br>Edge detector used is very localised |

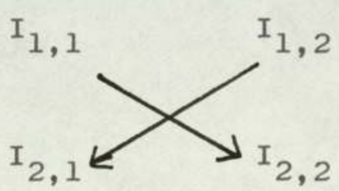
ii) Detailed Write Up

The operator used to measure the size of the 'edge' at a point, is a well-known cross operator. For an image of size n x m with pixels having grey level I(j,k) at point j, k (j = 1, .......n, k = 1,.....m)

The edge E is

$$E = (I(j, k+1) - I(j+1,k+1)) + (I(j+1,k) - I(j,k+1)$$

i.e. the size of the grey level difference or 'edge' between the points is determined as shown




If this is greater than a given threshold an 'edge' is regarded as having been found which may or may not be significant. Only experimenting with the threshold on a number of pictures will tell.

iii) Program Notes

The common block /FDATA/ S,R,DS,DR transfers the image size and location from MSTR. The top left hand of the image is at line R pixel S and its size is DS pixels by DR lines.

A number of questions are asked interactively by the main section which then calls a subroutine,

CALL EDGE1 ( P,IFN)

P is the edge threshold and IFN the logic number of the image file.

6.4.3 Subroutine HPLOT

i) Program Summary

| | | | |
|---|---|---|---|
| Title | HPLOT | | |
| Storage | object module | HPLOT.FTN | 7 blocks |
| | listing | HPLOT.OBJ | 16 blocks |
| | load module | HPLOT.LDA | 7 blocks |
| Peripherals | line printer for output<br>disk for data file<br>keyboard for interaction | | |
| Program length | 89 lines | | |
| Overlay structure | called as overlay 'HPLOT' from MSTR | | |
| Program structure | main interactive section<br>subroutines HSTGRM<br>SCLPLT | | |
| Nature of problem | to display the grey level distribution of the image | | |
| Solution | print a histogram showing the number of pixels in each grey level or grey level range | | |
| Limits | output limited to line printer width, printed as the program runs. Limit 50 columns. | | |

ii) Detailed Write Up

In order to examine the complete structure of the image it is useful to be able to see the grey level distribution.

Two subroutines are used to display this histogram. The first one called is

HSTGRM (R1,R2,INT,IR,IFN)

This takes the pixel grey values in the range R1 to R2 in image IFN. This range is divided into INT intervals. The number of times a pixel grey value falls within one of the intervals is counted and stored in IR(J) J = 1,.....INT.

The array IR is then passed to subroutine SCLPLT to plot the columns of the histogram. The subroutine called is

SCLPLT (IR,INT, IS)

The columns of the histogram are printed across the page, the column length corresponding to the number in the array IR. The maximum width of the plot across the page can be controlled by the parameter IS.

iii) Program Notes

Common block /FDATA/ S,R,DS,DR is used to pass the location and size of the image from MSTR to the program and its subroutines.

A table giving the details of the histogram and the location of the image is also automatically printed.

6.4.4 Subroutine QUANTI

i) Program Summary

| | | | |
|---|---|---|---|
| Title | QUANTI | | |
| Storage | listing | QUANTI.FTN | 12 blocks |
| | object module | QUANTI.OBJ | 28 blocks |
| | load module | QUANTI.LDA | 13 blocks |
| Peripherals | disk file for image data<br>line printer for optional output<br>disk file for output image<br>keyboard for interaction | | |
| Program length | 170 lines | | |
| Overlay structure | called as overlay 'QUANTI' from MSTR | | |
| Program structure | main interactive section<br>subroutines PROB<br>EQPROB<br>REQUAN | | |
| Nature of problem | To reduce all images to a standard form | | |
| Solution | Reduce the number of grey levels by at least one third and make each new level as probable as the other. This produces a standardised grey level distribution. | | |
| Limitations | Will quantise a maximum of 300 levels down to a maximum of 64. Does not work too well with noisy images or very peaky grey level distributions. | | |

ii) Detailed Write Up

In order to obtain consistent processing results, it is an advantage to have the images standardized. The grey level distribution of images can be a wide variety of shapes. If, however, it is squared off, i.e. all levels occur with the same frequency, a measure of standardisation is achieved. To re-arrange the levels to levels of equal probability three subroutines are used.

First PROB (F,FN,CF,MAX,MIN,IFILE,INLEV) is called to calculate the grey level distribution in the original image file IFILE. This distribution has INLEV levels. Options are available that will print out the distribution F, the normalised distribution NF, or the cumulative distribution CF. Then using an algorithm based on the equal probability algorithm of Haralick and Anderson (1971) the position of the new levels is calculated. For N new levels the cumulative frequency distribution CF can be divided into N equal sections $\frac{1}{N}$ apart.

The CF is searched to find the grey level nearest to probability $\frac{1}{N}$. This is unlikely to occur exactly at $\frac{1}{N}$ so the actual remaining probability is divided into N-1 sections and the next new level searched for.

In the program the cumulative frequency is stored in array CF.

The equal probability levels are calculated by the subroutine call

CALL EQPROB (N,K,CF,IQ,IMIN)

Which gives the N old cumulative distribution levels in CF and returns with K new levels in IQ. Suppose there are K levels to be found and the I-1 was found at grey level LFTOFF with true probability of CF (LFTOFF). This leaves a probability of ((1.0 - CF(LFTOFF)) /FLOAT(K-I+1)) to be given to each of the remaining K-I+1 levels. The next level is searched for in CF that has a probability nearest to 1.0-CF(LFTOFF))/FLOAT(K-I+1)) + CF(LFTOFF).

The K new levels cover the range of old levels IMIN to IQ(1), IQ(1) to IQ(2)........IQ(K-1) to IQ(K).

Using the final subroutine

REQUAN (IMIN,IQ,K,IOLD,NEW)

The K new levels in IQ are used to transform the image in file IOLD to a standard form in file NEW.

iii) Program Notes

The common block /FDATA/ S,R,DS,DR locates the image with top left hand corner at pixel S, line R, and DS pixels by DR lines in size.

The common block /SELECT/NOP is used as a reminder that this program could have been entered by selecting option 8 (NOP=8), Image Quantising or option 9 (NOP=9) Frequency Distribution. The value of NOP causes printing of the corresponding 'option selected' message to the keyboard.

6.4.5 Subroutine SPECT

i) Program Summary

| | |
|---|---|
| Title | SPECT |
| Storage | listing SPECT.FTN 13 blocks<br>object SPECT.OBJ 25 blocks<br>load module SPECT.LDA 22 blocks |
| Peripherals | GT40 visual display + 11/05 with 8K core<br>disk for image file<br>keyboard for interaction |
| Program length | 150 lines |
| Overlay structure | called as overlay "SPECT" from MSTR<br>calls subroutine FILE in MSTR |
| Program structure | main interactive section<br>subroutine MEASUR using light pen interaction<br>Picture Book subroutines used to build graphics |
| Problem | To visualise the clustering of points in N dimensional space |
| Solution | Use the graphics terminal to display a scatter plot. Each point representing one n-dimensional image point |
| Limits | only possible to display up to 900 2-D points. Data values of the points must be |

integers and must lie within the range 0-500

ii) Detailed Write Up

When doing unsupervised classification (clustering), it is often useful to be able to see the structure of the clusters and take some measurements from them.

This program allows this to be done by making use of the display capability of the GT40 graphics terminal. It is possible to display up to 900 2-D points. The display is limited to 2-D for ease of visualization and measurements. If higher dimensional data is possessed, pairs of dimensions have to be displayed in turn.

The dots are displayed relative to an x,y axis system on the screen. The data for each axis is stored in a separate direct access file. Each file corresponds to one band from a multispectral set of registered images. The dots displayed show the location of the spectral signature in the grey level space.

The word SQUARE is displayed on the screen, and by pointing to it a controllable square will appear on the screen. Using a light pen sensitive menu, which also appears on the screen, a number of movements are possible. The square itself is light pen sensitive and can be moved by the light pen.

The menu displayed is

FINISH
SIZE
DEC Y
INC Y
DEC X
INC X

INC and DEC increase or decrease the x and y size of the square.

Using these and the light pen sensitive square, the square can be moved and its shape changed to fit nicely around a cluster of points.

Pointing to the word SIZE causes the size and location of the square in the grey level to be printed at the keyboard. The word FINISH causes the screen to be erased and the subroutine to be exited.

iii) Program Notes

The common block /FDATA/S,R,DS,DR contains the size and location of the image.

The common block /MARKS/MP,MF,MG,MT is required by the Picture Book language to keep track of the location of the entries in each chapter of the graphics book.

The DATA statements are used to set the ASCII characters for the words to appear in the menu on the screen.

The size and location of the square can be measured and printed as often as required.

Requesting a display of more than 900 points will continually overwrite the display on the screen. This will cause the menu location to be overwritten with points. If there is no menu on the screen there is no way to exit from the subroutine.

6.4.6 Subroutine FILTER

i) Program Summary

| | | |
|---|---|---|
| Title | FILTER | |
| Storage | listing | FILTER.FTN 6 blocks |
| | object | FILTER.OBJ 15 blocks |
| | load module | FILTER.LDA 7 blocks |
| Peripherals | disk for input and output images | |
| | keyboard for interaction | |

| | |
|---|---|
| Program length | 75 lines |
| Overlay structure | called as overlay 'FILTER' from MSTR |
| Program structure | main interactive section<br>subroutine FILTER |
| Problem | To find some simple feature extractors |
| Solution | Use a set of 3 x 3 operators that act as weights in the summation of the 3 x 3 pixels covered by the filter |
| Limitations | Only 11 filters coded. They work only on groups of 3 x 3 pixels. The filter is stepped only 1 pixel at a time so that every pixel has an output from the filter |

ii) Detailed Write Up

This is an algorithm that was coded to find out if it could extract anything useful about the image structure. It contains 11 filters called by the subroutine FILTER (IFN,IFF,IFNUM). Filter number IFNUM is scanned across image in file IFN and the result stored in image file IFF.

The filter operates on a block of 3 x 3 pixels, and the operations performed are simple sums of the centre and surrounding pixels. The result is written to a new image file and is regarded as being a measure of the 'detail' in the image at that pixel position. The type of 'detail' detected depends on the filter and hence these are known as 'detail filters' (Taylor 1972).

The sum of the filter is formed by adding up the sum of the pixel grey levels according to the sign of the element of the filter.

For a filter

| | | |
|---|---|---|
| -1 | -1 | -1 |
| +1 | +1 | +1 |
| -1 | -1 | -1 |

operating on the group of pixels

| | | |
|---|---|---|
| A | B | C |
| D | E | F |
| G | H | I |

gives a filter output O of

$$\emptyset = (D+E+F)/3 - (A+B+C+G+H+I)/6$$

The sum is weighted to produce zero output (i.e. zero detail) if the area is uniform.

The 11 filters used and their sums in the order they are numbered in the program are:

| | | | | |
|---|---|---|---|---|
| | + | + | + | |
| (1) | - | - | - | $\emptyset = (A+B+C+G+H+I)/6 - (D+E+F)/3$ |
| | + | + | + | |
| | + | - | + | |
| (2) | + | - | + | $\emptyset = (A+D+G+C+F+I)/6 - (B+E+H)/3$ |
| | + | - | + | |
| | + | + | + | |
| (3) | + | - | + | $\emptyset = (A+B+C+D+F+G+H+I)/8 - E$ |
| | + | + | + | |
| | + | + | - | |
| (4) | + | - | + | $\emptyset = (A+B+D+F+H+I)/6 - (C+E+G)/3$ |
| | - | + | + | |
| | - | + | + | |
| (5) | + | - | + | $\emptyset = (B+C+D+F+G+H)/6 - (A+E+I)/3$ |
| | + | + | - | |

(6)
$$\begin{matrix} - & + & - \\ + & + & + \\ - & + & - \end{matrix} \quad \emptyset = (B+D+E+F+H)/5 - (A+C+G+I)/4$$

(7)
$$\begin{matrix} + & - & + \\ - & + & - \\ + & - & + \end{matrix} \quad \emptyset = (A+C+E+G+I)/5 - (B+D+F+H)/4$$

(8)
$$\begin{matrix} + & 0 & - \\ + & 0 & - \\ + & 0 & - \end{matrix} \quad \emptyset = (A+D+G)/3 - (C+F+I)/3$$

(9)
$$\begin{matrix} + & + & + \\ 0 & 0 & 0 \\ - & - & - \end{matrix} \quad \emptyset = (A+B+C)/3 - (G+H+I)/3$$

(10)
$$\begin{matrix} + & + & 0 \\ + & 0 & - \\ 0 & - & - \end{matrix} \quad \emptyset = (A+B+D)/3 - (F+H+I)/3$$

(11)
$$\begin{matrix} 0 & + & + \\ - & 0 & + \\ - & - & 0 \end{matrix} \quad \emptyset = (B+C+F)/3 - (D+G+H)/3$$

Similar but larger and more complex filters of this sort are described by Hawkins and Elerding (1967). These can be used for detecting shapes.

ii) Program Notes

The common block /FDATA/S,R,DS,DR is used to transfer image location from MSTR to the program and its subroutine.

6.4.7 Subroutine SMOOTH

i) Program Summary

| | | | |
|---|---|---|---|
| Title | SMOOTH | | |
| Storage | listing | SMOOTH.FTN | 5 blocks |
| | object | SMOOTH,OBJ | 13 blocks |
| | load module | SMOOTH.LDA | 6 blocks |

| | |
|---|---|
| Peripherals | disk file for input and output image<br>keyboard for interaction |
| Program length | 64 lines |
| Overlay structure | called as overlay 'SMOOTH' from MSTR |
| Program structure | main interactive section<br>subroutine SMOOTH |
| Nature of problem | To reduce noise in the image and provide a slight enhancement effect |
| Solution | Apply a one dimensional weighted filter to the lines. A new pixel value is obtained from a weighted sum of its neighbours along the same line |
| Limits | only filters of 5,7 or 21 terms are used. only pixels on the same line are used, information from adjacent lines is not considered |

ii) Detailed Write Up

In order to reduce noise in the image, an average over a number of pixels could be used, but this also has the effect of blurring or reducing the resolution of the image. Francis (1975) describes a filter that is used to enhance certain types of areas in photographs. This filter seems suitable for the task in hand. Smoothing occurs only along adjacent pixels in a line: pixels from adjacent lines are not used. Also the central pixels have a much higher weighting than the outside pixels in the filter. This has the effect of sharpening the smoothing process thus reducing the tendency to decrease the resolution of the image.

For a line of pixels labelled A to Z

ABCDEFGHIJKL ...............RST........VVWXYZ

The filters for any point K whose smoothed value is $\overline{K}$ are

for 5 terms

$$\overline{K} = (17 \times k+12(J+L) - 3\ (I+M))/35$$

for 7 terms

$$\bar{K} = (7*K+6(J+L)+3(I+M)-2(H+N))/21$$

for 21 terms

$$\bar{K} = \left[60*K+57(J+L)+47(I+M)+33(H+N)+18(G+O)+6(F+P) -2(E+Q)-5(D+R)-5(C+S)-3(B+T)-(A+U)\right] /350$$

The smoothing is weighted so that a uniform area gives the values unchanged.

The subroutine is called by

CALL SMOOTH (ITERMS,IN,IOUT,LINES,ICOLS)

the term of the filter is ITERMS, this is applied to the image in IN and the result written to the image file IOUT. Due to the nature of the filter pixels at a distance less than ITERMS/2 from the ends of the lines are not smoothed. LINES and ICOLS give the new size of the image.

iii) Program Notes

One line is read, smoothed and written to another file. Doing it this way makes it possible to write the smoothed image back into the original image file. This way the overwritten image is not lost before it is smoothed.

The common block /FDATA/S,R,JS,DR is used to transfer the image size and location from MSTR to the subroutine.

6.4.8 Subroutine BNDRY

i) Program Summary

| | | |
|---|---|---|
| Title | BNDRY | |
| Storage | listing | BNDRY.FTN 12 blocks |
| | object module | BNDRY.OBJ 23 blocks |
| | load module | BNDRY.LDA 11 blocks |
| Peripherals | disk file for image<br>disk file for intermediate results<br>line printer for output<br>keyboard for interaction | |
| Program length | 134 lines | |
| Overlay structure | called as overlay 'BNDRY' from MSTR | |
| Program structure | main interactive section<br>subroutine BOUND | |
| Problem | To detect all areas in the image similar to a sample area. To print a close boundary around those areas | |
| Solution | the mean and variance of the sample is calculated and used to define a similarity measure. Boundaries are detected by eliminating all internal points. | |
| Limits | output is printed line by line as program runs. Boundary finding process will leave lines of pixels untouched. | |

ii) Detailed Write Up

The aim of this algorithm is two fold. Given a sample area it will find all other areas in the image that are similar to it. It will then construct a closed boundary around these areas.

The subroutine call that initiates this is

CALL BOUND (L1,C1,DL1,DC1,L2,C2,DL2,DC2,IFILE,KFILE,IA,IB)

The sample area L1,C1,DL1,DC1 in image file IFILE is used to calculate a similarity measure. This measure involves calculating the mean and variance of the sample. Then if a pixel grey level from any other part of the image lies within two standard deviations of the mean of this sample it is regarded as being similar to the pixels constituting the sample. Placing a limit of two standard deviations helps to keep noise out of the area selected.

All the pixels within the area defined by L2,C2,DL2,DC2 are tested. All similar areas are stored temporarily in KFILE. IA and IB are parameters that control printing of the areas in KFILE or the boundary around the areas in KFILE.

The boundary is constructed by eliminating all 4 and 0 connected pixels from the detected areas in KFILE. 'Connectedness' is when two pixels touch each other. Any one pixel can be touched by 8 other pixels, four along the four sides and four at the corners. Four-connected points are those pixels that have four pixels touching the four sides.

For example if the detected area is

```
A  B  C  D
E  F  G  H
I  J  K  L  M  N
                  Q
            O  P
```

the result of eliminating all 4 and 0-connected points is

```
A  B  C  D
E        H
I  J  K  L  M  N

            O  P
```

This is the closed boundary around the area. Note that lines of points which are not boundary points, such as MN, are not eliminated.

iii) Program Notes

The common block /FDATA/ S,R,DS,DR passes the location of the image from MSTR to the subroutine.

The subroutine detects all the similar areas first and stores their true pixel values in KFILE. When this is completed the boundary detection is started. The print outs are done at the completion of the relevant stages.

The detected image in KFILE is stored starting at line 1 column 1 of KFILE regardless of the location in IFILE it came from.

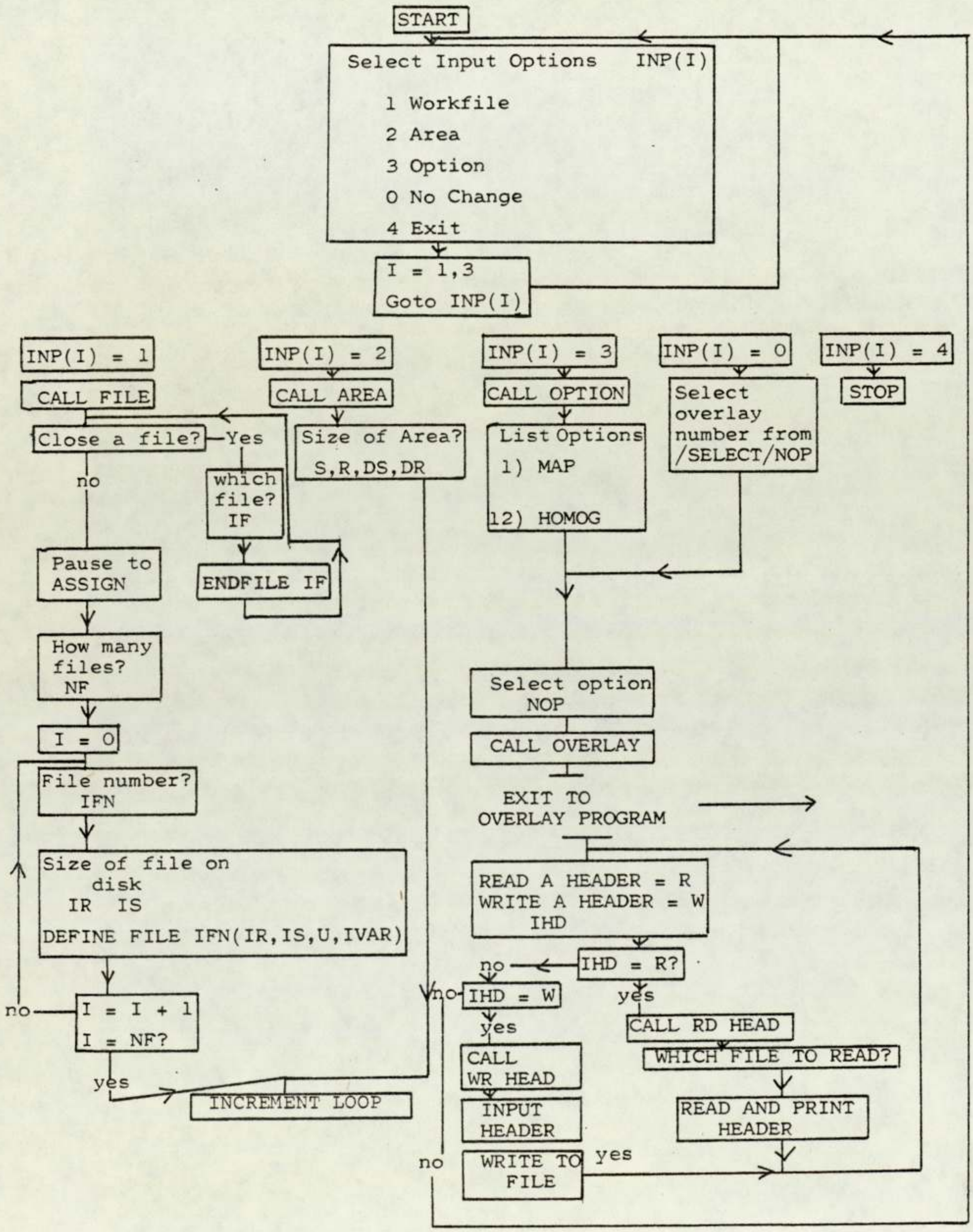
The scan area for IFILE is defined by L2,C2,DL2,DC2 and not by the common block.

6.4.9 Main program MSTR

i) Program Summary

| | | | |
|---|---|---|---|
| Title | MSTR | | |
| Storage | listing | MSTR.FTN | 13 blocks |
| | object | MSTR.OBJ | 28 blocks |
| | load module | MSTR.LDA | 33 blocks |
| Peripherals | keyboard for interaction | | |
| Program length | 147 lines | | |
| Overlay structure | calls overlays | MAP , QUANTI | |
| | | HPLOT , SPGTDM | |
| | | EDGEI , CLSTR | |
| | | FILTER , BNDRY | |
| | | HANDLE , SMOOTH | |
| | | SPECT , NEWONE | |
| | | NEWTWO | |
| Program Structure | main section with overlay calls<br>subroutine FILE, AREA, OPTION<br>WRHEAD, RDHEAD | | |
| Problem | to control the running of the interactive software system | | |

Figure 19 Flow Diagram of MSTR



| | |
|---|---|
| Solution | establish a master program that selects the relevant operating modes and calls the overlay programs |
| Limits | limited to the 11 coded overlays named according to their function, plus two additional ones NEWONE, NEWTWO that can be coded. |

iv) Detailed Write Up

This program controls the operation of the interactive software system. It is split into a number of sections, each of which has a specific function. (Figure 19)

The first task of the user when running the ISS is to make an input selection from one or more of the following:

1) CHANGE WORKFILE
2) CHANGE AREA ON FILE
3) CHANGE OPTION
4) NO CHANGE
5) EXIT

Each of these when selected operates a different section of the program.

