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# THE AUTOMATED RECOGNITION OF URBAN DEVELOPMENT FROM LANDSAT IMAGES

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ABSTRACT

The problems and progress made in the development of automated methods for the recognition and extraction of urban land use features from LANDSAT digital data of the UK are described. In the data examined so far density slicing in one waveband appears to be almost as effective as multiwaveband classification in selecting the urban areas. While absolute boundaries may be difficult to delineate, new developments may be recognisable which would be adequate for monitoring needs. It appears important to include the effects of seasonal change and make use of texural analysis in the classification process.

## I. INTRODUCTION

This paper presents preliminary results obtained from a program of research concerned with the automated recognition of urban development from images obtained from the LANDSAT Earth Resource Satellites. The research is being undertaken by the Image Analysis Group at Harwell for the Department of the Environment (DOE). The factors leading DOE to initiate the research, the facilities available for the study, the form of the LANDSAT data and its limitations in terms of cartographic accuracy and resolution are discussed. Results of automated classification of urban areas by density slicing and a technique based on maximum likelihood rules are presented with comments on the direction of future work.

The Department of the Environment is concerned with collecting information on both the extent and distribution of developed land in England and Wales and the rate at which land is being taken up by development. Such information is important in the formulation of regional planning strategies and national policies but its availability is limited because of the inadequacy of traditional land-use data which has been collected primarily for other purposes (eg agricultural surveys), contains many generalisations, has no consistent set of guidelines and is often out-of-date. Because there is an increasing need by Government for up-to-date and reliable land-use statistics at national level the DOE has initiated a programme to improve the data collection and analytical techniques. One part of this programme is the use of 1:60,000 RAF aerial photography flown in 1969, together with 1:50,000 Ordnance Survey (OS) maps to provide a base-line inventory of 'developed' land. 'Developed' areas are defined[1] for the DOE project as areas of five hectares and above covered by bricks and mortar, land uses associated with these features and such open space as exists primarily for 'urban' use. This work will be completed in 1976[2].

However, regular aerial survey of the UK would be both very expensive and because of cloud interference not always obtainable. The DOE is therefore seeking to establish an alternative, rapid survey system coupled with an automated analytical system for monitoring urban development. Such a system would offer three main advantages:

1. Regular and comprehensive surveys related to a single time base;

2. A reduction in time and manpower required to produce national data;

3. Objective data based on consistent criteria.

Alternative survey techniques being investigated include the use of side-looking radar (SLR) and multispectral scanners (MSS). SLR has the advantage of being more independent of the weather[3] but the higher resolution Q-band synthetic aperture radar is still not commercially available in the UK, and the imagery is more difficult to interpret. In comparison MSS imagery from the American LANDSAT satellites is readily available and relatively inexpensive compared to aerial surveys. Its principal limitations are the low resolution (element or pixel size is approximately 80m) and the interference of cloud, but imagery is obtained from each satellite every 18 days and it should be possible to select cloud-free images annually.

In the programme of work it is intended to examine other forms of data such as panchromatic, false colour, infra-red line scan and SLR imagery in order to establish their potential for land-use monitoring. Emphasis will be given to the study of material already in digital form. This approach eliminates the losses and errors introduced in photoprocessing and digitisation and allows the data to be manipulated by a computer without degrading its quality. Extraction of features is unlikely to be completely automatic, but rather an interactive process and thus the term 'automated' is preferred to 'automatic' in this text.

Since the work programme is at an early stage the paper concentrates on results obtained from LANDSAT imagery. An initial selection of urban areas has been made (Reading, Hemel Hempstead, Newmarket) to enable a variety of urban features and types of rural-urban fringe to be studied. The availability of aerial photographic cover and ground truth was also a deciding factor in the choice of test areas.

## II. FACILITIES AVAILABLE FOR THE STUDY

The main centres capable of analysing the data recorded by the LANDSAT satellites are in the USA and Canada and these are described in the literature[4] as are some of the proposed NASA facilities[5,6]. While the Harwell Image Analysis Group's processing system (HIPS) was mainly developed for analysing data produced for Non-Destructive Testing purposes[7], it has facilities very similar to those offered by the American groups. The HIPS system is summarized in Figure 1 and has been described in more detail elsewhere[8,9].

Imagery recorded on film is transformed into digital form using a Flying Spot Scanner under the control of a small computer, whereas digital data on magnetic tape is read directly into the main Harwell computer, an IBM 370/168. A notable feature of the system is the fast data-link between the main computer and the local small computer. This enables complex operations on large images to be rapidly carried out in the main computer while the results of these operations can be transmitted to the small computer with its interactive display facilities. At the small computer, complex operator-interactive processes such as selection of training areas, density slicing etc., can be carried out and the results immediately assessed.

The display facilities include both monochrome and colour displays. Grey scale monochrome pictures may be stored in a Hughes model 639 storage memory device and displayed on a TV monitor. Selective erasure and data editing facilities are available. The colour display system, a Digital Equipment Corporation VT31, will be operational in 1976. The VT31 is a process controller with a 442 kbit store capable of addressing with 3 bits 512 points on 288 raster lines of a colour monitor and thus producing up to 8 different colours. In addition locations from the screen can be made using a 'tracker-ball' facility.

Permanent output can be obtained either by photographing the above displays or by obtaining monochrome grey scale pictures on 35mm film from the Calcomp 835 CRT plotter attached to the main Harwell computer.

