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Urban Land Mapping from Remotely Sensed Data

Results suggest that the Landsat resolution is compatible with the requirement to map developed areas of 5 hectares or larger.

Abstract: *All developed areas, of five hectares or above, in England and Wales were mapped using aerial photography flown in 1969. The Department of the Environment is now undertaking research and development with the Image Analysis Group, Harwell to enable the monitoring of urban growth from this base year by Landsat imagery. It is necessary, therefore, that the automated classification of urban growth from Landsat data be comparable to the aerial survey. To ensure this comparability it is necessary to quantify the differences in the classification systems and to emphasize the use of ground verification procedures.*

Present indications are that the Landsat resolution is compatible with the DOE's basic requirement to map developed areas of over five hectares, though the capability to monitor change with the high level of accuracy required has not yet been established. The paper describes the ground-truth checking procedures and problems encountered in monitoring urban growth.

Introduction

The Department of the Environment (DOE) 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 taken up by development. In general, information about the use to which land is put in the United Kingdom (UK) has not been available. Claims have been made by some environmentalists that land is being destroyed by urban development at an alarming rate. While the limited statistics available do not confirm this view, the need for more comprehensive information does exist if land-use policies are to be monitored quantitatively. To meet this requirement a survey of developed areas from 1969 aerial photography was completed

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in 1978 and five categories of urban land use have been mapped at 1:50,000 scale. The maps cover the whole of England and Wales, and all "developed" areas greater than five hectares have been digitized for computer processing and constitute the first national data base of built-up areas. Further details relating to this survey are given below and a full description is given by Smith *et al.* (1977).

There is now a need to up-date regularly the initial data base. In order to test the feasibility of using the Landsat satellite data, the DOE and the Image Analysis Group of the Atomic Energy Research Establishment, Harwell, have developed a system for handling, displaying and classifying Landsat data (Carter and Jackson, 1976). The feasibility of using the Landsat data can only be checked by carrying out detailed "ground-truth" checks on selected test areas.

This paper describes the detailed checking carried out to test the results obtained for the Landsat data and the consistency of classification of specific land-use parcels. Detailed results for one test area are presented.

"Ground-truth," throughout the paper, will refer to land-use information collected from aerial photographs, topographic maps, and site visits and classified according to the urban land-use class definitions used for the 1969 Developed Areas Survey.

Remote Sensing Data Sources for Urban Land-Use Mapping

The data source for the survey of Developed Land in 1969 was 1:60,000 scale panchromatic aerial photography flown by the Royal Air Force in 1969. There would be three serious problems to be overcome, however, if the DOE wished to commission national aerial surveys on a regular commercial basis for the monitoring of land-use change.

These three problems are

- *The collection of data.* Problems of air traffic control and particularly the cloudy weather of the UK make comprehensive photographic cover on a regular basis both difficult and expensive.
- *The handling and classification of data.* Handling and organization of prints from many sorties in itself creates problems. Classification of the photographs must be undertaken by several interpreters, may take many months, and subjectivity in the classification procedure cannot be completely avoided.
- *The computer processing of data.* Following classification, the data must be digitized and processed into a format suitable for use with other data bases. This stage constitutes a major undertaking and, because of the numerous manual operations, is a common source of errors.

The cost of the above three stages is high, especially the acquisition of the data which may itself prove prohibitive. Also, while there is a high level of redundancy in 1:60,000 scale photography for national mapping restricted to urban land uses, this scale of imagery does not meet the needs of county and local planning authorities where scales of 1:12,000 and greater are typical. These factors and the increasing availability of alternative forms of data collection mean that it is important to consider other sources of land-use data which may be more appropriate or cost efficient for the collection and analysis of such broad national data. In particular, the last few years have seen the introduction of side-looking radar imagery (Henderson, 1977) for commercial and civil purposes and spaceborne imaging systems such as the multispectral scanners on-board the Landsat satellites.