The first input option calls the subroutine FILE. This then allows the user to close any open files, to assign new files and define their size.

The second input option calls the subroutine AREA. This allows the user to define the area, of the image in the image file, to operate on.

The third input option calls the subroutine OPTION. This displays a list of options which the user can use to perform various operations on the image. These operations are each carried out by a relevant overlay.

The operations and their overlays are:-

| | | |
|---|---|---|
| 1 | HISTOGRAM | HPLOT |
| 2 | EDGE DETECTION | EDGE1 |
| 3 | SYMBOL MAP | MAP |
| 4 | BOUNDARY FINDING | BNDRY |
| 5 | SPECTRAL PLOT | SPECT |
| 6 | CLUSTER ANALYSIS | CLSTR |
| 7 | IMAGE HANDLING | HANDLE |
| 8 | IMAGE QUANTISING | QUANTI |
| 9 | FREQUENCY DISTRIBUTIONS | QUANTI |
| 10 | IMAGE SMOOTHING | SMOOTH |
| 11 | FILTERING | FILTER |
| 12 | HOMOGENEITY IMAGE | HOMOG |
| 13 | NEW ONE | NEWONE |
| 14 | NEW TWO | NEWTWO |

On return from the OPTION subroutine the relevant overlay is called. The overlay program is executed and returns to MSTR.

Then the final section asks the user if a header should be written or read. The header which is stored in line 1 of the image file allows the user to keep track of the image in the file.

The program then loops back to the input selection.

iii) Program Notes

Common block /FDATA/S,R,DS,DR is used by subroutine AREA to transmit the location of the image in the file to the main section of MSTR. MSTR can then communicate this to all the overlays.

Common block /SELECT/NOP transmits the number of the option selection made in subroutine OPTION.

A PAUSE command is issued by subroutine FILE to cause a temporary exit from the program. In this exit the DOS command $\not{S}$AS is used to assign files to logic numbers.

### 6.4.10 Subroutine CLSTR

i) Program Summary

| | | | |
|---|---|---|---|
| Title | CLSTR | | |
| Storage | listing | CLSTR.FTN | 11 blocks |
| | object | CLSTR.OBJ | 29 blocks |
| | load module | CLSTR.LDA | 14 blocks |
| Peripherals | disk for image file<br>line printer for output<br>keyboard for interaction | | |
| Program length | 145 lines | | |
| Overlay structure | called as overlay 'CLSTR' from MSTR | | |
| Program structure | main interactive structure<br>subroutine INIT<br>REFINE | | |
| Problem | To investigate the tendency of multispectral data to form clusters in colour space | | |
| Solution | a general clustering algorithm that will work on any N-dimensional data. A two part program, one subroutine to make an initial guess at the clusters, another to refine this guess | | |
| Limitations | no classification map is produced. After each iteration the means of up to 10 clusters in a maximum of 5 dimensions is printed. The dimensional data must be stored one dimension in each direct access file. The data must be in registration. | | |

ii) Detailed Write Up

This program can be used to investigate the tendency for multi-dimensional data to form clusters in dimensional space. The data could be the grey values of the image in a number of bands or equally well the output of a number of different filters.

One of the main problems of clustering is the initial estimation of the cluster centres. This problem can be avoided if sequential clustering is used (Nagy and Tolaba 1972) where the clusters are constructed as processing proceeds. Using a method by Wacker AG (1969), which in turn is a modification of that by Swain and Fu (1968), an initial cluster estimating algorithm was drawn up. This is initiated by the subroutine call

INIT (M,N IFILE,COORD)

M is the number of clusters, N the number of dimensions, IFILE an array containing the file numbers and COORD a two dimensional array containing the cluster mean guessed for each dimension.

The initialisation algorithm is

Let $X_1, X_2 \ldots\ldots\ldots X_N$ be N L dimensional vectors from an image area. If the maximum number of clusters required is $M_m$, the $M_m$ initial centres are generated by:-

computing the sample mean of the N vectors

$$\mu_j = \frac{1}{N} \sum_{i=1}^{N} X_i$$

and the sample variance for each dimension

$$\sigma_j^2 = \frac{1}{N-1} \sum_{i=1}^{N} (X_{ij} - M_j)^2$$

$$j = 1, 2 \ldots\ldots L$$

Let $\sigma = (\sigma 1, \sigma 2, \ldots\ldots\ldots \sigma L)$

$\mu = (\mu 1, \mu 2, \ldots\ldots\ldots \mu L)$

Consider the real line intervals

$$\gamma i = [\mu i + \sigma i, \mu i - \sigma i] \quad i = 1, 2 \ldots\ldots\ldots L$$

the Cartesian product

$$\gamma_1 \times \gamma_2 \times \gamma_3 \times \ldots\ldots\ldots$$

defines a rectangular parallelepiped in the observation space which should contain most of the vectors from the image area.

The $M_m$ initial cluster centres can be chosen to be uniformly spaced along a diagonal of this rectangular parallelepiped

The kth cluster centre is

$$M_k = \mu + \sigma(2(k-1)/(M_m - 1) -1) \quad K = 1,2\ldots\ldots M_m$$

These initial guesses are passed by the array COORD to the subroutine

REFINE (M,COORD,N,IFILE,IT)

The parameters are the same as before, with the addition of IT which defines the maximum number of iterations through the data set.

The refinement is carried out as follows:-

The Euclidean distance of each vector from all the cluster centres is determined. The vector is assigned to the cluster for which the distance is a minimum and less than some threshold distance. This ensures isolated points far from any cluster are not attached to a cluster causing it to spread out too far.

New cluster centres based on the new vector assignments are recalculated, and the process of refinement is repeated IT times.

iii) Program Notes

The common block /FDATA/ S,R,DS,DR is used to transfer the image location from MSTR to the program and subroutines.

The area can be redefined in the interaction because clustering is very time consuming. This resets the values of S,R,DS,DR in the common block.

### 6.4.11 Subroutine HANDLE

i) Program Summary

| | | | |
|---|---|---|---|
| Title | HANDLE | | |
| Storage | listing | HANDLE.FTN | 7 blocks |
| | object | HANDLE.OBJ | 19 blocks |
| | load module | HANDLE.LDA | 8 blocks |
| Peripherals | disk file for input image<br>disk file for output image<br>keyboard for interaction | | |
| Program length | 95 lines | | |
| Overlay structure | called as overlay 'HANDLE' from MSTR<br>calls subroutine FILE in MSTR | | |
| Program structure | main interactive section<br>subroutine MOVE, SUBT | | |
| Problem | to provide some basic image handling routines | | |
| Solution | two were coded. One to move images for registration purposes, the other to subtract one image from another. | | |
| Limitations | in subtraction the absolute difference between the images is calculated, no account of the sign is taken in the result. The image movement is restricted to translation only. Rotation is not possible. | | |

ii) Detailed Write Up

To enable images to be registered for use in a clustering algorithm, the subroutine MOVE (MOV,IREG,L,IC) was provided.

To keep within the time limitation of the project the algorithm was coded to correct only for translation of the image. This was regarded as satisfactory for the requirements because the images were obtained with the $I^2S$ camera, which is optically aligned. For the accuracy required mounting in the Scandig carriage was sufficiently accurate to avoid rotation.

This algorithm simply shifts the image records by L lines and moves the pixels across the image by IC pixels. The image in file MOV is rewritten into the image file IREG.

The subroutine SUBT(IFILE,KFILE,ISUB) is a simple image subtraction algorithm provided in case it might be useful. The difference between corresponding pixels in images IFILE and KFILE is calculated and the result written to ISUB image file.

iii) Program Notes

Common block /FDATA/S,R,DS,DR transfers the image location and size to the subroutines from MSTR.

Because image subtraction may require up to 3 image files an option is given to call the subroutine FILE in MSTR to assign extra files.

6.4.12 Subroutine SPGTDM

i) Program Summary

| | |
|---|---|
| Title | SPGTDM |
| Storage | listing SPGTDM.FTN 13 blocks<br>object SPGTDM.OBJ 27 blocks<br>load module SPGTDM.LDA 12 blocks |
| Peripherals | disk file for input image<br>disk file for output image<br>line printer for optional output<br>keyboard for interaction |
| Program length | 151 lines |
| Overlay structure | called as overlay 'SPGTDM' from MSTR calls overlay 'QUANTI' |
| Program structure | main interactive section<br>subroutines HOMOG1<br>GREY<br>function INDEX |
| Problem | To gain information on the overall structure of the image |

| | |
|---|---|
| Solution | Measure the homogeneity of small areas of the image, and form an edge-homogeneity image. |
| Limitations | very slow. Needs quantised images with not more than 25 grey levels. Works on image blocks up to 5 x 5 pixels in size, scanned across the image. |

ii) Detailed Write Up

Before extracting detailed information from the image it may be more useful to obtain information on the structure of the image as a whole. One such piece of information is the homogeneity of areas of the image. Homogeneity means the pixels are of the same kind or similar, i.e. homogeneity is a measure of the 'sameness' in the image.

The homogeneity in this algorithm is calculated after the method of Haralick and Anderson (1971). First, what is called a Spatial Greytone Dependence Matrix (SGM) is calculated for each small image block. Haralick and Anderson used this primarily for the extraction of a number of features. However, they do show how to use the SGM to calculate a measure of homogeneity.

The SGM:-

This is calculated by the subroutine GREY (IDATA,LEX1, LEX2, LEX3,LEX4).

The image is divided into small image blocks and each one is processed in turn to eventually produce one number, the measure of homogeneity. The image block is passed to the subroutine in the 2-D array IDATA.

The SGMs are 2-D arrays where the i,jth entry is the number of times pixel grey values i and j occur next to each other in the image block. SGMs can be produced for any angle and over any range of pixels. This subroutine is limited to distance 1 i.e. adjacent pixels, and four angles horizontal (H) vertical (V), left diagonal (LD) and right diagonal (RD).

The four SGMs could be stored in four 2-D arrays, but to save storage advantage is taken of the symmetry of the arrays. Two adjacent pixels of grey value i and j can be stored in positions i,j or j,i of the SGM.

Instead a function INDEX (i,j) is used to return the value of the position of the entry i j in a one dimensional lexographic array. These arrays are LEX1,LEX2,LEX3,LEX4, one for each angle. H,V,LD and RD.

The entries in the LEX arrays are stored as follows:

| i \ j | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1 | - | - | - |
| 2 | 2 | 3 | - | - |
| 3 | 4 | 5 | 6 | - |
| 4 | 7 | 8 | 9 | 10 |

$i \geq j$

$$\text{INDEX} = \frac{(i-1)*j}{2} + j$$

$i < j$

$$\text{INDEX} = \frac{(j-1)*i}{2} + i$$

for example adjacent pixel grey levels 2,3 or 3, 2 are stored in LEX position 5.

To make it come out correctly at the end, the diagonal entries are doubled.

Homogeneity:-

The LEX arrays calculated for the image block are now passed to the subroutine HOMOG1 (IV,LEX1,LEX2,LEX3,LEX4) which returns the value of edge-homogeneity IV.

For a picture J an image point I can be transformed to a spatial picture of J's homogeneity - unhomogeneity structure.

For pixel i,j the grey tone (J(ij) can be shown to have the form

$$J(ij) = h_1(H)+h_2\ (RD) + h_3(V)+h_4(LD)$$

where $h_1$ $h_2$ $h_3$ $h_4$ are symmetric functions of two arguments.

h(n.m) functions can be

$(n-m)^2$ to enhance boundaries

$1/(1+(n-m)^2)$ to enhance homogeneous areas.

Considering a partition II(a,b) consisting of all pixels that are neighbours and have grey tones a and b, it can be shown that the average grey tone is a function of the neighbouring spatial grey tone frequencies P(a,b) and the h(n,m) functions. The average grey tone is

$$\sum_{i=1}^{N}\sum_{j=1}^{N} J(i,j) = \sum_{a=1}^{N}\sum_{b=a}^{N}\Big[h_1(a,b)P_H(a,b)+h_2(a,b)P_{RD}(a,b) +h_3(a,b)P_V(a,b)+h_4(a,b)\,P_D(a,b)\Big]$$

this algorithm is constructed to enhance the edges between homogeneous areas so the function $h(nm)=(a-b)^2$ was used. The P(a,b) function is the SGMs contained in the LEX arrays.

The edge-homogeneity measure (IV) is constructed from the average grey tone

$$IV=\sum_{i=1}^{N}\sum_{j=1}^{N} j(ij) = \sum_{a=1}^{N}\sum_{b=a}^{N} (a-b)^2[P_H(a,b)+P_{RD}(a,b)+PV(ab)+P_{LD}(ab)]$$

note N is the number of grey levels and $b \geq a$

iii) Program Notes

The common block /FDATA/ S,R,DS,DR transfers the image location from MSTR to the subroutines.

If the program has been entered without realising that an image of less than 25 quantised levels is needed, an option is given to call the overlay QUANTI. If this is done QUANTI overwrites SPGTDM in core and an image can be quantised. But as the common block /SELECT/NOP in MSTR is holding the option selection it is possible to return to SPGTDM by pressing CR. This avoids displaying and selecting from the option list again.

The image blocks are handled by arrays ISEG and IBLOCK. If an image block of L lines is specified then L complete lines are read into ISEG. Each image block of size P pixels by L lines is then taken from ISEG as needed and processed to find the edge-homogeneity value IV. One line of IVs are built in an array corresponding to the lines in ISEG. At the end of the line the IV array is written to the new image file and the next segment of image lines is read into ISEG.

# CHAPTER 7

## CONCLUSION

As explained in chapter 1 this thesis looks at the subject from the European point of view, and from the point of view of establishing a methodology for an automated system which could reduce the gulf between the user and system specialist.

This leads to requirements for flexible high quality input from photographs and a flexible system of analysis. Photographic input for cheapness and ease of storage and flexibility to suit needs of users and specialists.

The present methods of analysis as described in chapter 2 are not very flexible. They rely heavily on spectral processing giving classifications of the image into groups based on mathematical discrimination. The classification that can be produced may be of little use. It uses only the colour information in the image which is highly dependent on a large number of factors.

The hardware as described in chapter 3 is somewhat limited in terms of complete systems. The few operational systems are extremely expensive and built so that the result of any analysis is dependent on spectral processing. Many so called analysis systems in fact just enhance the image for humans to analyse. A major problem not dealt with in this thesis is the display and output of the final results in a form usable by planners and other users.

Two main questions arise from chapters 2 and 3, is multispectral photography a useful tool in its own right? and what is the problem which automation should be tackling?

The following guidelines are suggested in answering these questions:

1) Can the user get the required information from ordinary photography?

2) What is this information the user requires, what surveys are at present done manually?

3) Can the extraction of this information actually required be obtained by automation from its present source of ordinary photography?

4) If not then multispectral methods may be useful.

5) If multispectral is needed there should be a thorough program of all-year-round flights covering all objects under varying conditions as required.

6) It will then be possible to tell if the required information can be automatically extracted under some, none or all conditions.

7) What sort of automation is the user happiest with - visual with computer help - total automation, no mistrust of the black box, or something to make the manual job faster and less tiring.

8) How can this automation supply a cost beneficial throughput rate. Or is a reduction in cost the prime concern; is a higher throughput rate the main objective?

The system advanced in this thesis allows a user to digitise his present image source. There is no need to obtain some modern highly fashionable multispectral material. A user can then interact with the system and find out just how useful these automated systems are for his own use.

This, one must understand, is a research system that allows a user to investigate the image structure with a view to extracting information for his own use in automated systems. Operationally a faster hybrid analogue technique is required.

One must really question the whole present concept and approach to automation in Remote Sensing. What is it that people are trying to do! Generate more information in the hope that it will be useful or finding some question to fit the answer 'automate it'. Should we not be trying to help present surveyors overcome their data flow problems from their side of the fence, to enable them to obtain useful results in a reasonable time at a reasonable cost.

Before starting a survey the following need to be considered:

1) Define the objectives.

   It may not require m/s photography

2) Know the variables.

   Time, season, processing

3) Know the capabilities.

   Advantages, disadvantages of the type of photography and method of data processing

4) Correct for distortions.

   Use ground truth panels, and controlled photo processing

5) Decide if analysis is to be by man, computer or both.

Given that analysis of multispectral photography requires automation, mainly because of its intrinsic data capacity, is this a cost effective approach to providing the information a user wants? Is it good enough that the reason for automation is to handle the increase in data from the new sources of imagery, or should some weight be given to the increase in variety and volume of information required by modern planners? Some of the expensive systems can solve some of the problems. The systems could possibly speed up by a factor of 10 some of the interpretation or classification, but including this speed-up with the problem of getting data in and out of the computer probably makes no overall difference to the total job time.

Taking that automation is required what can it really do for a user? Chapter 4 outlines the type of system that should be developed and how to use it. Chapter 4 also explains some of the variety of information that could be obtained by automated systems from photography. The system proposed in this thesis does not attempt full automation yet is more than an enhancement system. With it the user can work with a classification that is really useful. A user can establish just what parts of the classification the system can deal with. A production system can then be established dealing automatically with parts of the imagery taking some or perhaps a great deal of work off the user, just calling in the user to make the more difficult decisions.

A methodology consistant with the above philosophy was developed as part of the research and is described in chapters 5, 6. The system developed is suitable for use by the general user and by the specialist image analyst. The user can try all the options given by the system to find which if any are suitable for a given application. The specialist is able to add quite easily further image processing algorithms for a user to try. This implies a close co-operation between user and specialist to understand each others needs.

Finally the real use of such a system from the user's point of view should be mentioned. It is from the user that the demand to automate certain functions should come as he has to justify its cost effectiveness in production. Users tend to think in manual terms and tend to ask of any automated system to reproduce manual operations. With the proposed system users should be able to orient their thinking to automation, and probably think of doing things that would never have been attempted manually. That is to say the aim is to re-orient the user's frame of mind from 'manually' thought processes to 'automated' thought processes.

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| 4th April | 1966 | 1 Volume |
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| 6th Oct. | 1969 | 2 Volumes |
| 7th May | 1971 | 3 Volumes |
| 8th Oct. | 1972 | 3 Volumes |
| 9th April | 1974 | 3 Volumes |

# APPENDICES

# APPENDIX 1

## A PROPOSED IMAGE ANALYSIS SYSTEM

The basic building blocks of this system are:-

1) Microdensitometer (MDM)
2) Computer
3) Data storage - magnetic tape
4) Filmwrite 2

The types of image processing operation that can be done by this system fall into 3 main classes:-

A) Point operations
B) Local operations
C) Global operations

Global operations are performed on the total image. These include geometric transforms, removal of lens vignetting or normalising the density distribution of the total image.

Local operations involve filtering, smoothing, texture analysis, or anything that uses a small area of the image.

Point operations are density transforms on individual points and include contrast stretching and density slicing.

Often image processing is split into two other divisions - position independent and position dependent operations. The first mentioned three can be grouped under these two headings, but for the purposes of organising the structure of the system the first three headings are best. Using the three types of image processing operation, it is possible to organise the system in three different ways, one to cover each operation.

A) Point operations.

The system can be connected as shown in Fig. 1

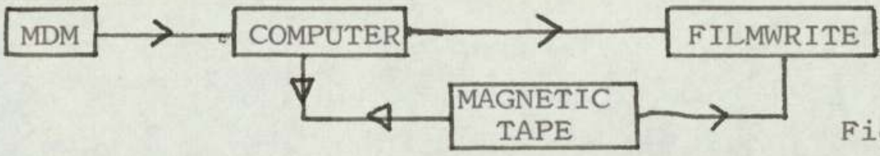



Fig. 1

Point transforms such as contrast stretching can be machine coded or even hardwired, the user just sets the degree of stretch required. The MDM can either be a Scandig or flatbed instrument. The system can be run on line as the required transform is usually very fast. Each point is digitised transformed and written straight back onto film using the film writer. There can be an option to store either the original or transformed data on magnetic tape. Storing the original data allows several runs to be made on the same data, but using slightly different transforms, without the need to re-digitise each time.

B) Local operations.

If a flatbed MDM is used then the system can be connected as Fig. 2.

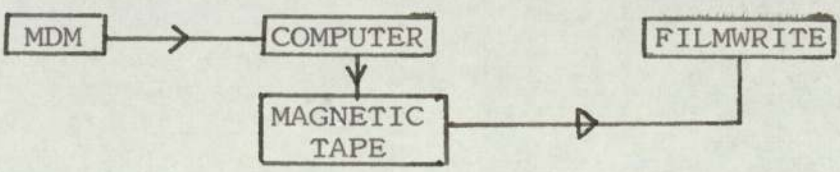



Fig. 2

In local operations say, for example smoothing, a small area of the image is digitised and the central point replaced by the average of the points. The resulting data is stored on magnetic tape until sufficient is acquired to use the filmwrite.

Using the Scandig as the digitiser the system could be as Fig. 3.

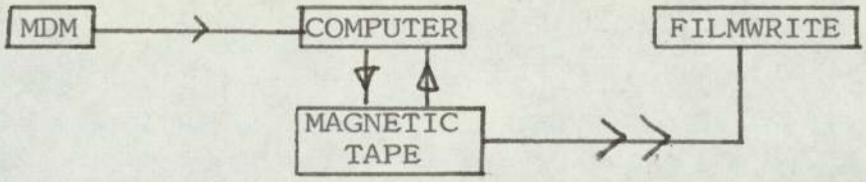



Fig. 3.

In this case to make the optimum use of Scandig it is best to put the data on magnetic tape then process it and write it.

C) Global operations.

For this work the system is best used as in Fig. 3 with a drum scanner. For some global operations it may be necessary to take the tape to a big computer to process it and bring it back to the Filmwrite to display it.

These are only suggestions on the way to use the bits of hardware. It will depend on individual needs as to whether you store the data on magnetic tape then process, or process as you digitise. Individuals need to weigh-up how much each method will tie up each piece of machinery for their particular use. They can then decide on the most cost effective structure.

What is attempted here is to show the scope and flexibility of an operational system, not a research system.

Research systems tend to be computer oriented, most research workers will spend all their time working on one or two images they have stored on magnetic tape. They will have little need for an expensive Scandig. However, they will need a digitising and filmwriting facility.

Perhaps a film writer is the first choice of purchase as this will enable them to see the results of their work quickly.

A return of post digitising/filmwrite facility would be quite acceptable to most people. For the price of a Scandig/Filmwrite they could keep themselves supplied with data for a very long time.

One further point about the operational system is that the computer can be based on a microprogrammable processor for fast working.