The majority of the computing for the present study will be carried out on the IBM 370/168 computer using the JPL VICAR image processing software, although most of the programmes to be used have been written at Harwell and inserted into the VICAR suite of programmes. VICAR enables a string of pictures to be readily processed automatically by specifying a fairly simple set of commands[10].

## III. LANDSAT DIGITAL DATA AND PROBLEMS OF CARTOGRAPHIC ACCURACY

The LANDSAT MSS produces four spectral band digital images labelled bands 4 to 7 from an approximately square region on the ground 181km x 185km. The spectral bands are respectively 0.5 - 0.6 microns (green), 0.6 - 0.7 microns (red), 0.7 - 0.8 microns and 0.8 - 1.1 microns (both near infra-red). The scanner has a ground resolution of about 79m. While the successive scan lines are spaced approximately 79m apart on the ground (~2340 scan lines per image) the sampling rate used by the MSS causes an overlap of 23m of the ground elements viewed along a scan line (~3240 samples per scan line) and hence an apparent pixel size of 79 x 56m.

The digital data is distributed on 4 or 2 computer compatible tapes[11]. It has been found useful to reformat the data onto one 1600bpi 9-track magnetic tape to create four complete waveband images. Each waveband can then be readily accessed and local regions extracted. For classification purposes, however, the four separate local waveband images are merged into a single data set in which four successive lines of data represent the different wavebands for a particular scan line.

The digital data has the disadvantage of being distorted[12] by geometrical errors. Corrections that can be predicted, such as scaling and removal of earth rotation effects, are relatively easy to apply but time dependent corrections, such as spacecraft attitude induced errors, need a knowledge of accurately located ground control points. These problems have been solved by a number of groups[6,13,14]. IBM have carried out these corrections for the DOE in the scene referred to in this report (E - 1228 - 10293) and the resultant picture and enlargements have been reproduced and described elsewhere[15,24]. None of the images reproduced in this report have had corrections applied.

At the present, early stage of the project, it is considered unnecessary to use precision corrected data, but in the later stages transformation and rectification of the data may be usefully applied. It is still necessary, however, to locate urban areas, check the training area positions and compare the classification results with known boundary data. The location of areas is no problem provided one can produce a picture of the digital data but to check the training areas locations it is necessary to transform from Ordnance Survey (OS) Northing and Easting coordinates to the sample and line coordinates of a particular LANDSAT scene. This is possible for local areas to within an accuracy of about 2 pixels by the use of three suitably placed ground control points and linear interpretation. Using this technique Northing and Easting 1km grid lines can be plotted on to visual displays of the digital data in order to help in the location of features. An example is shown in Figure 2 of such a plot. In a similar way known boundary data can be superimposed onto plots of the classification results.

## IV. LIMITATIONS IMPOSED BY LANDSAT PRESOLUTION

Great Britain is one of the most densely populated countries of Europe with an estimated[16] 8.6% of its total area (2 million hectares, 4.9 million acres) being urban land by 1970. In the two decades to 1970 the urban area is estimated to have increased by about 20%. Hence the change to be detected nation wide is only 1% per annum, with of course a much wider variation at the local level. Since this nation-wide annual growth rate represents less than one thousandth of the total non-urban area precise methods are required for detecting yearly changes.

The DOE are mapping, as explained in the Introduction, on a scale of 1:50,000 all urban areas of size 5 hectares or above into five broad land-use groups. Obviously, it would be very convenient to map urban land use categories from satellite imagery at a similar scale. But taking into account the resolution of the LANDSAT data it is unrealistic to expect anything reliable or useful from yearly monitoring using this data except in areas with large changes or aggregated areas. Comparisons of the 1:60,000 aerial photographs used by DOE and LANDSAT imagery shows the relative importance of a change in spatial resolution by a factor of about 80. Thus in an aerial photograph there may be 100 pixels per dwelling (1 are), whereas a single LANDSAT pixel may contain many dwellings. The resolution capability of the LANDSAT MSS is not simply the field of view but also depends on the conditions at the time of observation and the effects of contrast, radiance levels and the atmosphere. The radiance observed by a single pixel will be a mixture of radiation from several different land uses and increases the difficulty in the interpretation of a pixel.

The ability to delineate urban areas will very much depend on the contrast available between the urban and non-urban areas (and hence on the time of year) and is in any case difficult near the urban boundary because of the lower building density[17,18,19]. While, however, it may not be possible to detect urban boundaries absolutely it may be easier to detect a change in land-use from agriculatural to urban (particularly in the construction phase) which may be adequate for up-dating purposes.

The definition of urban areas used by the DOE in mapping these areas from the 1969 photography was partly determined by the scale and quality of the photographs. Satellite data at the resolution of LANDSAT imagery cannot be classified at the same level or expected to be based on the same definition. A more limited definition to accord with the restrictions of this data source will be used.

Finally a brief word on the problem of determining the accuracy of the results obtained from the automated analysis to be presented in the next section. The DOE have digitised the selected urban boundaries using a Ferranti Freescan digitising table from the urban land-use maps being prepared from the 1969 aerial photography up-dated to 1973 and subsequent years using more recent photography. The digitised data is transformed to OS grid coordinates and stored on magnetic tape.

## V. AUTOMATED PROCESSING TECHNIQUES AND PRELIMINARY RESULTS

Ground features such as residential areas, water etc., are classified into their appropriate categories on the basis of their reflectance values in each spectral band (spectral signature). In this situation the reflectance values for the various features form separate clusters in the multi-dimensional measurement space. The classification procedure is to define these clusters in the measurement space by a process known as training, then to identify some algorithm which describes the boundaries of the clusters and finally to classify all the pixels by assigning them to the feature whose cluster they are nearest to in measurement space.