The use of Landsat imagery for information at the national level overcomes many of the above problems related to the collection of data. Also, and most importantly, the cost of complete cover is very much less than for aerial photography. While the cloud problem is not solved directly by the Landsat satellites, the regular repetition of the orbits means that cloud-free coverage is likely at least on one or two occasions per year in the UK. The advantages of Landsat are now becoming well known (see Anderson, 1977; Gardner *et al.*, 1977) and include the synoptic coverage and computer compatibility.

The potential of airborne and spaceborne radar for urban mapping is less clear. The day/night and cloud penetration capability of radar is an obvious advantage of this data source for areas experiencing the weather of the UK. Complete cover of the UK by airborne radar would be both quicker and cheaper than a photographic survey due to the far less stringent demands for "good flying weather" and the wider swath-width of the obtained imagery. On the other hand, neither manual nor automated interpretation has yet been demonstrated as being able to give sufficient land-use information to justify the cost of this data acquisition.

Having assessed the feasibility of using space imagery for urban monitoring at the national level, the Department of the Environment is proceeding with research to establish a rapid survey system based on automated techniques of interpreting and classifying images. It is expected that the following advantages will accrue for the successful implementation of such a system:

- An increase in the amount and accuracy of land-use information for national and regional planning from regular and comprehensive surveys.
- An increased ability to monitor trends in land use and to assess the spatial consequences of implementing planning policies.
- A reduction in time and manpower required to produce national data.
- More objective information based on consistent criteria and related to a single time base.
- The application of the developed software to a wider range of inventory problems than just urban land use.

Collection of Ground Truth

The DOE survey of urban land use for 1969, referred to above, was used as the main source of ground-truth in assessing the accuracy of the Landsat classifications undertaken at Harwell. This survey mapped five urban land uses at the 1:50,000 scale incorporating all land-use parcels of five hectares or more. The five land-use classes were

A. Residential.
B. Industrial and/or commercial.
C. Education and/or community.
D. Transport.
E. Urban open space.

The five categories are defined in detail (DOE, 1978) with respect to the data sources so as to obtain a high level of objectivity in the interpretation, which was undertaken by a commercial air-survey company.

Using the above described "Developed Areas" maps, the outer boundary of the developed area for a number of test sites has been up-dated to the year of each Landsat classification with the aid of aerial photography, maps, and site visits. The location of these sites is shown in Figure 1. The updating has not been applied individually to all the categories of use since the present research is concerned only with monitoring change to the total developed area and not with change of land use within those areas.

Urban open space (Category E) has, however, been separately treated because the spectral return of such areas is similar to rural areas, and it has been therefore necessary to consider it as 'non-developed' for the purposes of automated classification. While it would be possible to add all 'non-developed' areas wholly surrounded by new growth to the total developed area, new peripheral urban open space cannot be so easily incorporated into the total urban area.

Finally, all water surfaces of over five hectares have been separately mapped irrespective of their land-use category, which may be B, D, E, or "non-developed" depending on the use made of them and their location in relation to other land uses. The

Fig. 1. Remote sensing test areas.

reason for this distinction was that, on the basis of a spectral return, no distinction can be made between water surfaces which are considered as being 'developed' and those which are considered as being non-developed.

Classification of the Landsat Data

The classification of the Landsat data may be undertaken (1) manually, (2) with computers plus manual assistance in the form of supervised classification algorithms, or (3) fully automatedly using unsupervised clustering techniques. In studying the potential of automated approaches to classification, research by Harwell has concentrated on the supervised approach. While unsupervised classification can be of great help in defining spectral signatures, the technique is often difficult to utilize effectively without considerable experience, and for the present it has been decided not to use such techniques in an operational system.