# APPENDIX 2

## INFORMATION REQUIRED FROM REMOTE SENSING

This is a list of some of the investigations that have been carried out using photographic methods to show the sort of information investigators have tried to extract. **This list covers the range of investigations reported in various proceedings of the Ann Arbor conferences.**

A. Inventory or count of plants, land and water animals to establish long term trends and fluctuations.

B. Synoptic overviews of surface temperatures to an accuracy of $\pm 1^{o}C$.

C. Analysis of wetlands and shorelines to establish boundaries, erosion, and substrate type.

D. Broad surveys of land use patterns, transportation nets, urban areas, soil and vegetation areas.

E. Repetitive systematic coverage of changes and trends in land use.

F. Information on the rate of urban encroachment and industrial/urban boundary changes.

G. Accurate surveys of forests equivalent to the present ten year ground surveys covering acreage, species, and size of trees.

H. Disease detection by contrast effects in healthy vegetation.

I. Mineral detection for construction engineering.

J. Site and route location for engineers.

K. Determination of wave height, length, direction and period.

L. Determination of water circulation patterns.

# APPENDIX 3

## SOME PROBLEMS ON THE QUANTITATIVE ANALYSIS AND APPLICATION OF MULTISPECTRAL PHOTOGRAPHY

A) Analysis using additive viewing

When the shutter on the multispectral camera exposes all bands at the same speed, the correct exposure is given by individual setting of the lens apertures. The exposures should be such that a white object reflecting equally throughout the 400 to 900 nm region has the same density in all bands of the processed negative.

The films should be processed so that the red, green, blue images have as nearly as possible the same gamma. This will produce good colour separation and allow the reconstitution of genuine true colour images in the viewer. If the IR band is processed under the same conditions as the other bands its gamma will be slightly higher but as this emphasises reflectance variations, this is an advantage in false colour reconstitution.

The transparency for additive viewing should be processed undodged, and to an overall positive/negative gamma of three or more - as in most aerial colour films. A high gamma means there will be a greater range of density in the transparency and thus a greater range of chromatic saturation will be obtainable in the additive viewing.

B) Densitometric analysis

Densitometric methods are used in automated systems to analyse multispectral photos. The density in each spectral band can be measured and if certain physical conditions of the system are known the density readings can be converted to a spectral signature based on the reflectance of the object in each spectral band. This signature is used in the automated systems to identify the object in the photo.

The resulting density of the film is very dependent on the physical conditions of the camera and processing.

The incident flux at the camera is sampled in four different bands. The film has a different sensitivity in these four bands and each band has to be given a different exposure by varying the shutter speed/lens aperture combination. This ensures each image lies on the linear portion of the H & D film curve. The H & D film curve relates the exposure to the resulting density. The slope of the linear portion is called the film gamma. The film gamma can be varied by processing in different chemicals or variation in the time and temperature of processing in one particular chemical.

Knowing the gamma in each spectral band or the overall gamma and the sensitivity of the film in each spectral band, the measured density can be converted to the exposure. However, as this exposure is taken at different speeds and apertures in each band a correction for this has to be applied to find the incident flux.

Even this is not the true incident flux because the lens absorbs light. Knowing the lens spectral absorption characteristics yet another correction can be applied. There is one more very important correction to apply and that is for lens vignetting. Lens vignetting causes a fall off in film density radially from the centre of the photograph, resulting in the same object having a different density if it lies on the edge or the centre of the frame.

This effect is very significant in additive viewing in false colours. Because of this density variation identical objects will have different colours according to whether they are in the centre or edges of the frame. Visual identification of objects should, therefore, be made for objects only in the same position on each frame.

Applying all these corrections to the measured density provides data that can be considered a spectral signature.

C) Some problems in the application of multispectral photography.

Unique spectral signatures for most environmental parameters are not known. Dynamic variables in the environment, such as variation in illumination, atmospheric attenuation and directional spectral reflectance exist which distort the underlying relationship between reconstituted image colour and the identity of the object. Instrument errors such as spectral properties of the lens and the dependence of photographic density on wavelength and processing can make the reproduction process inaccurate. It is also a physical fact that a unique spectra produces a unique colour but the inverse is not true.

Many of the environmental and instrumental variables can be quantitatively accounted for by placing targets of known spectral properties in the environment. Also measurements of incident and reflected solar spectra, laboratory calibration of the camera, controlled photo processing, and analysis of the additive viewer itself all help to reduce system variables.

Density differences (in the image of a ground object) in the different bands will exist where there exists variations in the spectral reflectance of the object. The additive viewer superimposes the images to produce a colour dependent on the variation in density in each image. The colour space can be altered by the observer. Where there is no density difference between the bands the image is a shade of grey from white to very dark if the 3 primaries are used.

The human eye is responsive to several million colour differences. To uniquely describe the appearance of an object with respect to the response to the stimulus known as colour the three variables of hue, brightness and saturation should be used. Calorimetric measurements of these will allow the colour space to be measured accurately, and if test panels or control strips are included in each frame, measurements from all frames can be reduced to a common base.

The advantage of multiband photography lies in the fact that the exposure in each band can be individually controlled and the viewer can be used to alter the image colour space to suit the needs of the observer.

The filters should be chosen based on some a priori knowledge of the scene spectral reflectance. This may involve some ground work immediately preceding the flight, using a telespectroradiometer to help decide on the best filters to use.

If at a later stage it is desired to reconstruct a true colour image then the pass band of the filters used must be broad enough so that the total visible spectrum is covered with no gaps. The pass band of a filter is the range of the spectrum it transmits.

To aid in measuring the chromaticity co-ordinates of the image a ground target consisting green, yellow, blue, red and grey panels should ideally appear at the beginning and end of each strip of photography. The role of these target panels is best demonstrated when photographs are taken from increasing heights. In ordinary colour photographs it is very difficult to distinguish the blue and green targets due to the increasing amount of atmospheric scattering with increasing height. In multispectral additive viewing the interpreter can adjust the chromaticity co-ordinates using illumination and filter controls to produce the most natural rendition of the colour panels knowing that they are certain defined colours. A white test panel is also very useful in this manipulation of colour space, because white is easier to reproduce than trying to reproduce the correct 'blueness' of a blue test panel.

One important and unresolved problem is that of what effect do angular variations of the sun and sensor have on the spectral signature recorded by the sensor. To some extent the effect of reddening in colour photos taken late in the day can be compensated for when using multiband photos in an additive viewer.

If any form of quantitative measurements are to be made on the multiband photos then a sensitometric test strip should be exposed at least on the start and end of each strip of film during development. Ideally this should appear on each frame of imagery.

# APPENDIX 4
## Photography

Multispectral photography generally refers to panchromatic or infra-red films used with a set of filters, but the term can equally be applied to colour or colour infra-red films.

In colour photographs three broad overlapping bands only are available for analysis and there is no advantage over that of visual interpretation in measuring the density of each layer. Indeed it has been reported (R.N. Evans, An Introduction to Colour, J. Wiley and Sons Inc. N.Y. 1948) that 2,000,000 combinations of hue, brightness and saturation are distinguishable by the human eye. So providing the processing is consistent (a very difficult job in colour) there should be no problems in identifying objects on colour films.

Aerial colour film with a haze cutting filter has about the same response as the eye and will give a true colour rendition of the scene. The filter screens out the blue cast caused by atmospheric scattering.

Infra-red colour film is normally used with a minus blue filter. This cuts out all the blue light because all the dye layers of the film are blue sensitive. Different colours can be printed through the infra-red dye layer to give a "false colour" image enhancing the discriminability of adjacent objects.

The usefulness of multispectral photography is most evident in black and white photography where narrow spectral regions can be recorded using filters and panchromatic or infra-red film. Any film filter combination that will help enhance the sought for object can be used.

Normally panchromatic film is used with a minus blue filter to cut out the scattered blue light and give a sharp image. Infra-red film has to be used with a black filter to cut out the visible part of the spectrum to which the film is also sensitive. Use of narrow band pass filter with these films will produce an image representing the amount of that colour in the scene. When a filter is used with infra-red film an interference filter must also be used as well, to block out the infra-red component of the spectrum that penetrates the filter made of gelatin or glass.

Colour Sensitivity of Photographic Materials.

Silver halides from which the film is made are sensitive to the blue end of the spectrum only. Below 0.4 microns the image lies on the surface of the emulsion. Below 0.33 microns the light is absorbed by the camera lens. The extension of the sensitivity to the green and red is achieved by colour sensitizing dyes added to the emulsion. Unsensitized film responds only to blue light and is known as colour blind film. Extension to the green results in orthochromatic film. Extension to 0.67 micron in the red results in panchromatic film sensitive to all colours in the visible spectrum but not equally sensitive to them all.

Extension of the sensitivity to 1.2 micron produces infra-red film. Further extension is not viable due to absorption or electromagnetic radiation by water in the atmosphere beyond 1.4 microns.

The longer wavelength infra-red radiation is scattered less than the shorter wavelengths resulting in increased penetration of objects. It is in the IR that significant reflectance differences occur between water and vegetation, between hardwoods and conifers, between healthy and unhealthy foliage. Lenses have to be corrected for IR to the order of 0.5% of the focal length of that in the green region.

The Reproduction of Colours in Black and White.

The pigments of most naturally occuring objects absorb and reflect to varying degrees different parts of the spectrum. These pigmentary colours are of much lower purity (saturation) than the primary colours. Thus a red rose appears red because most (45%) of the reflected light is red but all other colours are reflected to some extent. The colour of an object also depends on the colour of the illumination. A change from day-light to tungstun light has little affect on the visual appearance due to the accommodation of the eye. Film has no such property and a different colour is registered.

The human eye has a peak response to normal illumination at 555nm. This means that for an equal energy flux throughout the spectrum a yellow green object appears more luminous than a red or blue object. At low levels of illumination the eye becomes dark adapted and the peak response moves to 515nm. Film sensitivity does not change with the level of illumination.

Photographic emulsion is considered to reproduce colours faithfully in monochrome when the relative luminosities of the greys produced are in agreement with the relative luminosities of the colours seen by the eye.

This could be achieved if the film had the same sensitivity as the eye, but no film has such a response.

Aerial Colour Photography

Some common aerial colour films:-

Ektachrome Aero film - manufactured by Eastman Kodak is a film which produces a colour positive transparency.

Ektacolor Aero film - (Kodak) produces a negative film.

Anscochrome - manufactured by General Analine and Film Corp. is a negative.

Agfacolor - is a negative film.

Ektachrome Infrared Aero 8443 - (Kodak) is a fale colour positive transparency.

Colour negative film has the advantage over colour transparencies of greater exposure latitude and more control in obtaining the required colour balance.

It has often been said that colour has very much poorer resolution than monochrome films. Umbach* has said that colour with a fully colour corrected lens is nearly as good as pan film because most objects are a mixture of colours and are better resolved on colour film than black and white test targets would indicate. The slightly poorer resolution is more than compensated for by the 2,000,000 or more possible combinations of hue, value, and chroma that can be visually interpreted.

Ordinary colour film is composed of three layers sensitive to blue, green, and red light. Infra-red colour film has three layers sensitive to green, red, and infra-red. In printing the red is printed through the IR image, green through the red image, and blue through the green image.

*Colour and Metric Photogrammetry, American Society of Photogrammetry March convention 1967

Ultra-Violet Imagery

UV shorter than 300nm is absorbed by ozone and never reaches the Earths surface. UV radiation at longer wavelengths is very scattered but the 300-350nm is of interest because abrupt changes in ground reflectance begin to occur here.

In camera systems a film with no response beyond 550nm can be used. To obtain reasonable lens transmission quartz and lithium flouride optics have to be used resulting in very expensive lens systems. The interference filters used to select the band limit the off axis beam to $10^{o}$ else different wavelengths will be tuned-in.

In scanner systems the incidence angle on the optics is always small but the filter does tend to transmit a small amount of red and infra-red light. It is possible to cut this out but only by sacrificing some spatial resolution. The high degree of scattering in the UV band badly degrades the image and the best results are obtained with optical-mechanical scanners below 6000ft.

Thermal Infra-Red Imagery

This applies to the bands at 3-5 microns and 8-14 microns. Film is not sensitive to these wavelengths, so photographic images are recorded indirectly using scanner systems. The scanning system does not produce a metric picture, nor an absolute thermal record. It can however record temperature differences of only a few degrees celcius.

Side Looking Airborn Radar Imagery

Vegetation analysis through SLAR cannot be based solely upon image tone because the relative orientation of the ground slope to the radar beam affects the return beam intensity. As a minimum to identification tone and texture must be considered. To improve classification elevation and aspect need to be considered.

One species may have different tones on HV imagery (horizontal transmit, vertical receive) and HH imagery (horizontal transmit, horizontal receive). The range of the object affects the grey tone because at far range the angle of incidence of the beam to the vertical is much greater than at near range and therefore the reflected beam differs in intensity. Different combinations of species will often result in the same radar return.

Ideally the object should be covered by most of the available range of incidence angles so that the return over a range of angles can be analysed. This can be achieved by flight lines with greater than 40% overlap.

PHOTOGRAPHIC REMOTE SENSING CHAIN OF EVENTS

| Physical appearance ................. | Mathematical Representation |
| --- | --- |
| Downflow of radiation - | |
| | - Measured by radiometer |
| Atmospheric absorption - | |
| | - Atmospheric model |
| Reflection from surface - | |
| | - Interaction of EMR with the structure of the surface |
| Atmospheric absorption of upflowing radiation - | |
| | - Atmospheric model |
| Intensity distribution at the camera lens - | |
| | - Optical transfer and spread function of the lens |
| Latent density distribution on film - | |
| | - Optical transfer and spread function of the film |
| Developed density distribution on the film; - | |
| | - Chemical transfer function and H & D film curve |
| Measured density distribution | |
| | - Microdensitometer effects |

# APPENDIX 5

## Field Relations

### Soil

A knowledge of the surface soil composition obtained from aerial photos may make it possible to distinguish soil characteristics below the surface. Field checking will always be needed to establish the relation, but once established photo interpretation takes care of the vast volume of work.

The advantage of colour for soil interpretation becomes apparent very when those specific soil characteristics associated with soil colour are considered, or when deductive methods are used to associate crop conditions or soil patterns with soil characteristics. Using only the dimension of density in interpretation leads to a limited interpretation (inductive), a certain amount of deductive analysis is needed for a full interpretation.

Soil colour is one of the basic signatures of any soil, often denoting the major classification. Soil colour can change markedly or very little with soil moisture depending on the soil.

Only exposed soil surfaces are directly interpretable. Associated vegetation cover and geological parent materials require field work to establish the field relations.

### Geology

Identification of the three main rock classes - igneous, sedimentary and metamorphic is reasonably easy on the basis of density patterns. Individual rock types such as granite or sedimentary types can be deduced on the basis of landform drainage pattern vegetation cover and other associated clues.

## Vegetation

Timberland, brushland, grassland have distinctive patterns and can easily be distinguished on this basis even on pan black and white film. Using IR Aerographic with a Wratten 89B filter it is easy to distinguish between conifers and deciduous trees on the basis of density. Using the same film filter the patterns produced by hardwoods, softwoods and mixed woods, (together with their photo density), can be distinguished. However, these require a certain amount of pattern recognition.

Aero IR and Ektachrome IR can be used to detect plant stress by showing affected areas as a different colour or density to healthy areas. Potato foliage loses its IR reflectance when attacked by potato blight and this shows easily as a change in colour on IR Ektachrome.

Ektachrome aero and Pan films show slight colour and density changes in plants affected by Vertiullium wilt, drought damage and mineral deficiencies. Ektachrome IR has also been used in detecting salt affected areas in cotton fields. Healthy cotton appears bright red or pink, salt affected plants are darker red.

It would seem easy to automate a system to detect a single parameter such as a specific disease which shows up as a distinct density anomaly on the photograph.

Information required by Agronomiats is 1) type of crop in the field 2) the acreage of each field 3) the vigor and yield of each field 4) any agent responsible for loss of vigor.

## Hydrology

Differentiation between snow and non snow areas is very easy even on panchromatic films. By following the seasonal variation of snow hydrologists can regulate water flow more easily. Free water is easily detectable on IR b/w or colour films and automated systems to pick out and delineate the water areas are easy to set up.

## Engineering

Aerial photos are used by construction engineers in selecting sites for dams, roads, airfields, canals pipelines etc. Coarse textured materials that might provide basis for highways and airfields usually photograph light in tone. Here one can readily automate a system to search for likely material sites. Using further information of the drainage pattern and vegetation types gives further clues to site suitability for construction and materials.

## Classification techniques in experimental use

Experimental work on automatic classification is generally based on either spectral or spatial characteristics but not both together.

## Supervised learning

The typical classification experiment in either domain is open to criticism on several counts. The data collected in a single region under good conditions by airborne sensors is examined in its entirety by the experimenter who decides which areas are most representative of the region as a whole. The samples from these areas are assembled to form a training set characterised by ground truth information. A statistical categorizer or decision box is constructed on the basis of the statistical parameters extracted from the training set. The classification performance is evaluated on another portion of the data, the test set, also carefully selected to ease classification. The ground truth is known so the error can be checked. If the error is high the offending portions of the test set are included in the training set and the cycle repeated until the experimenter can claim greater than 75% accuracy.

Non-supervised learning

This, sometimes called clustering, is the name applied to methods of data analysis where only the observed values are used explicitly to group samples according to some intrinsic measure of similarity. Usually additional information on the number of expected groups or spatial constraints is used as well.

This approach has been used to alleviate the problem of multimodal probability distributions in supervised classification methods, to circumvent the need for 'a prior' selection of training samples, to extract boundaries between homogeneous regions, to condense the amount of information stored.

Clustering is conducted on an even smaller number of samples than most supervised classification experiments because the algorithms used tend to be very complicated and time consuming.

An experiment on nine classes extracted from colour aerial photography using a trichromatic microdensitometer has been reported (A189).

Crop recognition

The recognition of crop species by means of multispectral signatures has been studied since 1966. Much has been said about systematic coverage throughout the growing season, but most experiments use data collected in a single day.

Almost all the earlier work is based on data collected by the Michigan 12 channel m/s scanner or the Apollo 9 experiments. Most of the experiments have been performed by investigators from Michigan or LARS Purdue. The instruments used in data analysis were the CDC 3600 at Michigan and IBM 360/44 at Purdue. Most of the published reports came from this small group using the same data time and time again.

Using supervised learning the ratio of the training set to the test set has gradually decreased by the inclusion of carefully selected "representative" regions. Even so once the experimenter strays from the test area the training set usually has to be changed.

Among the feature selection methods used are principal component analysis, divergence and minimax pairwise linear discriminants. All agree that 4 to 6 channels give as good results as 10 to 12. But the subset chosen depends on the application.

Michigan and Purdue seem to agree that quadratic decision boundaries derived from the maximum likelihood ratio based on Gaussian assumptions is a good method of classification. The decision rule is to choose the class which exhibits the largest value $g(x)$.

$g(x) = (x-M_i)TK_i-1(x-M_i) + C_i$

x is a m/s measurement vector

$M_i$ the class mean vector from the training set

$K_i-1$ the class covariance matrix

$C_i$ a constant related to the a priori probability of classi

This can be computed in .3ms for a 6 - Dimensional sample of eight classes using table lookup and sequential search.

An improvement results if the individual vectors are replaced by the average for the field and a per field classification done (A6). The delineation of a vector as belonging to a particular field usually requires a clustering algorithm.

Efforts are under way to perform the classification on the basis of field boundaries, but linking up boundary segments to give a topological configuration is not easy (A4).

Recognition results range from 90% for a single crop picked out from the background (A88) down to 65% for 4 classes across a flight line (A63), to 30% on crops with training and test samples selected from different fields (A70). But on the four class problem mentioned almost half the samples were of soybeans hence one would expect an 'a priori' recognition of 50% without multispectral analysis.

The experiments are based on samples ranging from 59 samples (A193) to 50,000 samples (1% of the frame) of Apollo S065 photography (A 127,5,6). With usually about 3% of the sample for the training set.

The largest series of experiments to date were the summer 1971 corn blight surveys flown for processing by Michigan and Purdue. No results have come to light yet.

Terrain classification

In the absence of the simple one crop field structure the entering of ground truth to the classification programs becomes very difficult. Instead classification maps have been produced which when compared with maps of the area showed 'promising' results. A soils classification in Indiana showed difficulties in attempting to extend the classification to samples located 4 Km from the training set (A114,200). It is here that one finds the greatest use made of ground targets for spectral calibration (A52).

Shape detection

The major methodological difference between shape detection and crop discrimination lies in the relative scarcity of shapes to be detected compared with the classification of every point in crop detection. In one experiment (A44) each pattern was characterized by the output of a property filter consisting of intuitive measurements or statistical features. Eight different methods were then tried in the classification of unknown features (forced adaptive learning, "error correction", Madaline, piecewise-linear, mean square error, "iterative designs", Bayes weights and direct estimation). None come out superior.

A good description of the application of Golay rotation - invariant hexagonal - neighbourhood logic to the 500 x 500 arrays is given in (A 108).

A 70% classification rate was achieved for 54 scenes of ⅛" x ⅛" on 1:20,000 photography classified on the basis of the statistical dependence of grey levels in adjoining picture elements (A204).

A study by Simontt and Brooner (A500) in examining the feasibility of discriminating agricultural crop types with colour IR photography taken in late July over north east Kansas gave the following results. A Bayesian predict on 1218 points (the points being densitometric readings from red green and blue filter) for classifying 11 crop types the probability of correct classification was 0.17. Using four crop-group categories the probability was .36. The conclusion was drawn that using only density information July was not a good time for using colour IR to discriminate crop types.

Brunnshweiler (1957)(A501) found that on 1:12,000 photography in Switzerland Steiner (1969)(A502) obtained 90% accuracy when using the 3 best dates of photography together using linear discriminant analysis.

Pettinger (A503) relying exclusively on colour with colour IR photographs found that there were unique times when selected crops could be identified unambiguously from a collection of ambiguous crops which had considerable overlap. But individual crops had no unique spectral signature.

# APPENDIX 6

## Digital Image Processing

Uses of image processing

### A. Intensity manipulation

Optical systems generally have a spatially non-uniform response to light caused by vignetting etc., Calibration curves for this can easily be obtained and a correction applied to each picture element in turn.

Colour balance can be shifted by computer manipulation. Pictures photographed through two filters can be digitised and the digital values transferred by nonlinear table look up to the log - exposure domain. Subtraction of one from the other produces a picture whose value is a measure of hue. This picture can then be stretched and clipped in various ways to enhance any feature.

The average grey scale distribution of a large number of pictures from a given system should be uniform (A 156). If it is not this gives an average correction to be applied to each picture.

If the picture contains a ground reflectance colour panel of known spectral characteristics a correction can be applied to each picture element.

### B. Geometric Manipulation

These processes affect the position rather than the magnitude of the grey scale values.

A linear transform, pure rotation or pure translation, can be specified by the original and final location of 3 non colinear points. It is only necessary to perform the transform computations on a small segment of the picture, the rest of the picture is transformed by table lookup.

A projective transform requires 4 pairs of points and computations have to be performed for all the points.