One of the most difficult tasks is the selection of training samples which are a good representation of a feature throughout the area being examined. This is especially a problem with LANDSAT imagery of the UK where the complexity of the terrain makes the correlation with ground truth difficult.

There are two general approaches to the problem of classification, unsupervised and supervised. In the former approach pixels or group of pixels are selected at random and a clustering technique is used to form a given number of clusters in measurement space, which must then be related to ground truth. In the supervised approach, which is the one we have adopted so far, classes are defined from training areas of known land use.

So far we have identified training areas in two ways. In the first method the interactive display system has been used to define areas corresponding to particular colours on a false colour print of the local area. The second method involves selecting areas from 1:50,000 OS maps and using the methods outlined in Section 3 to transform to LANDSAT coordinates. While the latter method is particularly useful for well mapped features such as urban land, water, woods etc., it is not so useful for agricultural features where seasonal factors and crop type are of prime importance. In either method the training areas are tested for suitability with the interactive display facility. The histograms of the intensities are displayed, the mean densities and standard deviation found and density slicing tests carried out. These checks are to ensure that there is not something obviously wrong such as the presence of cloud cover and that training areas are internally homogeneous and are good representations of a class throughout the scene. The main difficulties (apart from the problem that a pixel may cover several features) are the large variations within a particular class from say variations in the soil type, moisture content, topography, etc., and lack of uniform illumination. While various normalisation procedures are reported to overcome some of these problems, in a large area several sets of training areas may be required.

So far only selected areas from the LANDSAT scenes of 8th March, 1973 and 29th July, 1975 have been examined. Examination of the different wavebands shows that the two visible bands appear to contain little information on urban features compared to the infra-red bands and while the two infra-red bands give clearly recognisable pictures they appear to be very similar. This is born out by the correlation coefficients listed in Table 1, where 100% implies perfect correlation and 0% no correlation. In Figure 4 a photographic enlargement of a Calcomp plot from band 6 of an area 14.2km x 16.8km centred on the town of Reading (8th March 1973) is shown as an example. The linear features (river, railway) are clearly visible as are the darker inner urban area and the lighter shading of the suburbs. For comparison a section of a 1:50,000 OS map of the same region is reproduced in Figure 5.

Since most of the urban information appears to be contained in one of the infra-red bands, density slicing has been used as a first attempt at selecting the urban areas. It has long been recognised that certain features, notably water, can be identified using density slicing but for urban areas the situation is more complex. This is evident from examination of the histograms of the distributions of the intensity values from the Reading area shown in Figure 3 for the above two scenes. The distributions are unimodel with a small range of reflectance values, especially in the visible bands, and it is not obvious where to place the boundaries for density slicing. Hence training areas were selected, as outlined earlier, for the Reading scene of 8th March 1973 corresponding as closely as possible to the different colours in a false colour picture picture of the Reading area. The training areas were chosen to represent water (deep blue), inner urban (mottled light and dark blue), outer urban (grey and browns) and vegetation (probably grassland) (orange). When the training area locations for the two colour tones identified in the urban area were transferred into OS coordinates they coincided with the central and outer regions of the town and hence the names inner and outer urban. However, the actual ground truth of these areas has not been checked and no particular significance should be attached to these names.

Table 1. Correlation (expressed as a percentage) between the different waveband images

| Area | Bands | | | |
|---|---|---|---|---|
| | 7 & 6 | 7 & 4 | 6 & 5 | 5 & 4 |
| 8th March 1973 | | | | |
| Reading | 95 | 5 | 20 | 71 |
| Newmarket | 95 | 49 | 44 | 67 |
| Hemel Hempstead | 94 | 23 | 16 | 70 |
| 29th July 1975 | | | | |
| Reading | 95 | -8 | 17 | 84 |

The mean intensity and standard deviations of the different training regions are shown in Figure 8. As expected from the earlier comments the separations of the means are only large enough in bands 6 and 7 to give a reasonable chance of distinguishing between the four classes by density slicing. The actual distributions of the intensity levels are shown in Figure 9 for band 7 and the boundaries chosen for density slicing are indicated by arrows.

Since the overlap between classes is minimal the resultant density slicing shown in Figure 6 has a close similarity with the false colour reproduction of the Reading area. The main discrepancy when the results are comparent to an OS map is that the outer urban density slice also selects the wooded areas (top left-hand corner in particular). This is because the wooded areas at this time of the year have a similar density range to the outer urban areas in band 7. Overlap with other classes also occurs in the other wavebands. Hence desnity slicing in this case fails in March to distinguish between woods and urban areas.

Somewhat similar results have been reported by Sattinger et al[20] with the comment that for a limited number of classes level slicing is a very rapid and economical processing technique.

Since density slicing may not always be so useful a classification technique based on principle component[21,22] (PC) analysis and maximum likelihood rules which uses the data from all the wavebands has been tried. The PC axes for a cluster are a set of orthogonal axes with origin at the mean value and having the property that the size of the variance is maximised along each subsequent axis until it is a minimum along (in this case) the fourth PC axis. The PC axes are found in turn for each class from the training area data. The extent of the clusters are obtained by assuming that the data has a gaussian probability distribution along each PC axis. The classification of an unknown point is then done as follows. The point is assumed to belong to a particular class and its coordinates in the PC set of axes associated with this class, found and hence its overall probability of belonging to this class. This is repeated for each separate class. The point is then assigned to a class according to its maximum probability. There is a rejection level at more than 3 standard deviations along any PC axis.