Properties of the system itself such as barrel distortion, film shrinkage or optical observations are best characterised by their effect on a calibration grid before use in the photographic run, or on fiducial marks on the camera optics. The actual correction can be incorporated with the generation of standard projections such as Mercotor. For a visual use the points can be left in their original position and a grid, say latitude and longitude, superimposed over them by reference to a few known points.

Spatial Frequency

When a picture is digitised the high spatial response of the system is limited within the passband defined by the Nyquist sample spacing, resulting in a loss of high frequency detail.

The amount of this loss may be measured in the x and y directions by photographing a suitable test chart, the two dimensional inverse of the rolloff curve is produced and Fourier-transformed. This filter is then applied by convolution to the picture resulting in a restoration of high frequency detail.

Removal of glare can be achieved by removal of the low frequency components. Complete removal of the low frequency components results in a picture of fine detail and edges only.

Motion blur can be removed by the convolution of the picture with a rectangular pulse corresponding to the length of the exposure.

The desired filtering may be performed directly in the space domain as a local operation (A179,10,11,156) by convolution with the fast Fourier transform (A80,50,2,186).

d) Parallax Measurements

Some results have been obtained using the assumption that the difference in the grey levels of corresponding trial pairs of points in the two pictures is a zero-mean Gaussian process and the departure of the displacement function from its average value over a small region is also of the same form. In this formulation the grey level difference distribution is conditional upon the parallax, for which the Gaussian continuity condition gives the 'a priori' distribution, Bayes' rule may be invoked to estimate the 'a posteriori' dependence of parallax on the picture distribution.

e) Resolution

The spacing of the picture elements in a scanned system must satisfy the Nyquist criteria of having at least two samples per cycle of the highest frequency at which there is picture information. But one standard magnetic tape of 2400 ft. length recorded at 800 samples per inch formatted to contain one line per digital record will hold a picture of about 4000 x 4000 picture elements.

f) Quantizing Accuracy

A given picture element will be converted to digital form by quantizing in terms of equal increments of film transmittance. The limiting factor in image processing especially at high frequencies is noise. In the presence of nlise the signal plus noise is assigned a digital level, to keep this error low the rms noise should be about ½ one digital step. Sources of noise include film scanning, light fluctuations, detecting system and A/D converter.

Transform picture coding

Transform coding is used to firstly convert a picture into a computer processable form and secondly to use as few computer words as possible to describe the picture.

First the picture is digitised into as few bits as possible needed to describe the original picture without loss of subjective image quality. This can be done by one of the methods below.

1) Pulse code modulation (PCM)

Consider an image that has been digitised into an array of N x N picture elements each quantized into $2^k$ levels. Any such array can be encoded by a sequence of $N^2$k bit words. This requires $kN^2$ bits per picture to code any of the possible $2^{kN^2}$ pictures.

For example in a picture of 256 x 256 elements with 8 bits per element there are about $10^{158000}$ possible pictures, each of which could be assigned a unique code. Suppose the picture is broken up into very much smaller sub-pictures and then use a code book look up for each sub-picture. Even for a sub-picture of size 4 x 4 with $2^8$ levels needs about $10^{40}$ code words. The present maximum storage capability of any computer is $10^{12}$ words.

2) Run length probability code.

A run is a sequence of scanning values of equal amplitude. The run length is the number of values in a run. Three code words are needed to encode a run. The first gives the scanning value, the second whether or not a run is taking place, the third the run length. It is only worth encoding runs of more than three identical words. The reduction factor is at most 1.2.

3) Differential pulse code modulation

Record an absolute level using the maximum number of bits then record the differences of subsequent levels from the initial level using fewer bits. Reductions of 1.5 to 2.5 bits per picture element are possible.

Transform coding:-

Two operations are performed. First a linear transform transforms the set of statistically dependent picture elements into a "more independent" set of coefficients. Second these coefficients are individually quantised and coded. As before it is more efficient to work in terms of sub-pictures. There are three linear transforms (A508):-

i) Hotelling transform.

The transform matrix that produces uncorrelated coefficients can be computed from the covariance matrix of the picture elements. This results in a set of $n^2$ coefficients, each of which is a linear combination of the $n^2$ picture elements. This requires $n^4$ computer operations.

ii) Fourier transform.

This is a Kroneckered matrix transform implementable by $2n^2\log_2 n^2$ complex multiplications.

$$A_{klij} = \frac{1}{n}\exp(-2\pi\sqrt{-1}(ki+lj)/N)$$

iii) Hadamard transform.

Again a Kroneckered matrix transform requiring the calculation of a normalising constant and $2n^2 \log_2 n^2$ additions.

$$A_{klij} = \frac{1}{n}(-1)^{b(klij)}$$

$$b(lkij) = \sum_{h=o}^{\log, n-1} (b_h(k)b_h(l)+b_h(i)b_h(j))$$

In terms of subjective quality the best transform is the Hotelling, then the Fourier and Hadamard all separated by .1 or .2 bits per element. In each case it is only necessary to code the first m coefficients that give a picture adequate for the needs.

LANDSAT digital data processing

The LANDSAT satellite orbits at 469nm carrying three return beam vidicon (RBV) cameras and four or five channel multispectral scanner (MSS). The characteristics of these are given below:-

| RBV band | Band width (micron) | Ground resolution | Image area |
|---|---|---|---|
| 1 | 0.48-0.575 | | |
| 2 | 0.58-0.68 | 150-270ft. | 100x100nm |
| 3 | 0.69-0.83 | | |
| MSS band | | | |
| 1 | 0.5-0.6 | | |
| 2 | 0.6-0.7 | 230ft. | |
| 3 | 0.7-0.8 | | 100nm swath |
| 4 | 0.8-1.1 | | |
| 5(ERTS B) | 10.4-12.6 | 700ft. | |

The data stream is transmitted to ground and recorded on 28 track tape along with telemetry signals. These are then converted to annotated 70mn photographic images. All data will be thus treated within 18 days of acquisition to coincide with the 18 day repeat photographic cover. The data processing network has been designed to handle 316 image sets per week. One image set contains three RBV and four MSS-RBV equivalent image frames. 5% of the images will be precision processed to remove radiometric and geometric distortions, and a further 5% will be converted into computer readable digital tapes producing 713 tapes per week.

# APPENDIX 7

## Creation of Image Files

Four images from one multispectral frame were used for test purposes. The images were taken in broad bands of blue, green, red and infra red. The size of each image was approximately 95 mm. square. They were digitised at 200$\mu$ intervals with a 200$\mu$ circular aperture. To ensure total coverage of the frames each was covered by 500 lines containing 500 pixels.

The digitisation was done on a Joyce Loebl drum scanner (Scandig) and the data stored on 9 track magnetic tape as 8 bit binary words representing a grey level in the range 0 to 255. Each tape record was 1024 words long and contained one scan line, thus half the record was empty in this case.

This 9 track tape was then converted to 7 track tape compatible with the DEC TU10 magnetic tape system. The DEC system requires tape records of 256 words, so each scan line was written into two new records and two records containing nothing were [illegible] This tape is still binary and, therefore, not directly useable by the system.

Using a program developed called CRPACK this tape is converted to decimal and stored in a direct access file on disk. Each record of the disk file corresponds to one complete scan line of the original image. A further problem came to light during testing of the program CRPACK. This was the fact that the four low and high order bits of the word had become reversed somewhere along the line. The program CRPACK also had to reverse the bits of each word before conversion to decimal.

Use of CRPACK

Using the standard file dumping program FILDMP V9 in the DEC system a portion of the tape is dumped to a file on disk in octal.

Running the program CRPACK each octal word is picked out of the dump. Its 4 low and high order bits are reversed and the new number converted to decimal. One complete image line is constructed from two dumped blocks and then put away as one record in a direct access file.

CRPACK also gives the option of reducing the image size by averaging a number of pixels. The image points finally arrived at can be a 1 to 1 mapping or an average of 2 x 2 or 4 x 4 pixels.

By referring to figure A1 the operation can be explained. Using PIP create a disk file to store the image. The file created here will be 63 contiguous blocks in size (1 block = 256 words). This will hold an image 125 lines by 128 pixels. This image is a 4 x 4 average of the 500 x 500 complete image.

Using FILDV9 310 (octal) blocks are dumped as octal values to a sequential file called TRANS.DAT. In the program CRPACK the image is always put in disk file #1 so IRED ONE has to be given the logic number 1.

for TRANS.DAT.

The program can now be run; it will ask for six values to be input as integer free format. File is the image file, line is the record number to start writing into. Block is the number of blocks dumped in decimal. 200 blocks equals 100 lines which are reduced to 25 on averaging. IR, IC are for a define file statement; they give the number of records and number of words per record. INV is the averaging factor.

On completion TRANS.DAT can be deleted and more blocks dumped. These will be put in IRED.ONE starting at record (image line) number 26 and so repeating the process until the file is built.

Figure A1 Creation of image files.

```
$ R  PIP
# IRED.ONE/AL:250

$ R FILDV9
# TRANS.DAT<MTØ:  /BL:1:310
$AS IRED.ONE,1
$AS TRANS.DAT,2
$RU CRPACK
INPUT    FILE, LINE, BLOCK,  IR,  IC,  IAV
           1,    1,    200,   125, 128,  4

$R  PIP
# TRANS.DAT/DE
$R FILDV9
#  TRANS.DAT<MTØ:  /BL:1:310
$AS IRED.ONE, 1
$AS TRANS.DAT, 2
$RU CRPACK
INPUT FILE, LINE, BLOCK,  IR,  IC, IAV,
        1,   26,   200,   125, 128, 4,

$R  PIP
# TRANS.DAT/DE
        etc.,
```

Program Summary

| | |
|---|---|
| Title | CRPACK |
| Storage | CRPACK.FTN<br>CRPACK.LDA |
| Length | 209 lines |
| Structure | main section interactive<br>subroutine PACK (FILE,LINE,BLOCK,IAV) |
| Problem | to convert a sequential binary image file to a random access decimal integer image file. |
| Solution | a program that operates on an octal tape dump and constructs an image file. |
| Limitations | highly specific to system and version 9 of DEC FILDMP. Can only convert the image original size or reduced by 2 x 2 or 4 x 4 average of pixels. Reverses the bytes of the binary word. |

## Program Details

The program was developed to perform the following to convert to a readable form:

1) Pick the octal numbers from a tape dump
2) Reverse the bytes
3) Convert the number to decimal
4) Reduce the image size
5) Re-pack into a direct access file

A short interactive section asks for the following

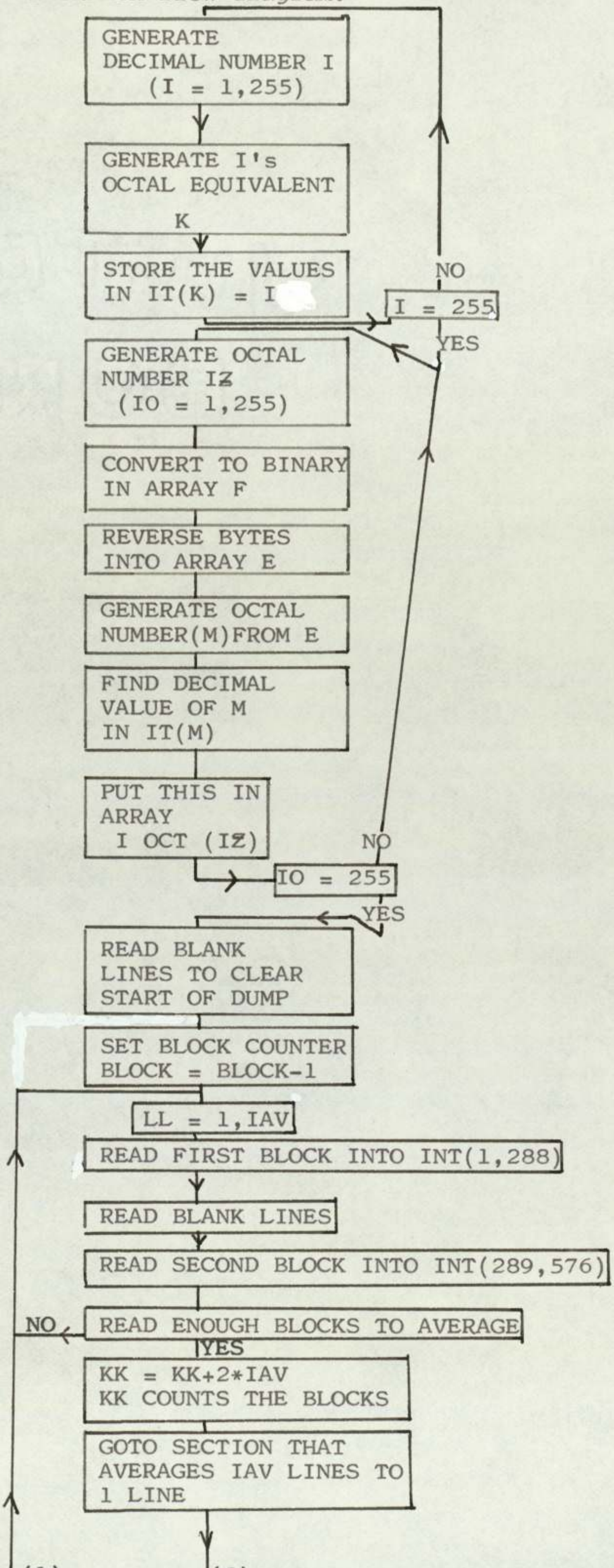
| | |
|---|---|
| FILE | the number of the image file |
| LINE | the record number (= image line) to start writing the lines into the image file |
| BLOCK | the number of blocks in the tape dump |
| IR | the number of records in the image file |
| IC | the number of words in the image file |
| IAV | the averaging factor<br>1 for no averaging<br>2 for 2 x 2 averaging<br>4 for 4 x 4 averaging |

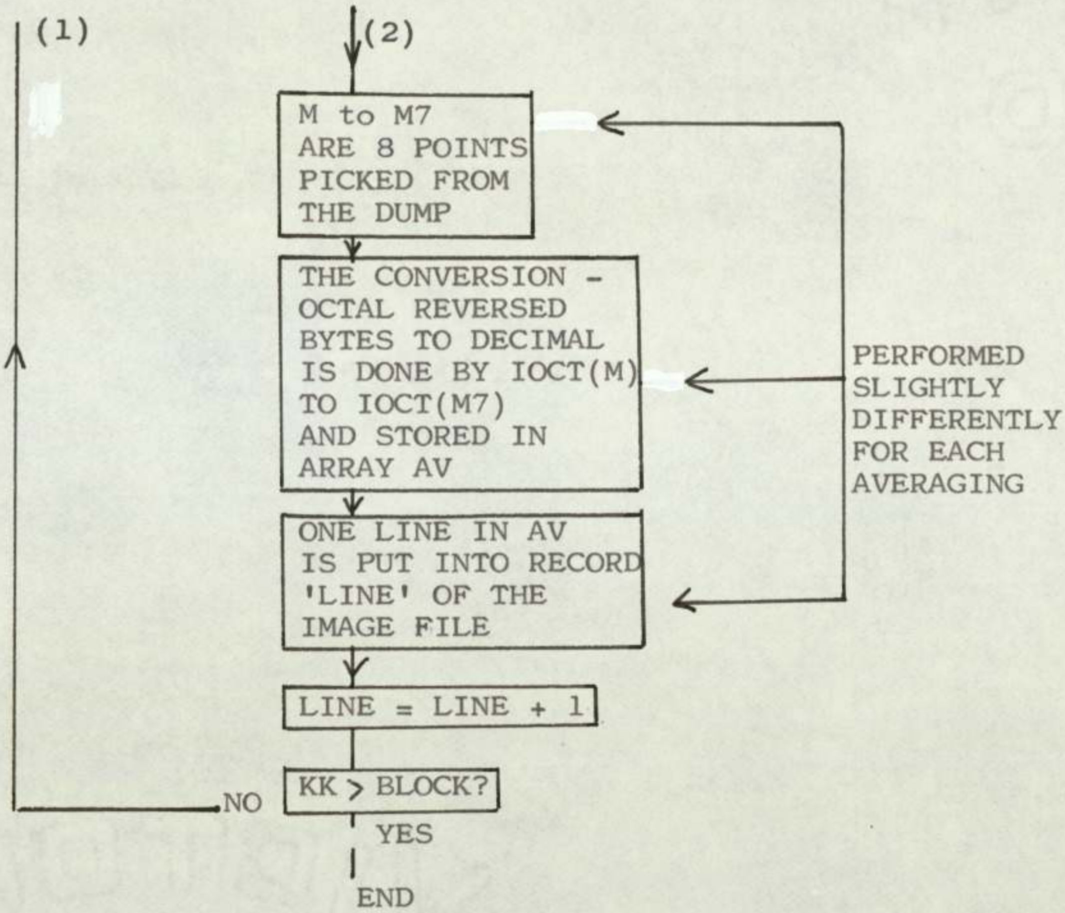
A call to a subroutine PACK (FILE,LINE,BLOCK,IAV) then operates the main part of the program.

The operation of the program is best understood by reading the flow diagram.

The aim of the first part of the program is to build an array IOCT for use in converting octal to decimal with byte reversal. For example, the octal number 277 in the dump has its byte reversal decimal value stored in array location IOCT(277). The octal dump is then unpicked and its octal numbers converted, averaged if needed and packed away in one direct access image line.

Figure A2 CRPACK flow diagram.




(1)
(2)
M to M7 ARE 8 POINTS PICKED FROM THE DUMP
THE CONVERSION - OCTAL REVERSED BYTES TO DECIMAL IS DONE BY IOCT(M) TO IOCT(M7) AND STORED IN ARRAY AV
ONE LINE IN AV IS PUT INTO RECORD 'LINE' OF THE IMAGE FILE
LINE = LINE + 1
KK > BLOCK?
NO
YES
END
PERFORMED SLIGHTLY DIFFERENTLY FOR EACH AVERAGING

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Appendix 8

As an example of the use of the system a sample run will be explained.

An image file was created containing a portion of a digitised image from an infra-red band of multispectral imagery. The file FINE.FOR contained lines 250 to 299; pixels 1 to 500 of the original image. These become lines 1 to 50 of the data file. Two temporary files EMPTY.TWO, EMPTY.TRE were created, these had room for 50 lines of 512 pixels.

The printout dialogue produced at the operator console is included in the following pages. This shows the sequence of commands required to carry out a number of operations on the basic image.

Initially selections 1, 2, 3 are chosen from the INPUT SELECTION LIST; after this only selection 3 generally needs be chosen to pick the desired option.

First the basic image was histogrammed to observe the distribution of grey tones, the image was then printed to line printer for visual guidance when further processing, and edge operators were applied, first with value 100 then 150 units of grey level.

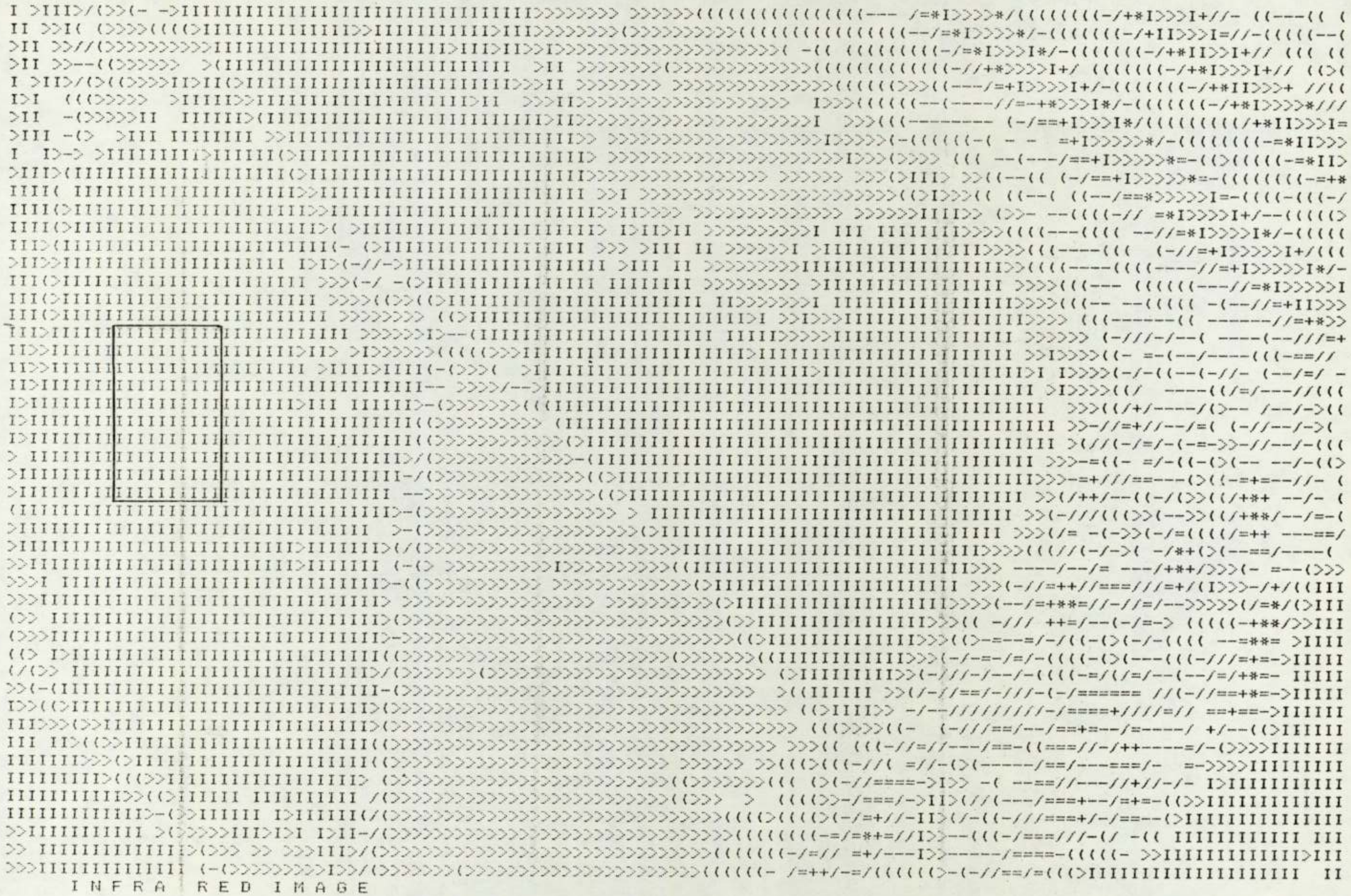
Using the small area shown on first print out map, all areas similar to this were then detected and printed out, and the boundaries were constructed around these areas.

Finally two different types of detail filter were tried but as can be seen from the print outs these do not show much unless selective grey level ranges are printed out - as in the final image.

```
H I S T O G R A M   P L O T


 FILE NUMBER      1


RECORDS      1 TO     50


PICTURE ELEMENTS     100 TO    249

LOWER BOUND      0. 00000UPPER BOUND    256. 00000

INTERVAL    8. 00000
   0
  10
  45*
  77**
 409***********
 451************
   0
   0
1228***********************************
1775**************************************************
  44*
  70*
 190*****
 199*****
   0
   0
   0
   3
  37*
  81**
 362**********
 303********
   0
 129***
 869************************
 804**********************
  94**
 112***
 112***
  96**
   0
   0
     I N F R A   R E D   I M A G E
```

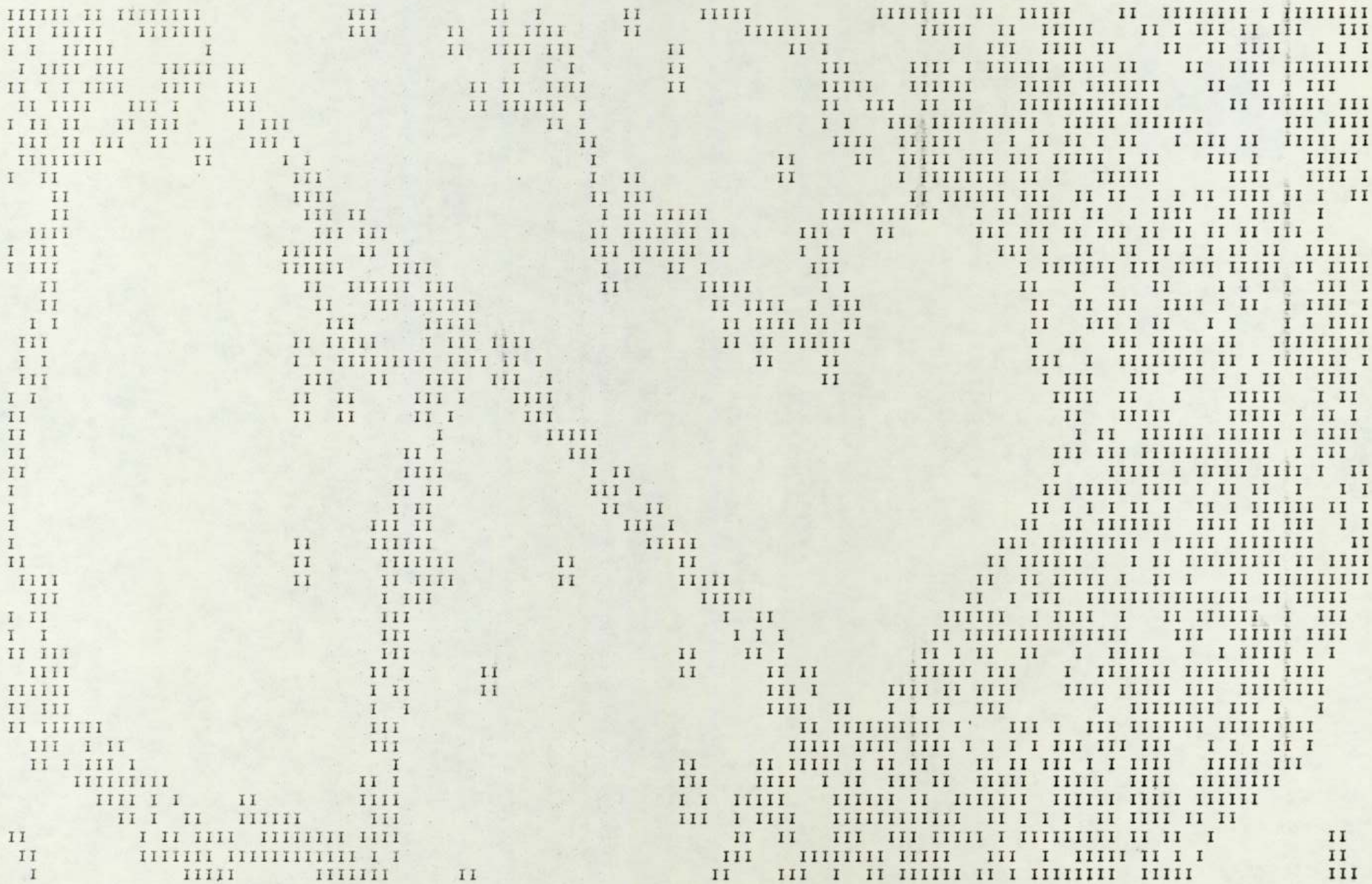
```
S Y M B O L   T A B L E
   0. OTO      32. 00 +
  32. OTO      64. 00 (
  64. OTO      96. 00 I
  96. OTO     128. 00 /
 128. OTO     160. 00 *
 160. OTO     192. 00 -
 192. OTO     224. 00 >
 224. OTO     256. 00 =


FILE NUMBER        1


RECORDS      2 TO     50


PICTURE ELEMENTS     100TO    224
```

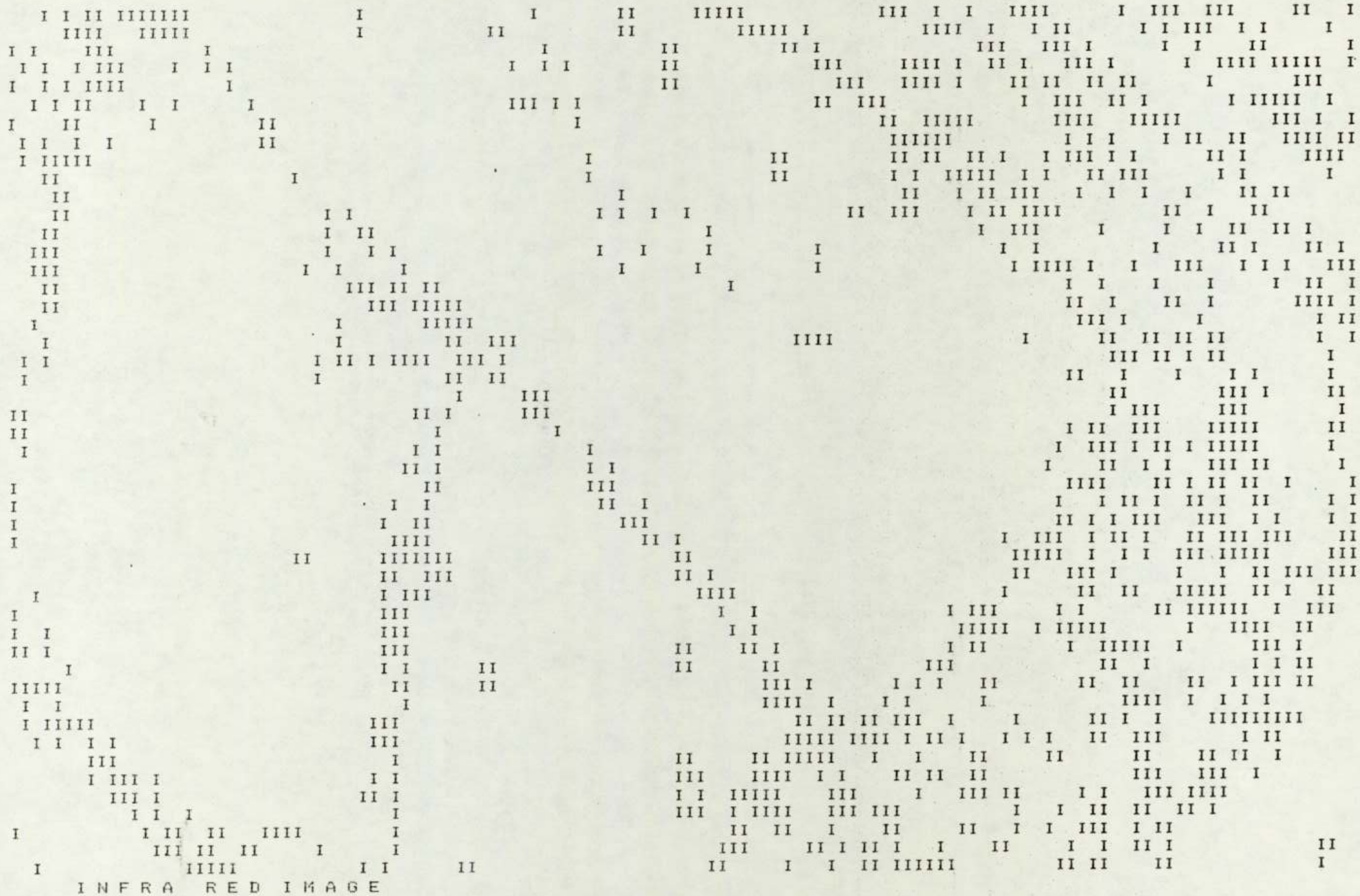
Plot1= Histogram Plot




Plot 2 Symbol Map of the Area

Plot 3 Edge Size 100





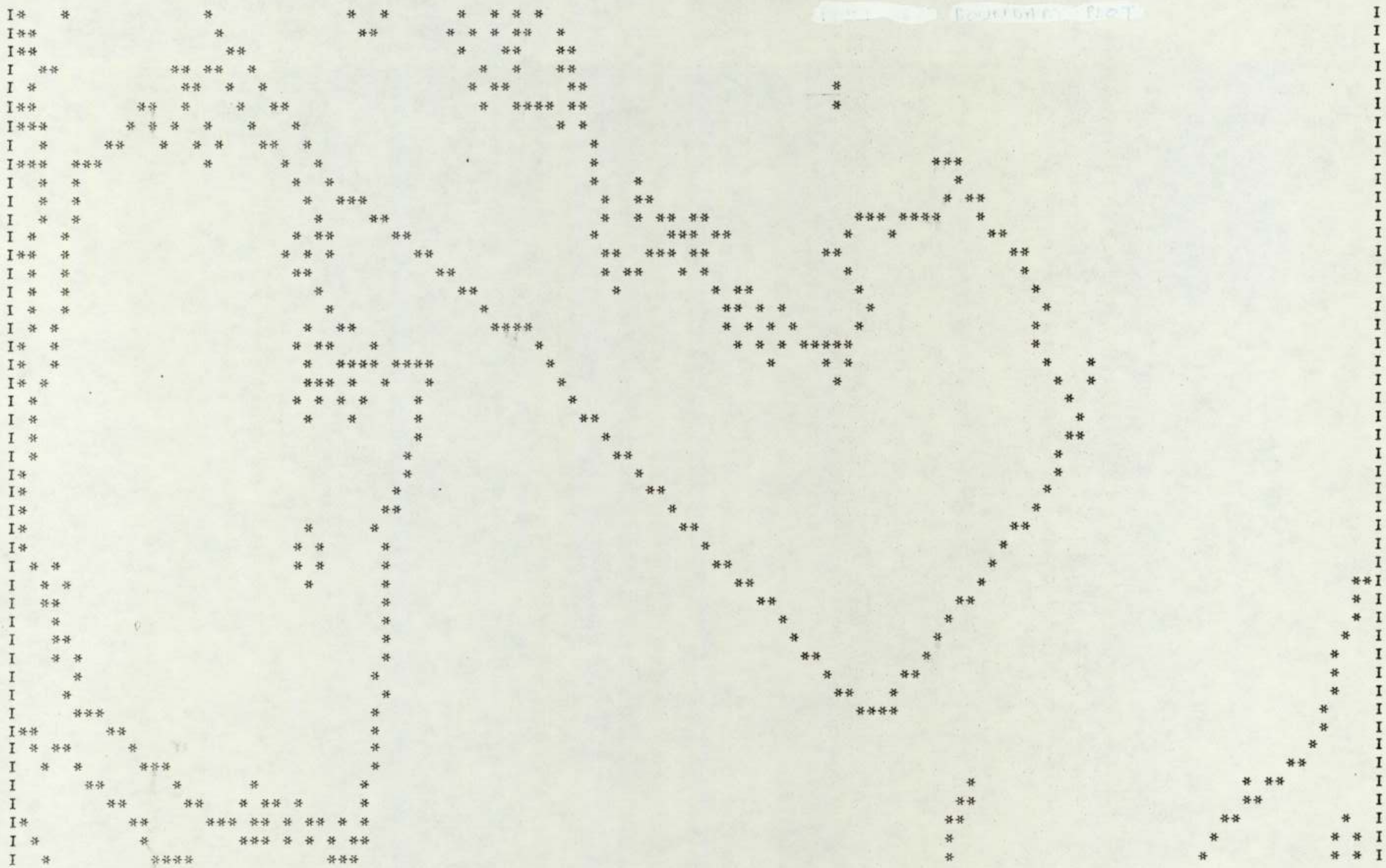

Plot 4 Edge Size 150

Plot 5 Area Detection

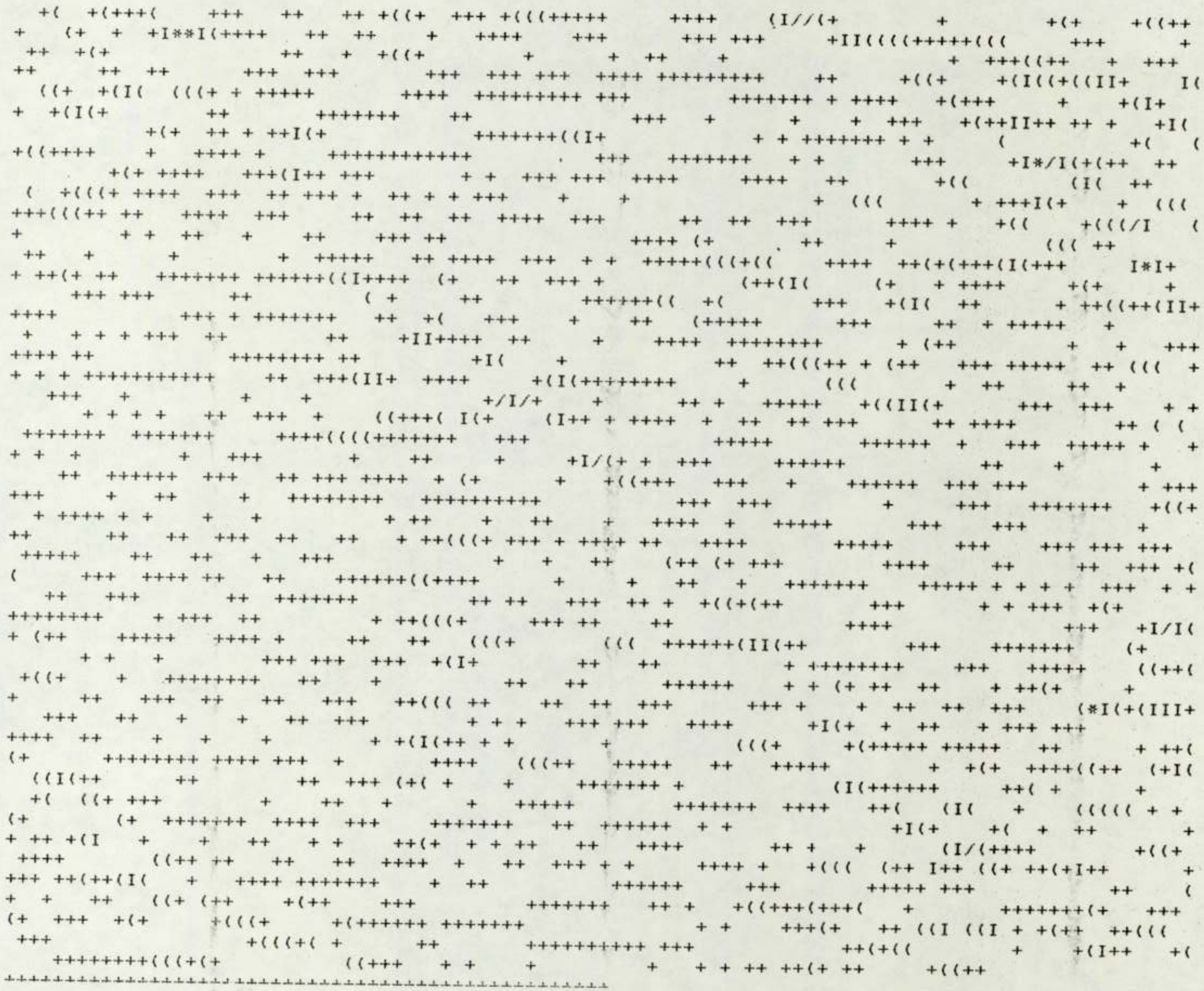
Sample Area was

LINES 20 TO 29

PIXELS 110TO 119



Plot 6 Boundary Plot



SYMBOL TABLE

| | |
|---|---|
| 0.0TO 32.00 | + |
| 32.0TO 64.00 | ( |
| 64.0TO 96.00 | I |
| 96.0TO 128.00 | / |
| 128.0TO 160.00 | * |
| 160.0TO 192.00 | - |
| 192.0TO 224.00 | > |
| 224.0TO 256.00 | = |

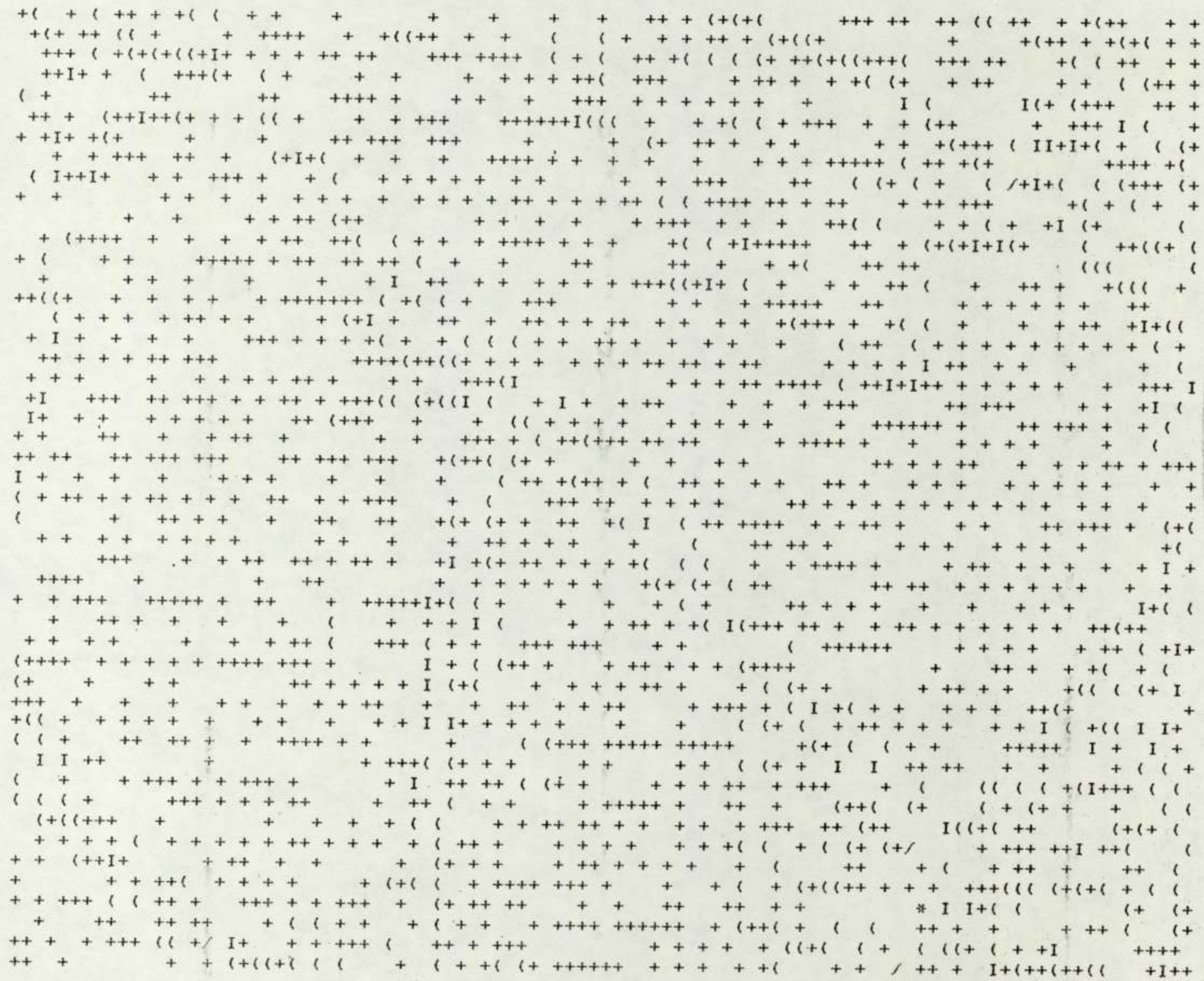
FILE NUMBER 2 FINE.FOR

RECORDS 2 TO 50

PICTURE ELEMENTS 100TO 199

FILTER 1

Plot 7 Filtered Image



SYMBOL TABLE

| | |
|---|---|
| 0. OTO | 32. 00 + |
| 32. OTO | 64. 00 ( |
| 64. OTO | 96. 00 I |
| 96. OTO | 128. 00 / |
| 128. OTO | 160. 00 * |
| 160. OTO | 192. 00 - |
| 192. OTO | 224. 00 > |
| 224. OTO | 256. 00 = |