The Reading area has been classified using the training areas for the four classes selected in the density slicing example. It was found that the projections of the training area data for the four classes onto the PC axes of any class gave no useful information, with almost complete overlap of the distributions, on axes 3 and 4 and that all the useful information was contained in the first two PC axes. As an example, the projections of the training area data onto the first two PC axes of the inner urban class are shown in Figures 10 and 11. The results of classifying the Reading area are shown in Figure 7. As expected because of the large amount of redundant information in the scene the results are rather similar to the density slicing results (Figure 6) and the comments made then still apply. This can be seen from the table of percentage correct classifications for the training areas for the density slicing and classification results with four classes given below. The loss in accuracy in the inner urban area is because part of this was classified as water. However with the described classification procedure it is possible to partially discriminate between urban and woodland making use of the fact that the woodland intensities overlap with different classes in the different wavebands. The results of including training areas of the woodland in the classification of the Reading area are shown in Table 2. While the wooded areas are well separated there is a reduction in the apparent correct classification of the outer urban area due to the fact that some of it is classified as woodland. With the 29th July scene using similar training area locations for the four classes to those for the 8th March scene, the results are more encouraging and the misclassification between water and inner urban is greatly reduced and the amount of woodland selected as outer urban is also reduced.

Table 2. Percentage correct classification for the training areas

| March | IU | OU | V | W | WOOD |
|---|---|---|---|---|---|
| Density slicing | 88 | 87 | 93 | 79 | |
| Classification (4) | 77 | 91 | 96 | 80 | |
| Classification (5) | 77 | 77 | 96 | 80 | 84 |
| July | | | | | |
| Classification (4) | 90 | 90 | 94 | 87 | |

Key: IU = Inner Urban, OU = Outer Urban, V = Vegetation, W = Water, WOOD = Woodland

Finally a comparison with the actual 1973 Reading boundary, derived as outlined in Section 4, is made in Figure 12 by plotting just the inner and outer urban areas from the classification of the 8th March scene using four classes and superimposing on this the outline of the boundary. The classification of woodland as urban is evident, but within the boundary the results are very encouraging and the unclassified areas can be seen from the OS map in Figure 5 to correspond to golf courses, parkland or playing fields. Such areas were included as urban within the original DOE definition of urban land.

## VI. FUTURE DIRECTIONS

Obviously many more examples are needed before it can be demonstrated that urban development can be monitored from satellite imagery. Also some redefinition of the composition of urban areas will have to be accomplished if such monitoring is to be carried out.

In particular there are two areas in which the classification procedures can be improved, firstly by the use of seasonal information and secondly by the use of texture analysis. The former will ensure that the maximum contrast between urban and non-urban areas can be used while the latter is more akin to the visual recognition process and hopefully it can utilise the linear features and the mottled appearance of the urban areas as a means of aiding the classification process. In the work on texture done so far, we have followed the approach of Haralick[23]. Harlick describes several easily computable (in the spatial domain) textural features based on grey tone spatial dependencies and reports that using texture alone he has achieved 83% identification accuracy in test sites selected from satellite imagery. These algorithms have been applied to the training areas in band 6 of the Reading area. Preliminary results give the kind of ranges reproduced by Haralick and are sufficiently promising to be pursued further.

## VII. CONCLUSIONS

The initial phase of the work reported upon was essentially a learning period of how to handle the data and classify urban areas but a number of conclusions already seem apparent.

The spatial resolution of the present LANDSAT imagery is only adequate for recognising rather gross geographical patterns. While absolute urban boundaries may be very difficult to delineate, 'new developed' areas should be recognisable and would be adequate for the revision of boundaries. Conventional land use definitions also seem inappropriate when compared to the classification of urban land by automated methods.

The small amount of data examined so far, appears to have considerable redundant information and hence density slicing was tried on a single waveband. The results are reasonable and when a classification technique using all the wavebands was tried there was only a small improvement, but this may not be true when a wider selection of data has been examined. As shown in the Reading example there can be a close simularity between parts of the urban and rural areas when vegetation is inactive and hence it appears to be very important to include the effect of seasonal changes into the classification procedure. The use of texture analysis could also provide additional aid in the identification of certain urban features.

## VIII ACKNOWLEDGEMENTS

We are grateful for the permission to use the VICAR software, originally developed by the Jet Propulsion Laboratory, California Institute of Technology. The assistance of P.M. Smith of Harwell in getting the software operational was invaluable.

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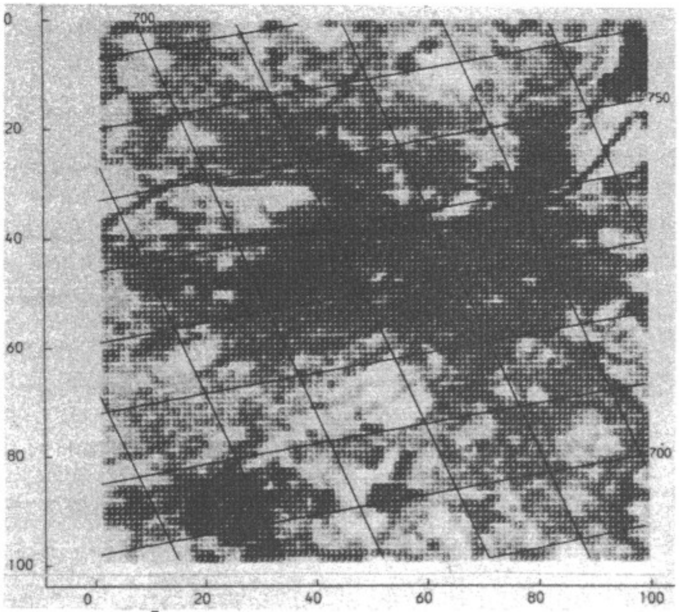