FILE NUMBER 3

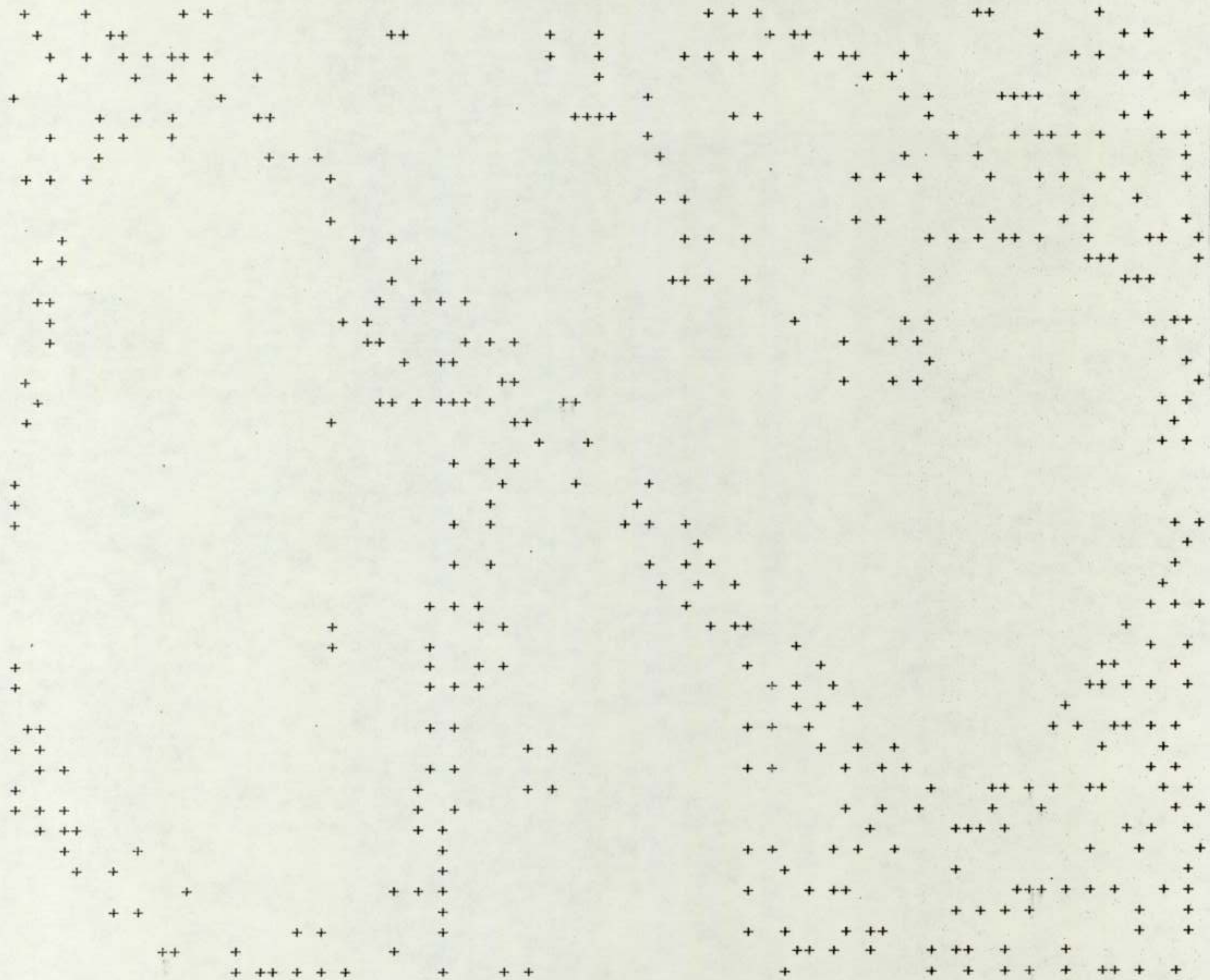
RECORDS 2 TO 50

PICTURE ELEMENTS 100TO 199

Filter 6

Fine for

Plot 8 Filtered Image



SYMBOL TABLE
30. 0TO 96. 00 +

FILE NUMBER 3

RECORDS 2 TO 50

PICTURE ELEMENTS 100TO 199

FILTER 6 INFRA RED FINE.FOR

Plot 9 Selected Part of Plot 8

```
$RU MSTR

***** ALL INPUT IS INTEGER FREE FORMAT UNLESS *****
***** INDICATED BY F AS F FREE FORMAT OR Y,N  *****
***** FOR YES, NO ANSWERS                     *****
***** ALL NUMBERS MUST END WITH A COMMA       *****

 I N P U T   S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
1,2,3,

DO YOU WANT TO CLOSE A FILE  Y OR N
N

PLEASE ASSIGN IMAGE FILES TO AVAILABLE LOGIC NUMBERS
TYPE CO TO RETURN TO PROGRAM

A005 000000
$AS FINE.FOR,1
$AS EMPTY.TWO,2
$AS EMPTY.TRE,3
$CO

HOW MANY FILES TO ASSIGN
3,

FILE NUMBER  ***
1,

SIZE OF FILE ON DISK

#RECORDS ***, #SAMPLES PER RECORD  ***
50,512,

FILE NUMBER  ***
2,

SIZE OF FILE ON DISK

#RECORDS ***, #SAMPLES PER RECORD  ***
50,512,

FILE NUMBER  ***
3,

SIZE OF FILE ON DISK

#RECORDS ***, #SAMPLES PER RECORD  ***
50,512,

DEFINE THE AREA TO BE OPERATED ON
RECORD START **, #RECORDS **  SAMPLE START ** #SAMPLES **
1,50,100,150,
```

```
WHICH OPTION DO YOU WANT?

 1 HISTOGRAM

 2 EDGE DETECTION

 3 SYMBOL MAP

 4 BOUNDARY FINDING

 5 SPECTRAL PLOT

 6 CLUSTER ANALYSIS

 7 IMAGE HANDLING

 8 IMAGE QUANTISING

 9 FREQUENCY DISTRIBUTIONS

10 IMAGE SMOOTHING

11 FILTERING

12 HOMOGENEITY IMAGE

13 NEWONE
14 NEWTWO
1,

SYSTEM TIME    11:35:10

OPTION CHOSEN
HISTOGRAM
LOWER AND UPPER BOUNDS OF DATA  F FORMAT
0.0,256.0,

NUMBER OF INTERVALS  ****
32,

INPUT IMAGE IN FILE
1,

SCALE
50,

A002 046600
$CO   Plot 1 is produced now

SYSTEM TIME    11:36:46

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
W

INPUT UPTO 80 CHARACTERS FROM UNIT 6
      I N F R A   R E D   I M A G E

WHICH FILE DO YOU WANT TO WRITE INTO
2,
```

```
SYSTEM TIME   11:37:39

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
R

WHICH FILE HEADER DO YOU WANT TO READ
2,

SYSTEM TIME   11:37:52

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION

 I N P U T   S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
2,3,

DEFINE THE AREA TO BE OPERATED ON
RECORD START **, #RECORDS **  SAMPLE START ** #SAMPLES **
2,49,100,125,
```

(change the working area to fit the plots on one sheet of paper)

```
WHICH OPTION DO YOU WANT?

1 HISTOGRAM

2 EDGE DETECTION

3 SYMBOL MAP

4 BOUNDARY FINDING

5 SPECTRAL PLOT

6 CLUSTER ANALYSIS

7 IMAGE HANDLING

8 IMAGE QUANTISING

9 FREQUENCY DISTRIBUTIONS

10 IMAGE SMOOTHING

11 FILTERING

12 HOMOGENEITY IMAGE

13 NEWONE
14 NEWTWO
3,
```

```
OPTION CHOSEN
SYMBOL MAP
SYMBOL TABLE?  Y OR N
Y

NUMBER OF SYMBOLS MAX 9
8,

VARIABLE LEVELS?  Y OR N
N

RANGE OF NUMBERS R1  R2      F    FORMAT
0.0,256.0,

INPUT IMAGE IN FILE
1,
```

Plot 2 is produced now.

```
SYSTEM TIME   11:49:53

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
R

WHICH FILE HEADER DO YOU WANT TO READ
2,

SYSTEM TIME   11:53:41

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION

 I N P U T  S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
3,

WHICH OPTION DO YOU WANT?

1 HISTOGRAM

2 EDGE DETECTION

3 SYMBOL MAP

4 BOUNDARY FINDING

5 SPECTRAL PLOT

6 CLUSTER ANALYSIS
```

```
7 IMAGE HANDLING

8 IMAGE QUANTISING

9 FREQUENCY DISTRIBUTIONS

10 IMAGE SMOOTHING

11 FILTERING

12 HOMOGENEITY IMAGE

13 NEWONE
14 NEWTWO
2,

SYSTEM TIME   11:54:21

OPTION CHOSEN
EDGE DETECTION
EDGE SIZE F FORMAT
100.0,

INPUT IMAGE IN FILE
1,
Plot 3 is produced now
DO YOU WANT TO TRY AGAIN Y OR N
Y

EDGE DETECTION
EDGE SIZE F FORMAT
150.0,

INPUT IMAGE IN FILE
1,
Plot 4 is produced now
DO YOU WANT TO TRY AGAIN Y OR N
N

SYSTEM TIME   12:00:27

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
R

WHICH FILE HEADER DO YOU WANT TO READ
2,

SYSTEM TIME   12:00:49

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION

 I N P U T  S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
```

```
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
3,

WHICH OPTION DO YOU WANT?

1 HISTOGRAM

2 EDGE DETECTION

3 SYMBOL MAP

4 BOUNDARY FINDING

5 SPECTRAL PLOT

6 CLUSTER ANALYSIS

7 IMAGE HANDLING

8 IMAGE QUANTISING

9 FREQUENCY DISTRIBUTIONS

10 IMAGE SMOOTHING

11 FILTERING

12 HOMOGENEITY IMAGE

13 NEWONE
14 NEWTWO
4,

SYSTEM TIME   12:01:26
```

```
OPTION CHOSEN
BOUNDARY FINDING
SAMPLE AREA

START AT LINE **, START AT PIXEL **,   #LINES **,   #PIXELS **
20,110,10,10,

SCAN AREA

START AT LINE **, START AT PIXEL **,   #LINES **,   #PIXELS **
2,100,49,100,

INPUT FILE **, SCRATCH FILE **
1,2,

DO YOU WANT THE TOTAL AREA PRINTED  Y OR N
Y
```

(Plot 5 shows all areas in the scan area similar to the sample area)

```
DO YOU WANT THE BOUNDARY PRINTED  Y OR N
Y
```

(Plot 6 shows the boundaries around the areas of Plot 8)

```
SYSTEM TIME   12:09:17

TYPE R    IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
R

WHICH FILE HEADER DO YOU WANT TO READ
2,

SYSTEM TIME   12:09:45

TYPE R    IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION

 I N P U T   S E L E C T I O N
```

```
1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
3,

WHICH OPTION DO YOU WANT?

1 HISTOGRAM

2 EDGE DETECTION

3 SYMBOL MAP

4 BOUNDARY FINDING

5 SPECTRAL PLOT

6 CLUSTER ANALYSIS

7 IMAGE HANDLING

8 IMAGE QUANTISING

9 FREQUENCY DISTRIBUTIONS

10 IMAGE SMOOTHING

11 FILTERING

12 HOMOGENEITY IMAGE

13 NEWONE
14 NEWTWO
11,

SYSTEM TIME   12:10:56

OPTION CHOSEN
FILTER

INPUT IMAGE IN FILE ****, OUTPUT TO FILE ****
1,2,

THE FILTERS ARE NUMBERED FROM 1 TO 11
WHICH ONE DOYOU WANT  ***
1,
 (Generate a filtered image into File 2)
DO YOU WANT TO TRY ANOTHER FILTER  Y OR N
Y,

INPUT IMAGE IN FILE ****, OUTPUT TO FILE ****
1,3,
Same input image  different filter  result in file 3
THE FILTERS ARE NUMBERED FROM 1 TO 11
WHICH ONE DOYOU WANT  ***
6,

DO YOU WANT TO TRY ANOTHER FILTER  Y OR N
N

SYSTEM TIME   12:13:25

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W   TOWRITE A HEADER
CR FOR NO ACTION

 I N P U T   S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT
```

```
TYPE IN UPTO THREE SELECTIONS
3,

WHICH OPTION DO YOU WANT?

1 HISTOGRAM

2 EDGE DETECTION

3 SYMBOL MAP

4 BOUNDARY FINDING

5 SPECTRAL PLOT

6 CLUSTER ANALYSIS

7 IMAGE HANDLING

8 IMAGE QUANTISING

9 FREQUENCY DISTRIBUTIONS

10 IMAGE SMOOTHING

11 FILTERING

12 HOMOGENEITY IMAGE

13 NEWONE
14 NEWTWO
3,

SYSTEM TIME   12:16:45

OPTION CHOSEN
SYMBOL MAP
SYMBOL TABLE?  Y OR N
Y

NUMBER OF SYMBOLS MAX 9
8,

VARIABLE LEVELS?  Y OR N
N

RANGE OF NUMBERS R1  R2      F     FORMAT
0.0,256.0,

INPUT IMAGE IN FILE
2,
```

(Plot 7 the filtered image)

```
SYSTEM TIME   12:19:05

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION

 I N P U T  S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
```

No selection, maintain previous one

```
SYSTEM TIME   12:19:28

OPTION CHOSEN
SYMBOL MAP
SYMBOL TABLE?  Y OR N
Y

NUMBER OF SYMBOLS MAX 9
8,

VARIABLE LEVELS?  Y OR N
N

RANGE OF NUMBERS R1  R2      F    FORMAT
0.0,256.0,

INPUT IMAGE IN FILE
3,
```

Plot 8, second filtered image

```
SYSTEM TIME   12:21:37

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
\\

 I N P U T  S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
```

(Continue with same option)

```
SYSTEM TIME   12:22:47
```

```
OPTION CHOSEN
SYMBOL MAP
SYMBOL TABLE?  Y OR N
Y

NUMBER OF SYMBOLS MAX 9
1,

VARIABLE LEVELS?  Y OR N
N

RANGE OF NUMBERS R1  R2      F    FORMAT
30.0,96.0,

INPUT IMAGE IN FILE
3,
```

Plot 9, Selected part of Plot 8)

```
SYSTEM TIME   12:24:38

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
W

INPUT UPTO 80 CHARACTERS FROM UNIT 6
  F I L T E R   6  I N F R A   R E D

WHICH FILE DO YOU WANT TO WRITE INTO
2,

SYSTEM TIME   12:25:38

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION
R

WHICH FILE HEADER DO YOU WANT TO READ
2,

SYSTEM TIME   12:25:49

TYPE R   IF YOU WANT TO READ A HEADER
TYPE W  TOWRITE A HEADER
CR FOR NO ACTION

  I N P U T   S E L E C T I O N

1 CHANGE WORKFILE
2 CHANGE AREA ON FILE
3 CHANGE OPTION
0 NO CHANGE

 4 EXIT

TYPE IN UPTO THREE SELECTIONS
4,

$R LOGKEY
```

Paper 1

# AUTOMATIC DATA PROCESSING FOR NON-MATHEMATICIANS

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## ABSTRACT

This paper aims to explain in a non-mathematical way some aspects of automated data processing related to the analysis of multispectral scanner and photographic data.

Supervised and unsupervised analysis is described.

Supervised methods require the input of a training set to construct a classifier: this classifier is then used to classify the unknown data.

Unsupervised methods or cluster analysis organise the data into classes or groups: the identity of these groups then has to be established.

Parametric, non-parametric, adaptive and non-adaptive variations to the above two methods are described.

Finally the problem of image registration is discussed.

## INTRODUCTION

A typical non-scientific user may be faced with the question "Is it necessary to apply a ratio transform to the data?" when he has no idea what a ratio transform is or what its effect on the data will be. On the other hand if he gives his imagery to a hardware specialist can he be sure the output he receives has not, during processing, lost some of the information he requires. The question arises 'who should analyse the date?' should it be the user or the hardware man?

The hardware man is able to use the systems to its fullest potential, and in doing so he would anticipate that the user's need would be fulfilled. A system operated by a 'data handling amateur' (a category into which most users fall) is most unlikely to yield optimum or even acceptable results.

This paper is a first step in bridging the hardware man/user gap by explaining in a non-mathematical way some aspects of automated data processing related to the analysis of multispectral scanner and photographic data.

For the purposes of this paper automated analysis refers to computer processes that result in the production of a map type output by the computer, rather than an enhanced image to aid human interpretation.

Multispectral imagery can be collected by scanners or cameras. Scanners can collect images in up to 24 narrow wavelength regions or bands of the electromagnetic spectrum. Cameras collect, at most, images in nine bands. For a given sensor the images in all the bands are spatially identical.

The scanner records the image directly on to magnetic tape as a voltage level, the voltage depending on the brightness of the scene, and the data on this tape can be fed directly into a computer.

Photographic images first have to be digitised before they can be processed by a computer. Digitisation is the process of converting to a numerical value the photographic density of very small areas of the image. Typically a photograph may be digitised into a million bits.

The measurement from each band has to be assembled into an n-dimensional measurement vector. The n dimensions of the vector are the n density values or scanner voltage levels relating to the same image point in each band. This can be visualised in the 3 dimensional case shown in Fig. 1. The measurement vector consists of the density values from an identical image point in the red, green and blue bands of a multispectral photograph. This measurement vector is sometimes known as the density signature. If a correction is made to this vector so that it relates more directly to scene brightness it is known as a spectral signature. The corrections applied remove the effects of the instruments on the data. In scanner systems the images in each band are collected in register with each other. In photographic systems each band is imaged separately and to obtain the measurement vector each band has to be digitised separately then overlayed or registered with respect to each other. This is dealt with later on in the paper.

This measurement vector is used in a number of automated analysis routines to identify the contents of the image. These analysis routines fall into two categories: supervised and unsupervised.

**Supervised Methods**

Supervised methods are those methods that require continual operator intervention to control their running. To identify an unknown measurement vector it is input to a classifer which then classifies it as belonging to one of a class or group of objects defined in the classifier. The classification is based upon some decision rule constructed in the initial phases of the analysis.

Generally the measurement vector from one ground resolution element of a particular ground cover type will not be identical to another element from a different part of the same area. But the vectors from the same type of area tend to be nearly the same and form a cloud or cluster[10] of points as shown in Fig. 2. The construction of the pattern classifier involves dividing measurement space into decision regions[8, 12]. Each region being one of these clusters which represents a particular ground type or class. During the classification process unknown data points are tested to see into which decision region they fall: they are then assigned to the class associated with that region. To construct a pattern classifier, decision surfaces or decision areas have to be determined (Fig. 3). Then some decision rule has to be devised that can be used to decide into which decision area a sample should be classified.

The position and extent of these decision surfaces are found by using a set of samples known as the training set. The initial clusters constructed from the training set define the position and extent of the decision regions.

The training samples are measurement vectors taken from a collection of known areas which should contain all the classes to be identified. This use of a known set of samples at the beginning of the analysis is one of the main characteristics of supervised learning.

When the clusters have been established from the training set it is often easier to construct a classifier by defining the boundary separating the cluster. Unknown samples are then classed depending on which side of the boundary they lie. Mathematically this is called setting up the discriminant functions that are used to discriminate which decision area an unknown sample belongs to. These discriminant functions are the mathematical equations used to describe the decision surfaces.

However, the situation is not quite straight forward as that when handling remote sensing data, which requires a more statistical approach because

a) the data exhibit many incidental variations (noise) which tend to make the within class variation of the same magnitude as the between class variation.

b) there is some uncertainty concerning the true identity of the training classes, or their ability to be extrapolated to be representative over the entire area to be classified.

c) the clusters may overlap in measurement space causing difficulty in discriminating the boundary between them.

d) the data may not be assignable to any class.

However:

b) can be overcome using adaptive methods. These methods use the result of the classification to constantly modify the decision surface. Alternatively cluster analysis (see later) can be used to eliminate the need for training samples.

c) suggests an approach which leads to decision rules that identify one class as more likely than all the other possible classes.

d) suggests the need for a class to allocate all unidentifyable samples.

In most cases the form of the mathematical functions used are assumed to be known i.e. the equations are known. Only certain parameters or constants of the equations are calculated using the training set. Such methods are known as parametric methods.

Methods for which not even the form of the function is assumed are termed non parametric and are very difficult to implement. The general parametric assumptions used in remote sensing are that the data is multrivariate, normal and gaussian. This enables simple statistical methods to be used to set up the functions, and in fact the cluster distribution can be characterised by the mean and covariance matrices of the training samples.

Sometimes the classifier is described as a Bayes classifier. This means that the classifier is designed to minimise the average (expected) loss: where the loss is the missclassing of a measurement vector.

Using these techniques it is possible to arrive at a maximum likelihood decision rule[7]. This rule classifies a measurement vector as belonging to the decision area for which its probability of belonging is greater than its probability of belonging to any other decision area. With an additional proviso that this probability is greater than some threshold value to reject any sample not really belonging to the class. Such reject samples come from fences, roads and isolated buildings. The way this threshold is set is to put the training samples back through the classifier they have just been used to set up. The parameters of the classifiers can then be adjusted to reject say 5% of the samples, this usually ensures that most of the future samples that do not really belong to a given class are rejected.

### Unsupervised Classification

Unsupervised methods[2, 3, 8] start with the raw data, put it through a classifier and output the data as a map. The computer divides the image into a number of groups or homogeneous areas on the output map. A small area of the data can then be selected and compared to the ground truth data of the same area. The correspondence between the groups on the output and the ground truth data can be established. The rest of the output can then be classified according to the ground cover type each group represents.

As previously mentioned the measurement vectors from the same terrain type tend to form associations in measurement space termed clusters. The cluster from vegetation generally being formed in a different place to the cluster for water (Fig. 5). The clusters are built up point by point by the classifier. Each sample is tested to see if it lies close to or within a present cluster[6]. If it does it is amalgamated into the statistics describing that cluster and labelled as belonging to that cluster. If not it is either rejected or kept as the possible start for a new cluster. The compactness of clusters can be determined by statistics which measure the separation of clusters to their internal dispersion.

Two main methods of clustering are sequential clustering and K-means clustering. These work well if the clusters formed are reasonably spherical but if the clusters are stringy then a different approach is needed.

Sequential clustering is a one pass operation i.e. the data is read once only and assigned to a cluster or rejected. This has the disadvantage that samples passed over cannot be re-examined to see if they form another cluster. Each point is taken in sequence from the data set and examined only once. The operator can define a maximum number of clusters to be formed and if this number is exceeded some clusters are merged, or dropped if they contain an insignificant number of points.

In K-means clustering a number of arbitrary cluster centres are chosen by some means. The entire data set is then grouped around these centres using some statistical parameter, such as minimum Euclidean distance, to assign the data points to a particular centre. All the points associated with one centre are used to calculate the new centre of the group which is then used as the input to the next run and so on until the centre remains in about the same place between runs. Problems arise due to the arbitrary nature of the start points and choosing a fixed number of groups to force the data to fit.

Some clustering methods[2] combine both these methods. Sequential clustering is used to establish the initial clusters, however many there may be, then K-means is used to refine the clusters. In all cases however it is still often desirable to limit the number of clusters formed. Usually eliminating all the tiny clusters removes 5% of the points but reduces the number of clusters by 70%. This means that on the output map 5% of the points are blank but only say eight different groups exist instead of about 22.

### Adaptive/Non Adaptive Improvements

The parameters of likelihood ratio classifiers are fixed by calculating them from training sets. The classifier is then used by extrapolation or interpolation to identify samples over the entire area. Errors are introduced by the natural variability of the scene, the atmosphere, the sun and the sensor. Some approaches called non adaptive construct additive or multiplicative functions to fit the data to correct for these variations. These functions are functions of say, position in the flight line or spectral channel. They are also known as preprocessing[11] or signature extension[1] and are applied to the data before classification. The problem arises in choosing the function before processing starts that is likely to have the best effect on the data. A very common one used is the ratio transform. In this the ratio of the data in one band relative to the neighbouring band is taken and this ratio used in the processing.

The alternative method called adaption[4] starts off using the sets established during training and each time a sample is recognised as belonging to a class the parameters of the class are updated incorporating the recognised sample. This has the effect of causing the clusters to drift in space but preserve their shape.

Adaptive methods require less operator intervention, but it may still be desirable to use some standard non-adaptive transforms on the data to remove say sensor distortions. Once this is done other distortions can be removed by trial and error application of non-adaptive transforms or allowing a continual adaptive update to the data.

### Image Registration

Scanner data is collected by the same aperture for every channel and the measurement vector is reasonably easily obtained. Photographic data is imaged by separate apertures (lenses) for each band. The photographic density of the image is then digitised and these digitised images are registered so that spatially identical points are coincident and the measurement vector can be obtained. Registration may also be needed for scanner data taken at different times.

The problem is to identify similar points in bands in which the spatial variation of the scene is the same but the spectral variation is different. Once these are identified the degree of translation, rotation and scale correction can be calculated and applied to the data as a set of transforms.

First using a grey scale printout on a line printer, or visual display unit, roughly similar points are identified between two bands. This can be done for a number of areas over the frame and an average shift obtained. Or for greater accuracy small areas of say 20 x 20 points can be selected and using the convolution theory of Fourier[13] analysis the two areas are exactly matched. This is repeated for a number of small areas and the shift data is fitted to a least-squares procedure which determines the 2-D shift to be applied to bring the two bands into register.

**Field vs Point Classification**

In per point classification each sample point is tested against all the decision areas to find the one it belongs to. Per field classification[5] collects together all the points from a given field or designated area and decribes the area by the same set of statistical parameters used in the classifier. The entire area is then classified. The problem is inputting into the computer the area to be classified, it requires continual operator intervention but not at a very high level of understanding. It tends to be more accurate because the classifier has more information to work on and system noise and other spurious effects tend to be averaged out. This can also lead to addtional information being used, such as the texture of the enclosed area, which gives further clues to the area's identity.

**Experimental Example**

To illustrate some of the points outlined unsupervised analysis was performed on a small sample of data.

Four band multispectral photographs were obtained at a scale of 1:15,000 over a test area in Sedgwick, England. Using a Joyce Loebl Computer Controlled Microdensitometer (Fig. 7) two lines were scanned in three frames (Fig. 6). Each line was over an identical part of the image. This was ensured by using the magnification viewing screen on the Microdensitometer. Each line contained 250 samples 200 microns square and separated by 200 microns. As the data was known to be in register from the digitisation there was no need to apply a registration procedure to the numerical data.

The measurement vector was formed from the readings from the three bands. This 3-D vector was used to produce a computer printout showing the structure of the clusters (Fig. 5a). For ease of viewing they were printed as a set of two dimensional plots. From this output three clusters could be distinguished, and the location of these were used as the input to a K-means clustering program. In an operational system all this is done by the computer. It is presented here in a way to show what goes on unseen inside the computer. After a few iterations the position and extent of the clusters are determined and the program then classifies the samples according to the cluster to which they belong (Fig. 8).

Putting this into the mathematical terms. Two decision surfaces have been constructed which divide the 3-D measurement space into three decision areas in which each area has a cluster associated with it. The cluster can be related to some ground cover type or types on the image. This is a parametric procedure because the clusters are described by equations which have as their parameters the mean position and dispersion of the clusters.

To show the effect of a ratio transform the same data was transformed as follows:-

$$X = \frac{\text{band } 2}{\text{band } 2+3+4} \qquad Y = \frac{\text{band } 3}{\text{band } 2+3+4}$$

The third ratio using band 4 is not needed because the sum of all the three ratios equals one. So using two the third is known. Mathematically the third ratio is said to be redundant as all the information is contained in the X and Y ratios.
The analysis procedure is the same except the measurement vector is now 2-dimensional. The results are shown in Fig. 5b and Fig. 9. The points in Fig. 5b are less dispersed than those in 5a and this results in a more accurate classification.

Up to this point the ground truth has not been used. Now if comparisions are made of the output with the ground truth it may turn out that group 1 corresponds to wheat in the ground truth area, group 2 to soil and so on. So that where these groups appear in the output, classifying the unknown samples, the ground cover type is known.


ACKNOWLEDGEMENTS

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Dr David Van Rest    IHD Scheme


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Paper 11

# THE USE OF SPATIAL INFORMATION IN COMPUTER ANALYSIS OF MULTISPECTRAL PHOTOGRAPHY

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Abstract

Objects in the imagery are delineated using a closed boundary finding algorithm. Spatial and spectral features of the objects are obtained, and these features are used in a hierarchical system constructed from a priori knowledge of the scene. Spectral or spatial features are used at each level to separate subsets of classes for that level.

CONTENTS

## LIST OF FIGURES

# The Use of Spatial Information in Computer Analysis of Multispectral Photography

## A Introduction

The present state of computer analysis systems use a simple type of computer programme that generally requires a training set on which the identification is based. For operational convenience the amount of training in the programme is generally kept to a minimum. This is the equivalent of employing someone as an image interpreter who had been trained on just a few training samples. The limited experience of the operator is bound to affect the amount of information which he can extract from the imagery and under these circumstances much of the relevant information on the imagery will not be identified or extracted.

Take for example a new born baby and an unprogrammed computer: consider how more powerful is the baby's brain yet how long it takes to learn to recognise objects.

It takes about five months for most babies to recognise the presence of an object and once this stage has been reached, by using the other senses, he builds up a store of information. This is what the computer should be doing; as it recognises objects it should store the characteristics of the object that aided the recognition.

By about twelve months baby has grasped the idea of permanence: square objects stay square, objects out of sight do not cease to exist. Subsequently he recognises the same object presented from different view points. Compare this with computer analysis of spatial patterns, where the computer has to recognise patterns presented from different angles. At a later stage the baby learns the importance of size and shape, which in normal air photo interpretation and in computer analysis are important factors.

For the baby this builds up into an ability to recognise a red ball and a white ball both as balls. Later the infant is able to classify specific things he has not seen before, for instance a poodle seen for the first time is recognised as a dog.

The ultimate aim would be to devise a computer programme to perform at the same level as a human brain, but it is most unlikely that this will ever be achieved. However, by building a multi-component programme the operation of the human reasoning power can be partially simulated. With this approach in view this paper outlines a hierarchical system that treats the whole 'scene recognition problem' in a flexible manner.

But first a few more words about the computer/human similarity. From the many features or pieces of information about an object presented to a human, he is able to select those particular features required to class the object: to some extent this is done in present statistical based computer programmes.

In addition to selection man is capable of filling in missing bits, as in Figure 1, which despite the missing pieces, shows a recognisable object. This ability is related to the fact we base our recognition on 3-D images: a thing which the computer does not do. What we see in the photograph is a 2-D representation of a 3-D object. We relate the 2-D spatial structure to what we know of the 3-D world. The computer has no knowledge of a 3-D world and cannot relate the image as we do. A 3-D description can be extracted from a scene only by a priori information. For example an object seen in a photograph may be described as a 'house'. But 'house' is a description of a 3-D object. The photograph is 2-D and the 2-D description is a set of connected quadrilaterals.

B Outline of System

How can a description of a particular object from a 2-D aerial photograph be extracted by computer processing? Using a single parameter set, such as the photographic density in a number of bands, gives a very limited range of answers. All it really does is order the data into a number of groups which are, by a comparison, labelled at some stage as representing some class of object.

Classifying each individual point in turn has only a limited accuracy. To improve this accuracy people have classified whole areas at a time. But much of the potential information in the collected area of points is being wasted.

In order to improve the efficiency of the data extraction process of these areas and to further aid classification, it seems sensible to consider the spatial and texture information in addition to the spectral.

This paper considers a multi level procedure to extract spectral, spatial and textural pieces of information from multispectral imagery. Here multispectral covers the range from ultra violet to microwave, whilst these pieces of information referred to are known as 'scene description parameters', or 'features'.

First the boundaries of an area must be delineated in every band selected for use. Then spatial and textural features of the area can be extracted. Often within a closed boundary there will be other 'significant edges' that can be extracted. These edges are not necessarily boundaries of an object, but edges that the human eye will often latch onto when first glancing at the area. These significant edges may aid recognition. Finally the spectral signature of the area can be found.

Assuming a world model is known by the computer, an hierarchical scheme could be set up classifying the objects in the model. Each successive level of the hierarchy uses a scene description parameter to decide into which group a specific item is to be placed. Classification can proceed until the required level of detail has been reached.

C <u>First Stage Processing</u>

(i) Area delineation by boundary finding

The edges or boundaries around an area could be detected by a simple grey level detector. However, an edge seen by the eye is not necessarily detectable by machine. This is because the change of grey level is so gradual compared to the sample area digitised, that the edge is not identified.

A lot of edges are defined by textural differences and not solely by grey level changes. See for example

Figure 2 where the grey level across the edge of two types of forest trees is fairly constant.

To detect an edge that has a finite width an operator, a finite number of digitised samples wide, has to be applied. An operator is a set of mathematical operations, the results of which are used to decide whether or not an edge passes through the group of points covered by the operator.

One type of operator consists of comparing in pairs, the average grey level of non-overlapping neighbourhoods either side of a point. The relative orientation of the neighbourhoods determines the direction of the edge, and the size of the neighbourhood the width of the edge.

Detecting every edge in the scene would clutter the output up too much. Rosenfeld and Thurston (1971) describe a conspicuous edge detector which by combining the output of operators that detect edges of different widths, retains only conspicuous edges and suppresses the edges making up the object itself.

The problem of locating texture edges is that the pattern either side may be the same, but at a different scale. The average photo density either side of the edge is the same, so to make a detectable edge the photo density is changed by applying a simple detector such as a Roberts Cross Operator.

Rosenfeld et al (1972) take this further by considering refinements to the size and orientation of the neighbourhood. The final result is an operator that handles a range from conspicuous, small, isolated objects to edges of large regions. This does not however guarantee closed boundaries around areas. An example of results obtained is shown in Figure 3.

The above method does not utilise the full potential of multispectral imagery. A boundary in one band may not appear so clear in another band, so some boundaries may be missed.

The boundaries that are required are those around regions within which the image points belong to the same object. One way of finding a collection of nearly identical image points is by clustering. For a complete description of clustering see Ball (1965).

Assumptions now have to be made about the data set. The data has to be Gaussian and describable by Euclidean distance. Each image point is described by an image resolution vector (IRV). The elements of the vector are the density values from each band of multispectral imagery. A boundary is where adjacent image resolution vectors are dissimilar. To overcome noise clustering is performed on groups of elements.

Wacker (1969) describes a method where a clustering cell larger than a boundary cell is used (Figure 4). The boundary cell contains IRV's. The junction of all boundary cells is the total picture. The boundary cell is situated in the middle of the cluster cell. The IRV's in the cluster cell are clustered. The boundary cell is scanned horizontally and vertically to find the edges. The type of output is similar to Figure 3.

The methods described so far do not guarantee closed boundaries. If a classifier is to classify an area then the area must be enclosed by a complete boundary so that the classifier knows which points to use. There are ways of smoothing and closing boundaries but this involves extra work. It is better to get closed boundaries in one step.

(ii) Closed boundary finding

A simple approach that ensures everything in a given area is one object is image partitioning. This does not detect the true boundaries of the region but merely a regular region such as a square, within which all the picture elements belong to the same object.

Robertson et al (1973) described an image partitioning algorithm that divides the image into successively smaller rectangles and produces a partition that minimises some chosen criterion function. The criterion function is used to decide whether or not to further split a rectangle. Each object is approximated by one or more rectangular blocks of image points. This ensures a complete boundary as shown in Figure 5. The partitioning is based on the grey level vector from all the bands, and gives a very crude blocked representation of the image.

Clustering and image partitioning are both methods of grouping data and they both use essentially the same criterion of minimising inter group scatter. However because of texture, clusters may overlap in measurement space. It is claimed that in partitioning, the existence of a partition that completely separates objects is guaranteed.

One method for finding the true boundary around an object is described by Kettig and Landgrebe (1973).

The method is to build up areas from small groups of picture elements. An area starts with one group of picture elements and expands laterally and down the flightline, absorbing more groups. When a group is sufficiently different from the amalgamated group a boundary point is registered. The problem of gradual boundaries is avoided by comparing the candidate group to the group from a large area.

This, in common with clustering and image partitioning, requires the areas to be reasonably homogeneous. This limit on texture may make these methods best for uses connected with the agricultural scene and general vegetation.

This last method, known as hypothesis testing, is further explained in Gupta et al (1973). Each group of picture elements is tested in a two part hypothesis.

1) To see if the group is similar to the area
2) To see if the group itself is homogeneous

The boundary must be found in all spectral channels before the final decision is taken.

The logic that ensures the build up of closed boundaries in simple in operation but complicated to explain. It is explained in Gupta et al (1973). Figure 6 shows the type of edges produced.

A number of factors need to be considered when investigating the possibilities in boundary detection. Simple grey level or gradient operators produce results that are noisy, localised, discontinuous, of varying width, and gradual boundaries are missed. The more complicated neighbourhood operator produces some good results, but in common with the first mentioned method, boundaries may not appear in all bands and closed boundaries are not guaranteed. A boundary generated from the association of a lot of edges may not enclose a meaningful object.

Clustering is more stable, less noisy, but time consuming and does not guarantee closed boundaries. Image partitioning gives a crude approximation to the image but gives completely closed areas. Hypothesis testing gives closed boundaries, is time consuming and may not work on highly textured data. The boundary is a genuine boundary, enclosing an area that is part or whole of one object.

D Second Stage Processing

Spatial Processing.

Now that areas have been delineated the scene parameters have to be extracted. There are two main components that can be used, spectral and spatial. For an introduction to spectral signatures and spectral processing see Preston (1974).

For spatial processing two main methods of extracting spatial information are the statistical approach and Fourier analysis.

Haralick and Shanmugan (1974) describe a statistical method they used in the analysis of one ERTS frame. The frame was divided into image blocks consisting of 64 x 64 resolution cells. From each of these image blocks a set of spatial grey tone matrices was extracted. From each matrix a set of thirty-two textural features were extracted. Figure 7 shows the extent of the detail available in a typical size pixel block used in these types of investigations.

Each of those image blocks represented about 7.5 square miles on the ground. This brings out an important point in spatial processing. The detectable objects must have texture greater than this size, and be no smaller than this area. To this effect the following classes were chosen by Haralick and Shanmugan; coastal forest, woods, annual grass, water, urban areas of large and small irrigated fields. These areas were considered to have texture sufficiently large enough to show in an image block of 7.5 square miles. These areas were classified, using the thirty-two textural features to partition space into regions separated by hyperplanes using linear discriminant functions. This type of processing is explained in Preston (1974).

In Ramapriyan (1972) the spatial frequency of Fourier transforms of the image blocks were used as spatial features. In this case the image blocks were taken from aerial photographs. Each block consisted of 25 x 25 picture elements covering about 50 ft x 50 ft on the ground. Figure 7 gives some idea of the data shown in this size of area. Compared with the image blocks of the first mentioned case these image blocks could be used to classify objects with finer detail. The classes used were grass, trees, water, staked tomatoes, treated ground tomatoes, and untreated ground tomatoes. The classification method was based on 'Minimum Mahalanobis Distance'. In each case it is important to consider the size of the ground resolution element and image block in relation to the texture of the object on the ground.

One most important point in spatial processing is that the data must be normalised to remove both grey level variance and variance due to rotation. Haralick and Shanmugan (1974) used equal probability quantisation to remove grey level variance. Angle independence was achieved by averaging the features from matrices taken at various angles. Ramapriyan (1972) normalised the Discrete Fourier Transform values. To remove angle dependence the spatial frequencies at various angles were found and the features used consisted of the means, variations and ranges.

E <u>Third Stage Processing</u>

Scene Analysis.

The following information has now been extracted by the computer:-

1) The boundary around the object
2) Significant edges within the object
3) Textural information
4) Spectral information

These now have to be fitted together into some form of coherent structure that leads to a classification of the area in terms of the world known to the computer.

A very good description of scene analysis is given by Duda and Hart (1973) in which two basic assumptions are made:

a) certain pieces of information have been extracted and are available in symbolic form
b) a priori structured information about classes of scene to be analysed is known.

The task is to combine the symbolic information with the a priori known structure to produce a description of the scene.

The type of a priori information required involves knowledge of the spectral signature of the object, its spatial shape and its textural composition. Some work has been done along these lines, for example Sayn-Wittgenstein (1970) investigates spatial structure.

There is also a need for contextural information, i.e. information on the areas surrounding the area under investigation. Often the surroundings give a strong clue to the identity of an object, for example Bajcsy and Tavakoli (1973) use this idea of context in identifying bridges as thin extensions of land surrounded on two sides by water. These contextural features can be linked by the use of connected or relational graphs (Figure 8).

Multispectral processing does not necessarily mean using all bands at once. The combination of bands showing edges best would be first, then others - such as a microwave band - could be used to pick out some textural feature.

This selection of first spectral then spatial features (then perhaps further spectral features) in building up a description of an object, suggests some form of hierarchical classification system. This system can incorporate within it at each stage such classification methods as clustering that help decide which features best match those in the hierarchy. Also the connected graphs can be incorporated. Each time a match is found a new branch of the hierarchy is followed and a scene description parameter is established. (Figure 9).

Skaley and Hoffman (1973) describe a hierarchical system using a priori information on the characteristics of different materials. The system uses spectral and spatial features at each level to identify the objects. At each level there is a set of features that separate subsets for that class or level. At each level a numeric code can be assigned to provide a library reference that can be fixed to position coordinates and areal measurements.

Some important points are: the investigator must have some idea of what he is looking for, and the physical characteristics that help identify that object. These characteristics can be matched to sensors that optimise their detection. The characteristics are then put into a hierarchical system that contains all the objects that make up the 'world' of the user. The system does not have to be applicable to many different users. These characteristics are established in the system as a set of features at various levels of the system. Each feature helps in making a decision at that particular level. These features have to be obtainable also from the output of the sensor system. It is this output applied to the hierarchy that results in the classification of the scene.

Note also that to establish the features a distinction must be made between a priori information and the use of localised training sets.

The different classes can be defined in terms of features most useful to a given user. Each user can build up a library of features for his own use. These can be related to the scene description parameters, which can be accessed by a rapid table look up such as described by Eppler (1971). The table can be built up from the results of a binary yes/no decision at each level of the hierarchical system.

F Methodology of the System

Starting with the raw multispectral data it first has to be normalised with respect to grey level variance. This, at least, enables consistent relative spectral signatures to be obtained. The authors are not convinced of the possibility of obtaining absolute spectral signatures, but, for example, the green/infra-red ratio can be useful in picking out vegetation from say, water.

A boundary finding operator is then applied to the data to extract closed boundaries. Here there are two main choices: image partitioning or hypothesis testing. Image partitioning gives a crude blocked representation of the total image. It may then be necessary to apply say, a significant edge detector, to extract roads and other features that can be overlayed onto the blocked image to round off the blocked appearance. Hypothesis testing can be used to give the natural boundary of the object.

When this stage is reached the area within the boundary can be analysed to establish its scene description parameter and classified. This is a basic methodology that can be applied to various disciplines such as agriculture, soils, or geology. In each case it is necessary to establish which features enable the objects in the scene to be classified, and how to fit these into a hierarchical classification structure. It is also important to know the structure of the world model that the user is working in.

For an illustration consider a world model consisting of rivers, roads, lakes, forests, soil, grassland, cropland and urban areas. Referring to Figure 9 a structure has been built that uses features extracted from multispectral imagery obtained in the visible and infra-red bands. Using the data obtained from within the closed boundary of an area, a spatial feature could be extracted giving, for example, the number of edges per unit area. Urban areas tend to have a high number of edges per unit area and therefore using this feature the identity of the area can be established. It can be given the scene description either 'artificial scene' or 'natural scene'. Then the processing proceeds to the next level of the hierarchy. It must be remembered that the size of the area and the number of samples in it critically determine the texture that can be detected. Many other spatial features that can be used have already been mentioned, but in all cases it requires a priori knowledge of the structure of the object to enable a suitable feature to be picked for classification purposes.

After using the system for some time the user will be able to build up sets of features that are of most use, depending on the scale of photography, time of flight etc. The system should prove flexible in that it is possible to operate under many conditions, and be used to any level of classification; but as with any human interpreter the programme requires a period of training to become familiar with the subject.

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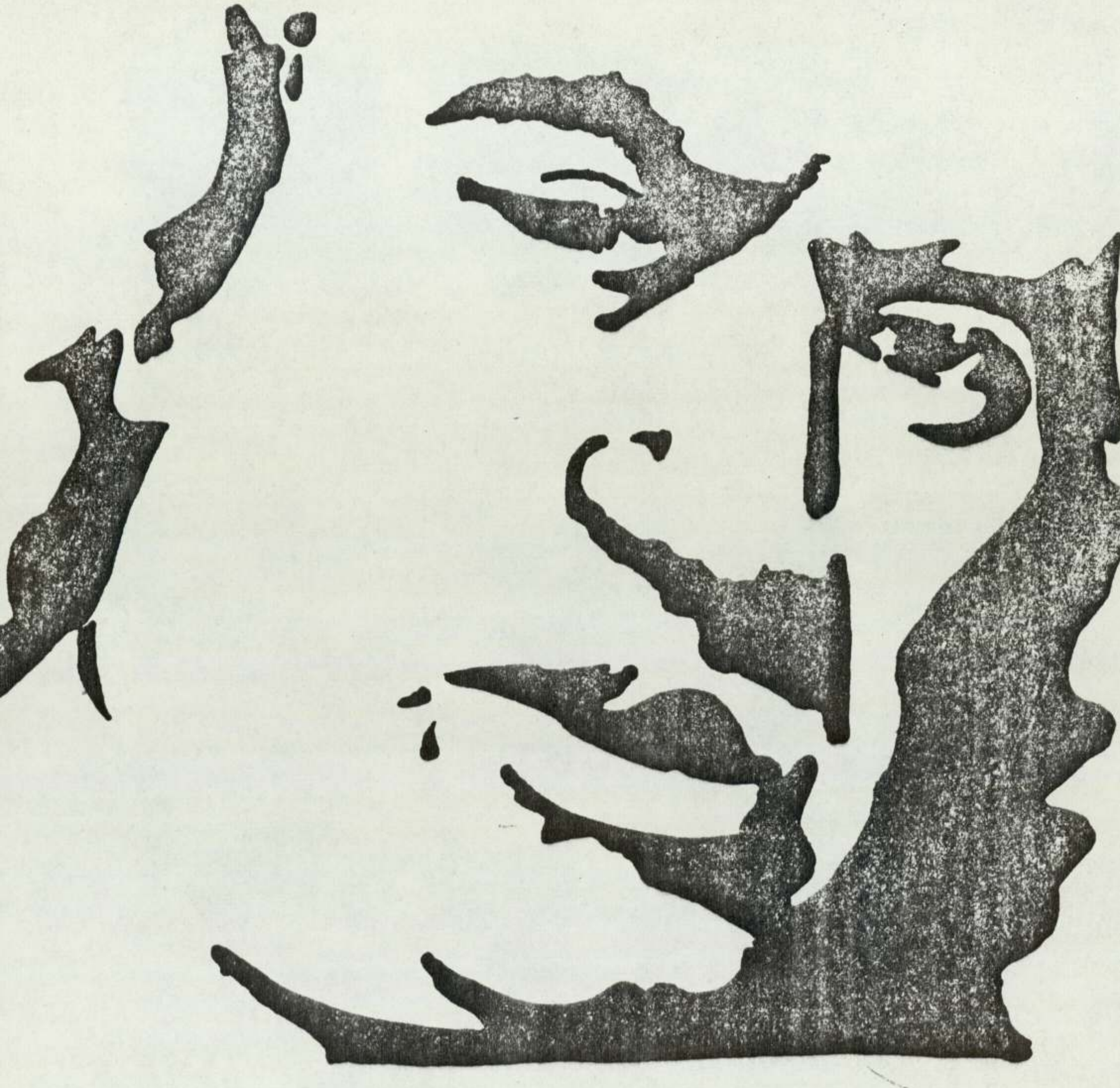

Figure 1. Demonstration of the ability of the human brain to fill in missing pieces of information to relate a 2-D patten to a 3-D description "face".


Figure 2. Aerial photograph showing texture as the main criterion for distinguishing between tree types.