<u>Figure 2.</u> Addition of the 1km Northing and Easting Ordnance Survey Grid lines to a CalComp plot of the inner Reading Area (100 x 100 pixels - band 6)

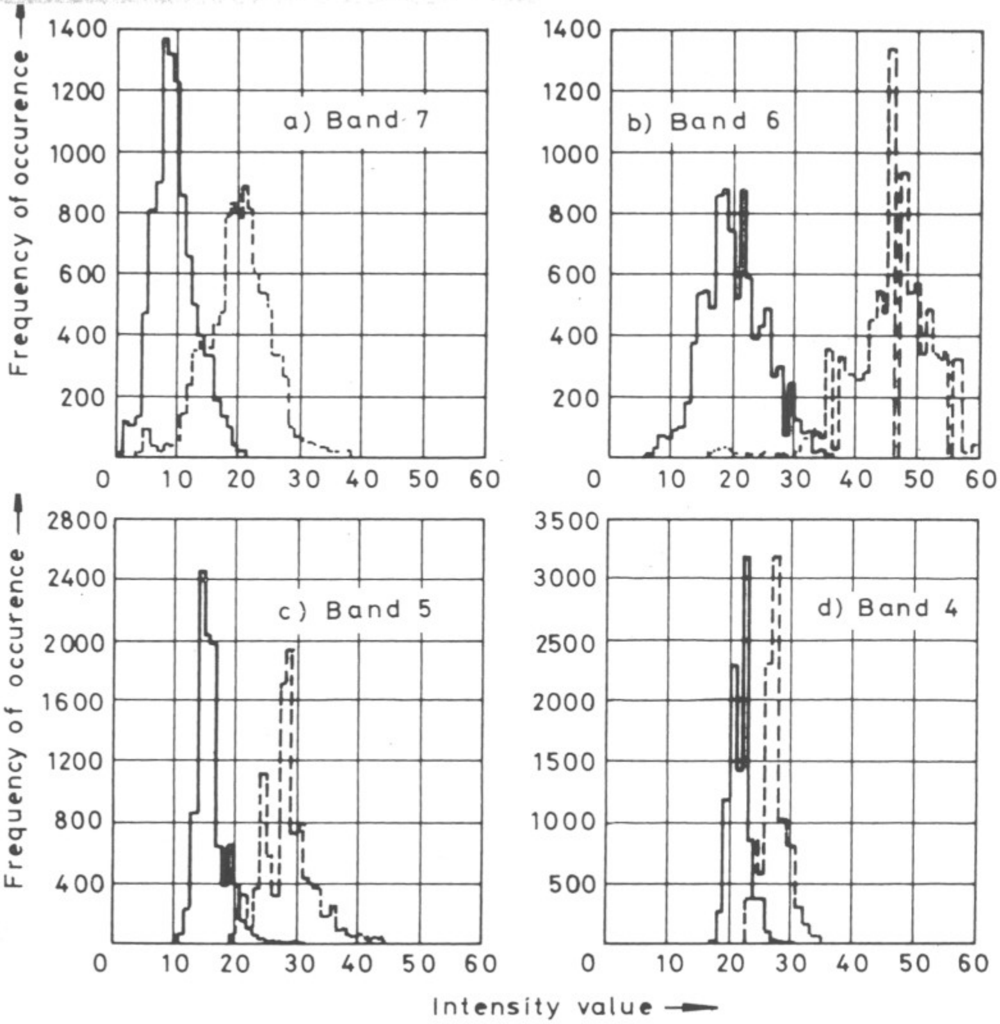


FIG 3 DISTRIBUTION OF INTENSITY VALUES FOR THE READING AREA TAKEN FROM LANDSAT IMAGE

——— E-1228-10293 (8th MARCH 1973)

- - - - E-2188-10165 (29th JULY 1975)

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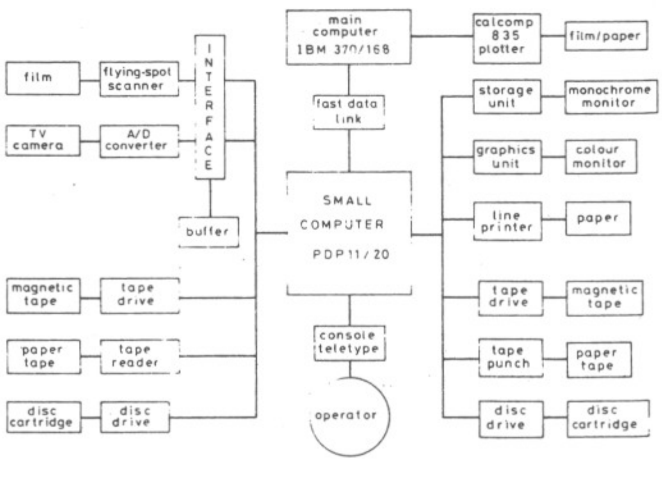


FIG I SCHEMATIC BLOCK DIAGRAM SUMMARISING HIPS

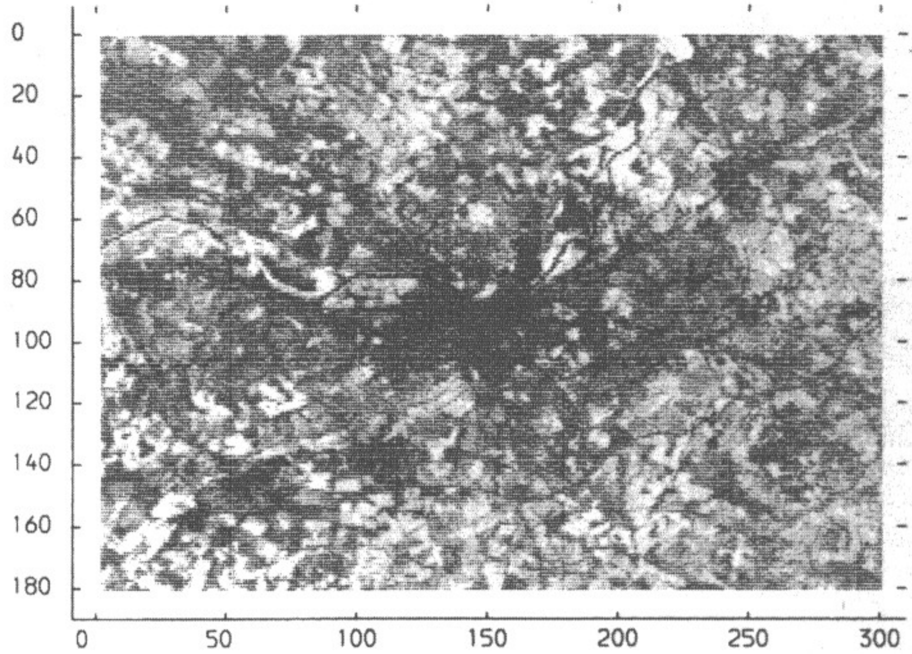


Figure 4. Enlargement print of a CalComp plot of an area 300 samples by 180 scan lines centred on Reading from the digital data (band 6) of LANDSAT scene E-1228-10293 (8th March 1973).

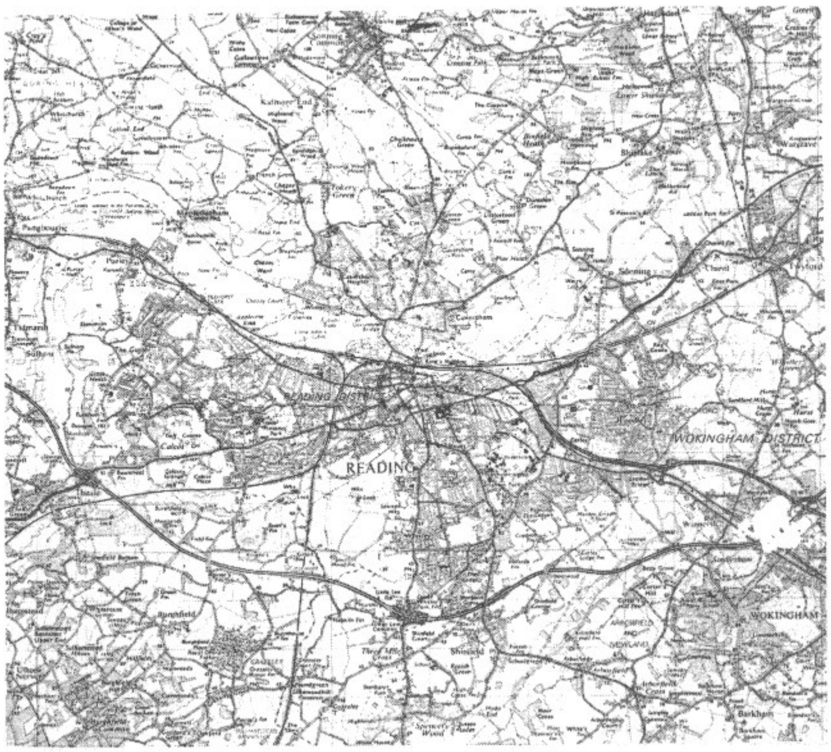


Figure 5. Reproduction (not to scale) of an area centred on Reading from a 1974 1:50,000 OS map (original in colour). Crown Copyright.