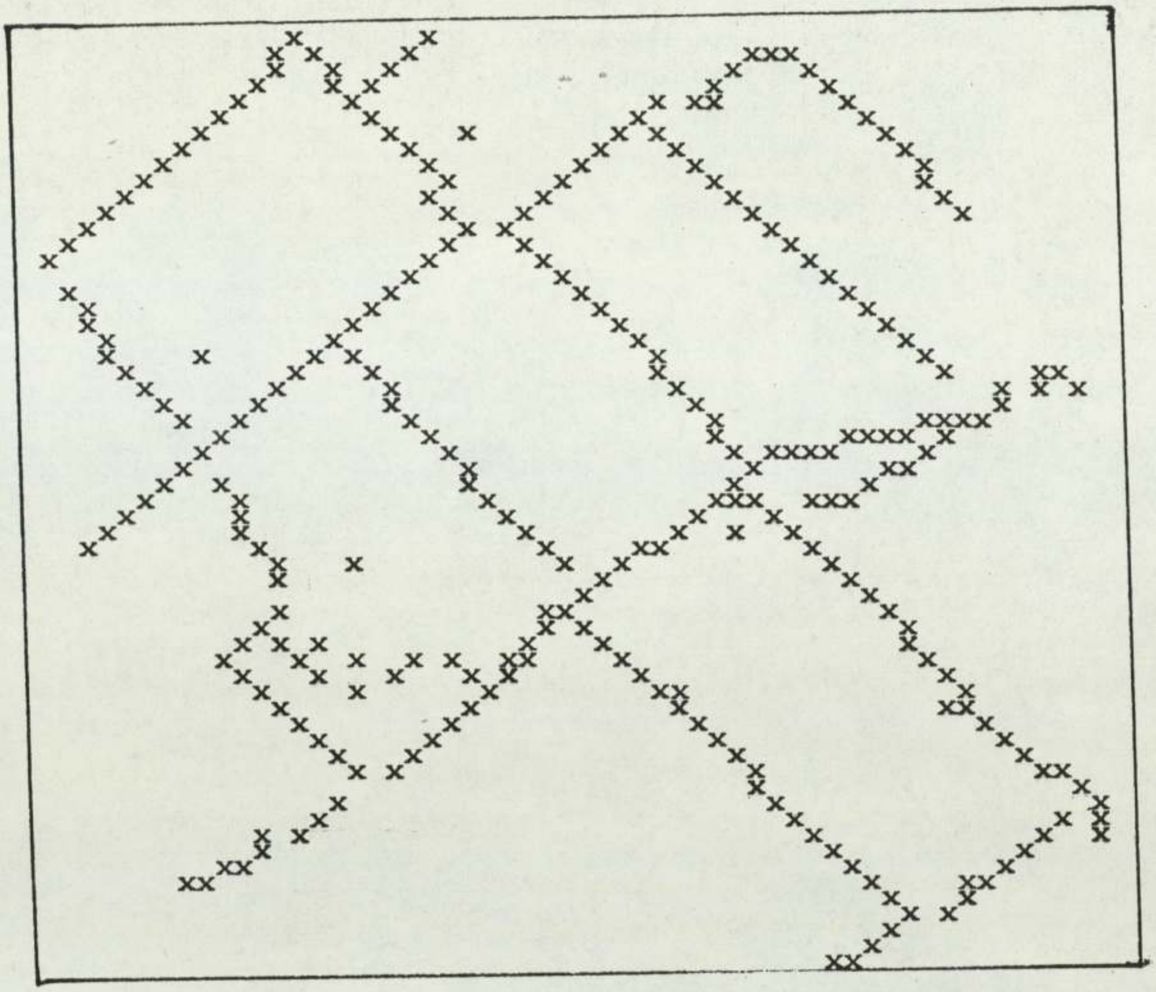

Figure 3 Edges from a typical grey level edge detector

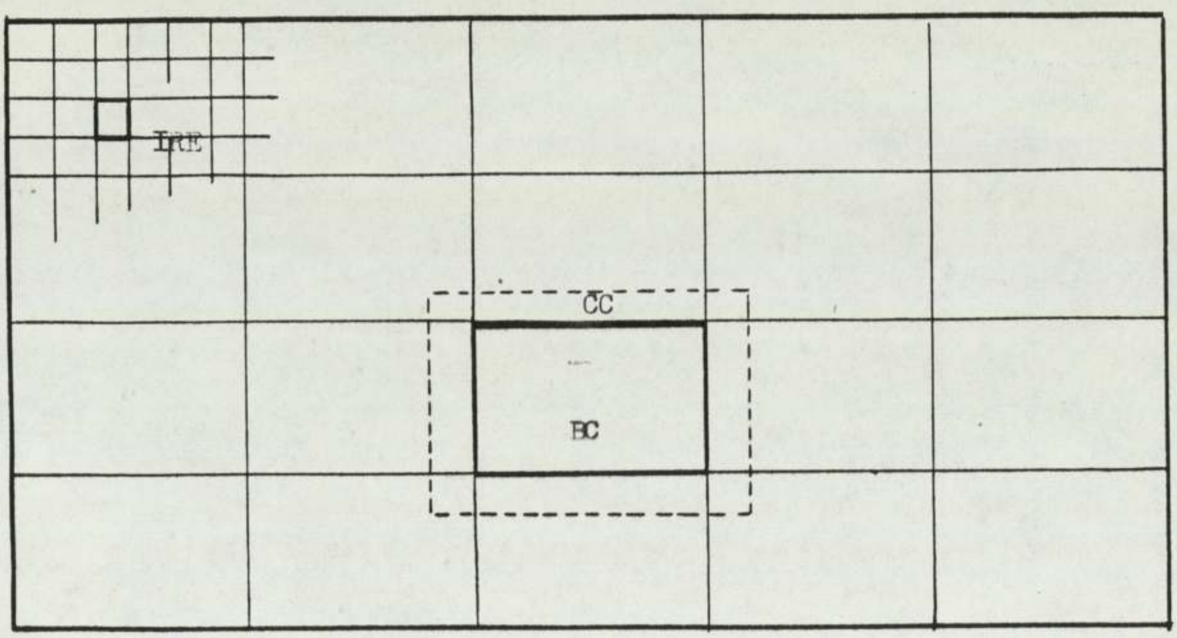


Figure 4. Relationships of image resultion element, clustering cell and boundary cell.

(CC) (BC)

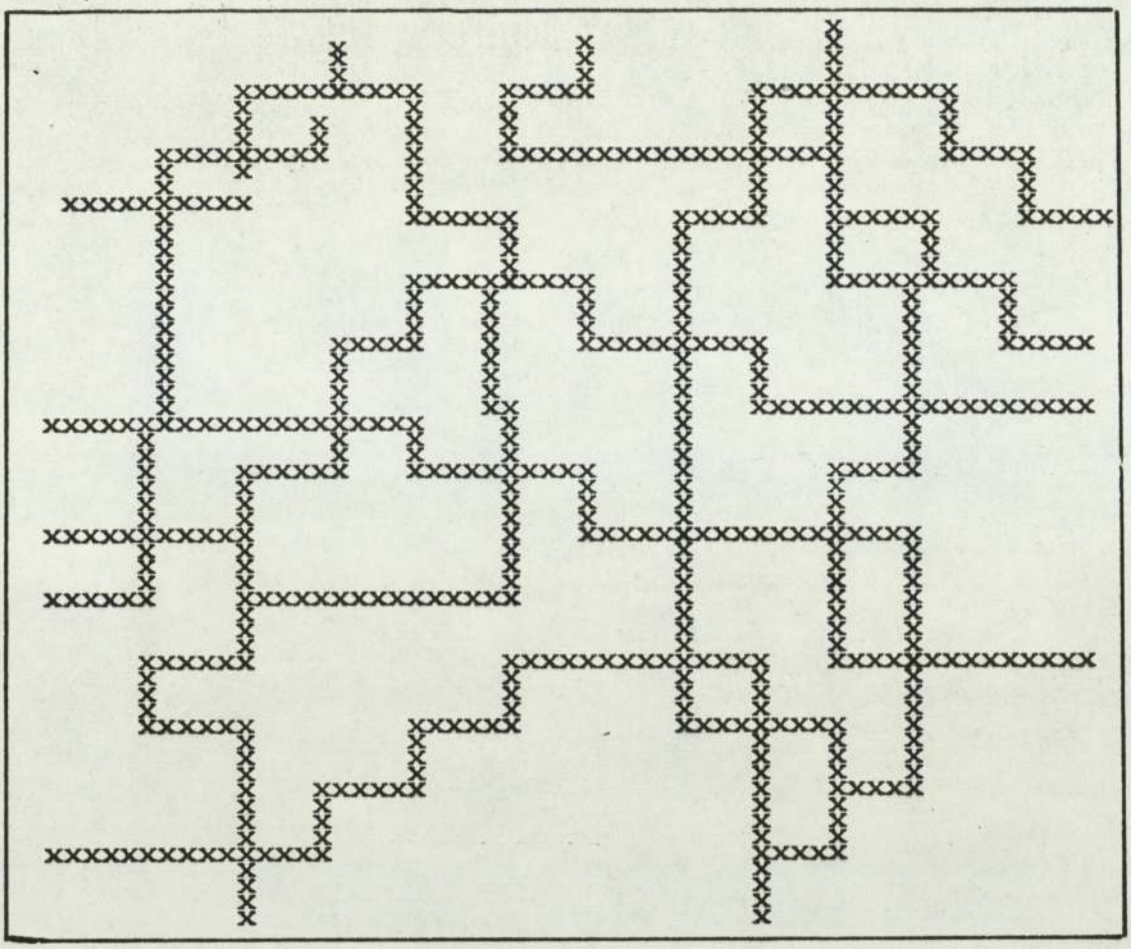

Figure 5 Image Partitioning

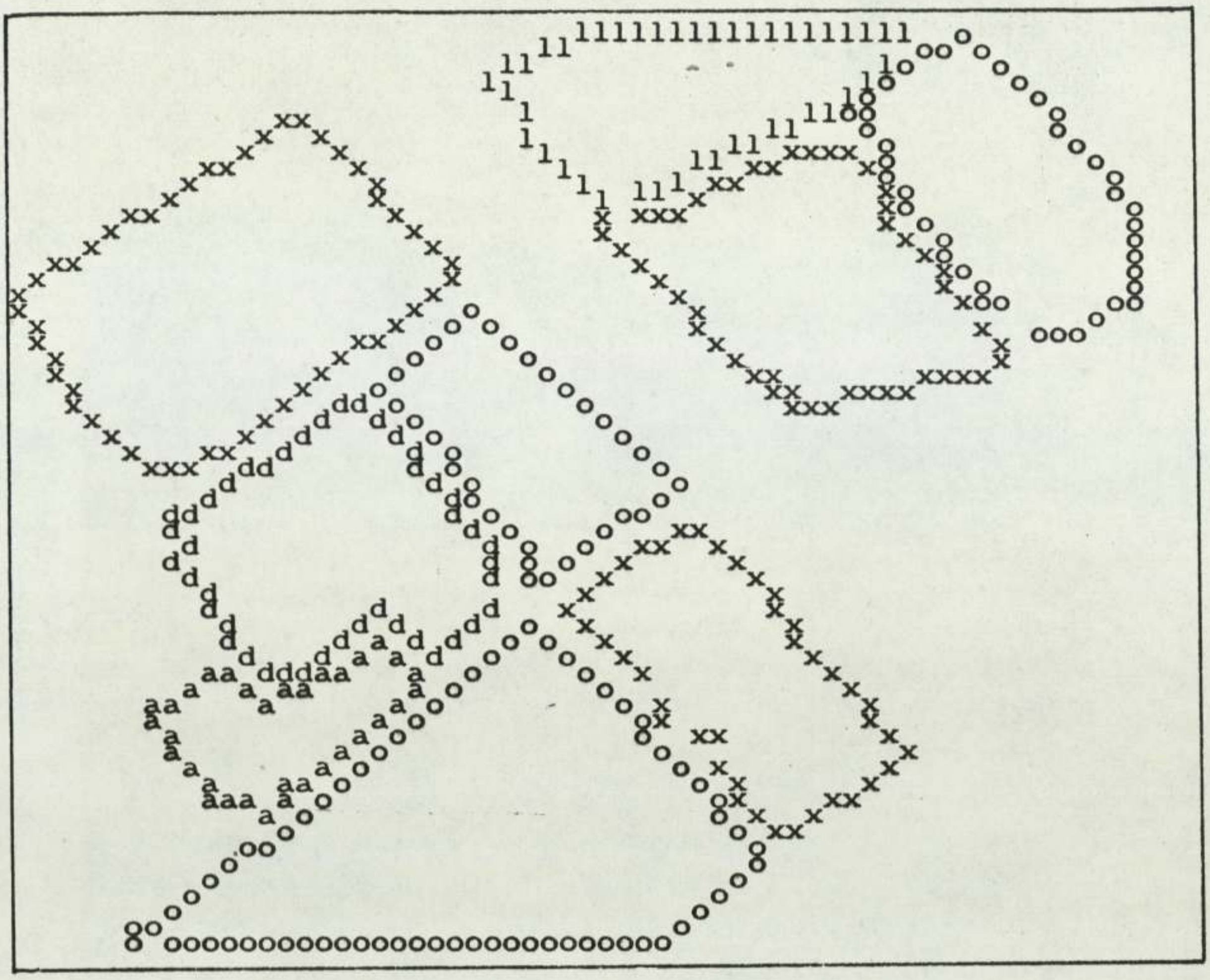

Figure 6 Closed boundary detection typical of hypothesis testing procedures.

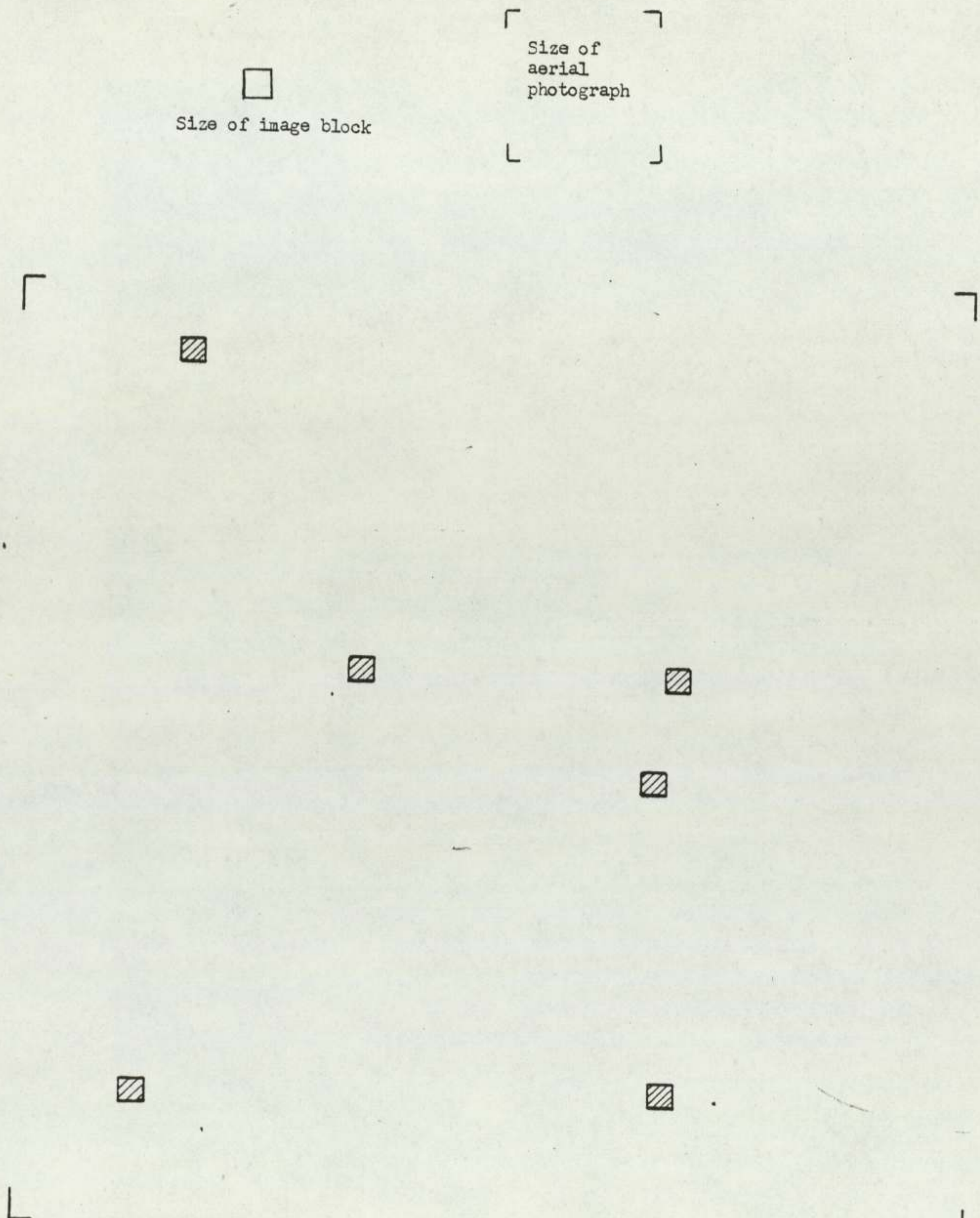


Figure 7. Size of image block typically used in spatial analysis of aerial photography.

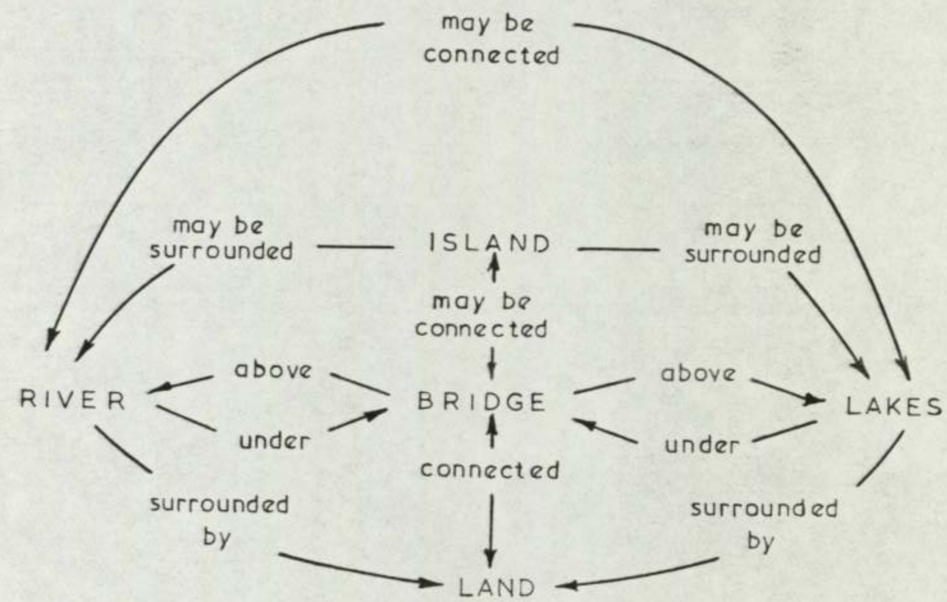


Fig. 8 After Bajcsy and Tavaloki 1973. The connectivity graph for a world model consisting of land, rivers lakes, bridges and islands.

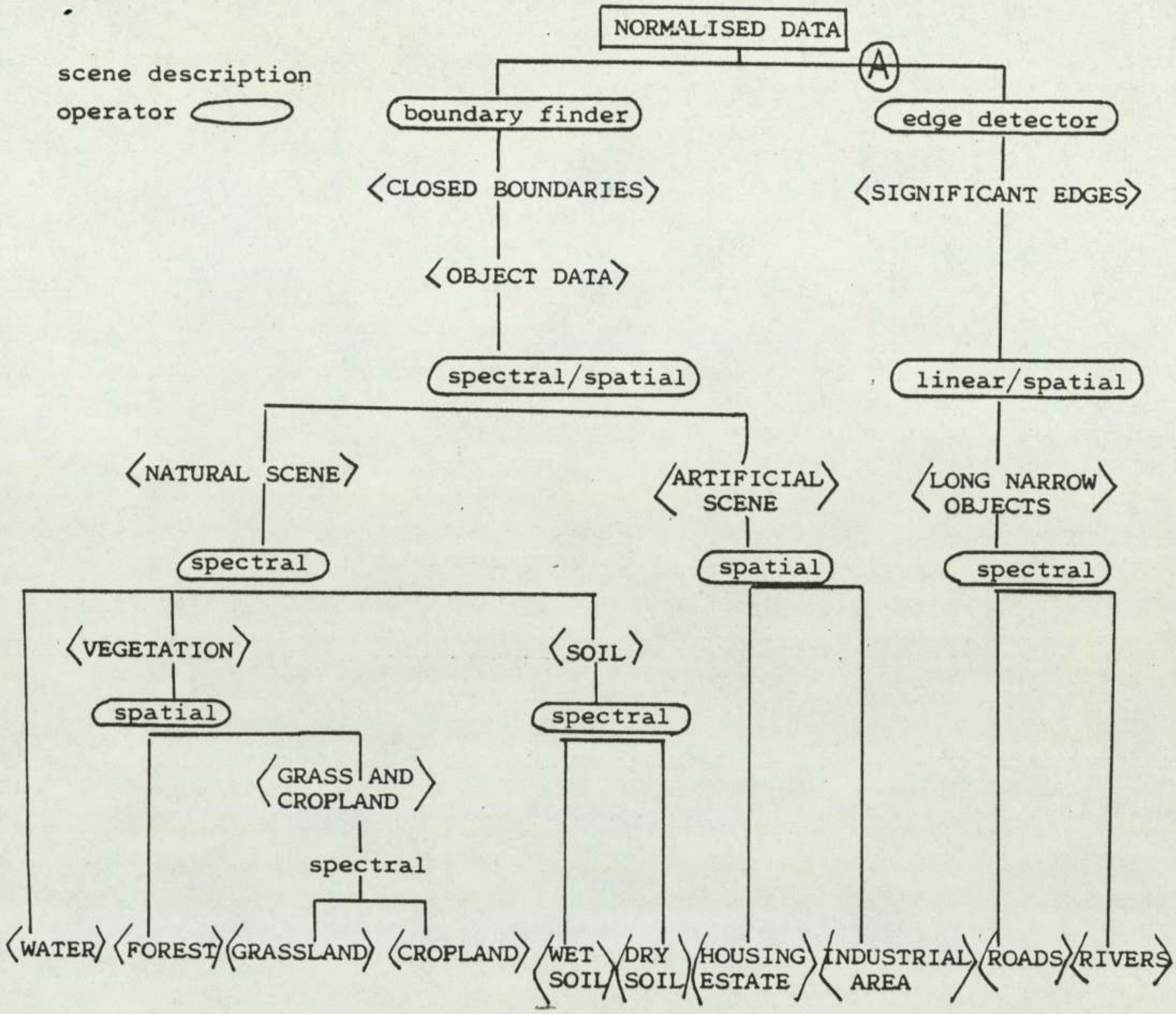


Figure 9 Hierarchical classification system showing features used at each level.