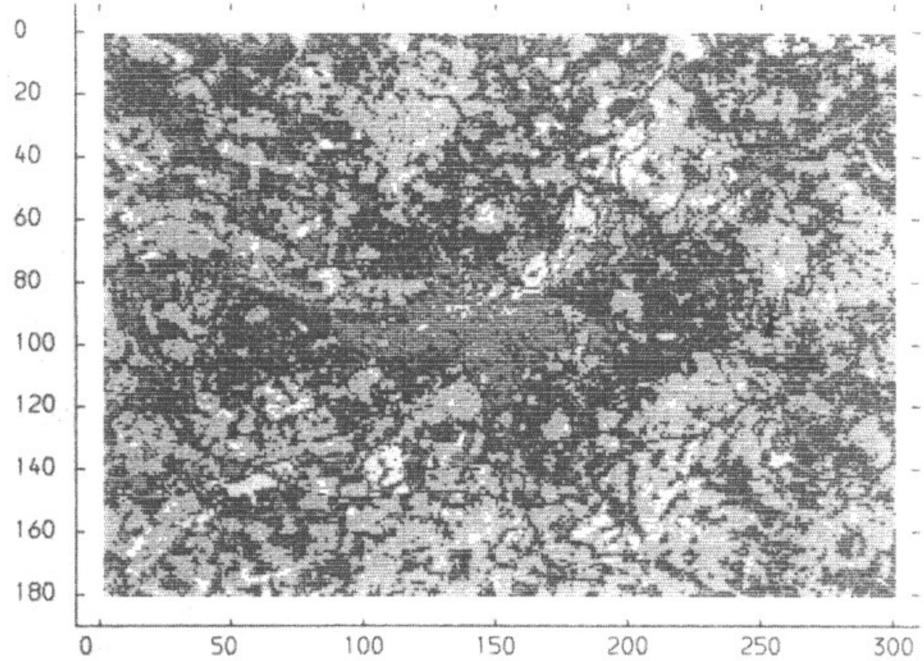


Figure 6. Result of density slicing in band 7 of the Reading area (8th March 1973) to pick out the outer urban (black), inner urban (dark), vegetation (medium) and water (very lightly shaded) areas. Areas not selected are white.

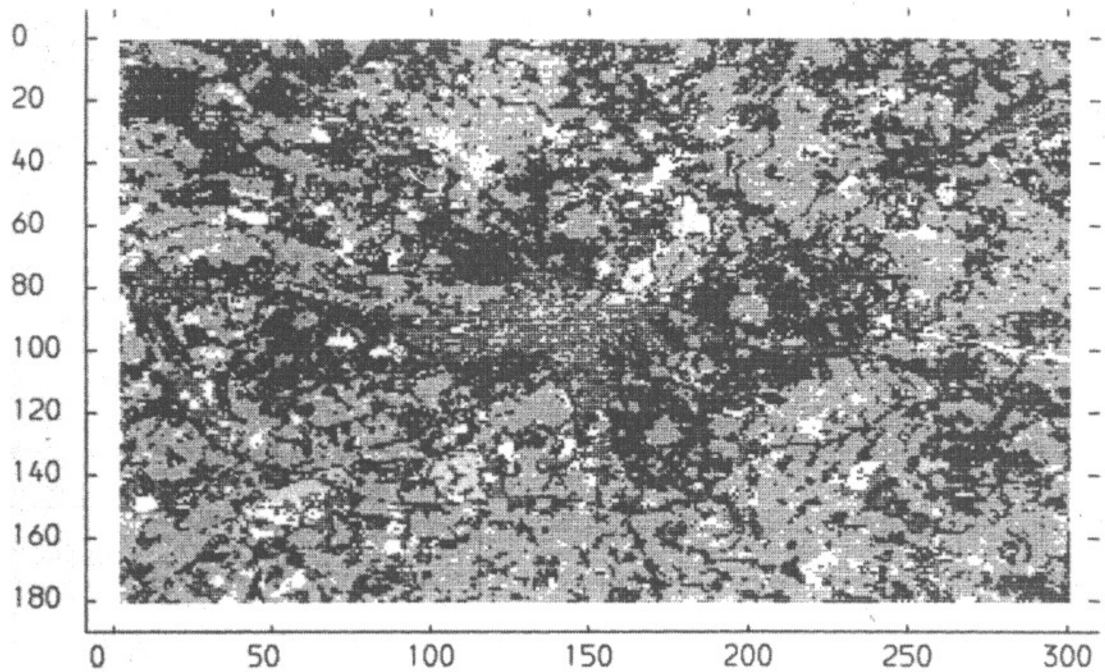


Figure 7. Result of classifying the Reading area (8th March, 1973) using all the information, into, outer urban (black), inner urban (dark), vegetation (medium), and water (very lightly shaded) areas, with white representing areas not classified.

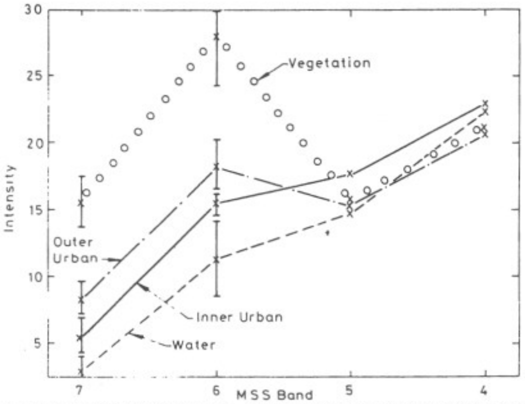


FIG. 8 MEAN SPECTRAL VALUES AND STANDARD DEVIATIONS FOR TRAINING AREAS SELECTED TO REPRESENT VARIOUS CLASSES IN THE READING AREA OF LANDSAT IMAGE E-1228-10293

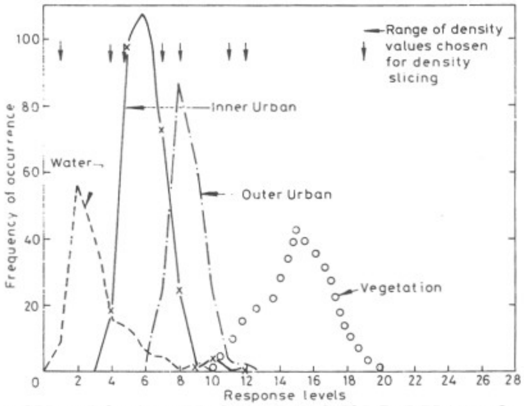


FIG. 9 DISTRIBUTION OF INTENSITY LEVELS FOR THE TRAINING AREAS REPRESENTING THE VARIOUS CLASSES IN THE READING AREA IN BAND 7

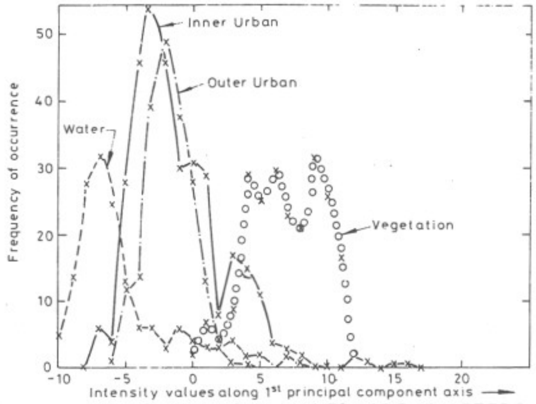


FIG. 10 DISTRIBUTION OF INTENSITY VALUES FOR THE DIFFERENT CLASSES IN THE READING AREA WHEN PROJECTED ONTO THE FIRST PRINCIPAL COMPONENT AXIS OF THE INNER URBAN CLASS

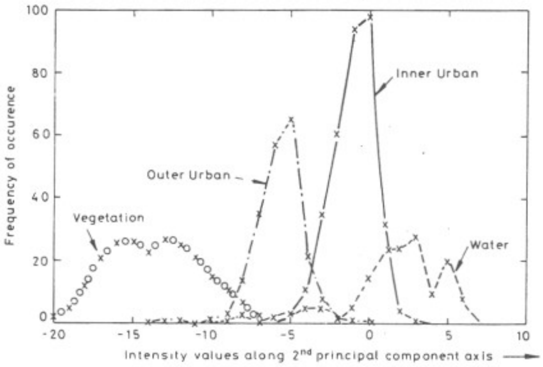


FIG 11 DISTRIBUTION OF INTENSITY VALUES FOR THE DIFFERENT CLASSES IN THE READING AREA WHEN PROJECTED ONTO THE SECOND PRINCIPAL COMPONENT AXIS OF THE INNER URBAN CLASS

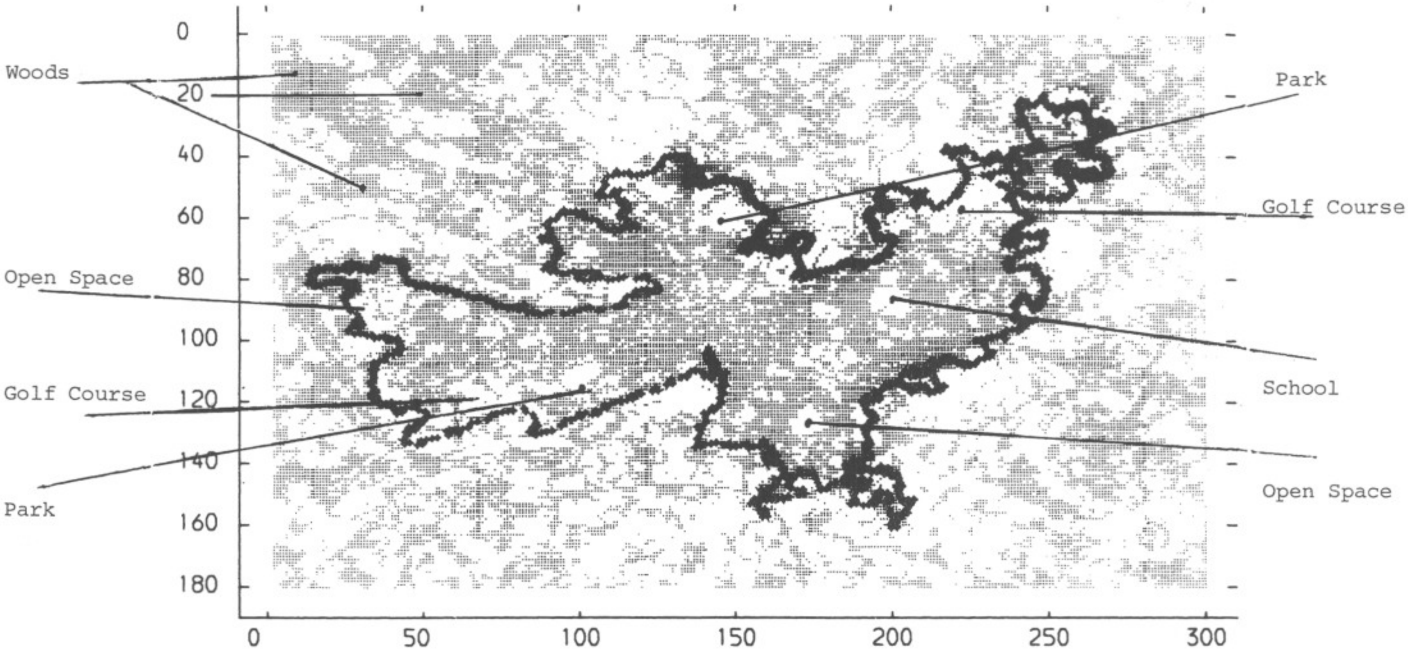


Figure 12. Comparison of the classification results for the inner and outer urban areas of Reading (light shading) with the DOE digitisation of the urban boundary from urban land use maps for 1969, updated to 1973 (black points).