If accurate monitoring is to be undertaken, then irrespective of the approach used in the classification of the Landsat data, geometric rectification of the Landsat scene is necessary. While certain of the geometrical distortions can be predetermined and corrected routinely (e.g., attitude effects), others can be only corrected or, more properly, reduced in magnitude by the use of "Ground Control Points" (GCP's). GCP's chosen are physical features identifiable in the Landsat scene and whose locations are precisely known. The data presented in this paper have been rectified to the National Grid of Great Britain using a polynomial mapping function and nearest neighbor interpolation program written at Harwell. The standard error obtained was ~1 pixel (i.e., ~50 m). A number of programs for rectification are described in the literature (Wie and Stein, 1976; Bernstein, 1976) and the DIRS software from the COSMIC Library, which is more comprehensive than the Harwell program, will be used in the near future for the DOE work.

The next stage in classifying the image is the display and visual examination of the rectified scene. A direct comparison of the displayed image with existing maps and ground-truth is now possible and enables suitable training sites to be defined for a range of land-use classes (urban, water, woods, agricultural, heathland, etc.). Then, in order to assist the classification, the principal component axes of the Landsat data are determined for the training areas of each class. This data transformation maximizes the variance in the grey-levels recorded for each training class such that the first axis is in the direction of greatest variance and the remaining axes are associated with decreasing data variance. In order to classify each point in the image, it is transferred in turn onto each set of the principal component axes. The orthogonality of the principal component axes and an assumed Gaussian probability distribution for the data along each axis now allows classification of each point by allocating it to the land-use class for which it has the greatest probability (maximum likelihood) of belonging to (for a more detailed description see Carter and Jackson (1976)).

Experiments have also been carried out using high quality color photographic prints of enhanced Landsat data at scales of up to 1:50,000. The results of the visual interpretation of these data have been found to be helpful in developing the approach to automated feature extraction. If production of such high quality, large scale color products can be made more cost efficient, it is also considered that much information at a local level could be extracted from them, where presently special photography or ground surveys would otherwise need to be commissioned.

Ground-Truth Checking

Whichever method of classification is used, it is also essential to be able to compare spatially and quantitatively the results of the automated classification with ground information. The spatial aspect is of particular importance for some purposes and yet often ignored. If one requires to know only the total increase in urban land between year N and year M, then as long as misclassified rural land is 'compensated' for by an equal hectarage of developed land misclassified as rural, the misclassification is immaterial. If, however, the increase in urban land is such that it causes concern due to, say, the possible loss of high quality agricultural land, the location becomes important and "compensating" errors significant. One cannot confidently provide information from Landsat data on such problems as the quality of agricultural land being lost to development unless it is known in detail where, and under what circumstances, misclassification occurs. At the worst extreme one may have a very high level of overall accuracy in classifying developed areas, but the localities where change has occurred and which are of especial interest to the planner are consistently misclassified.

The DOE and AERE are therefore following a rigorous system of ground-truth checking and implementing the following steps:

- Ground-truth is provided by up-dating the survey of developed land for England and Wales to the date of the Landsat imagery (see section on Collection of Ground Truth).
- The ground-truth is digitized, encoded, and stored in raster form on a matrix of 50 m or 100 m squares referenced to the National Grid.
- The classified Landsat data are rectified onto the same matrix as the ground-truth.
- The Landsat data are classified into the required land-use categories.

After the above four steps, the differences between the ground-truth and the classified results can be calculated by the computer and the results then analyzed in terms of the spatial location of the differences. The areas of misclassification as well as correct classification are first plotted onto 35 mm film as one hectare squares such that the type of discrepancy or agreement between the ground-truth and Landsat classification is identified. The computer plots are then enlarged to a scale of 1:50,000 and printed in multiple colors superimposed over the black-plate of the Ordinance Survey 1:50,000 topographic map.

By using the "difference-maps" described above, the discrepancies between the ground-truth and classified results may be allocated quantitatively into four categories.

DIFFERENCES DUE TO THE AMBIGUITY AND SUBJECTIVITY OF THE GROUND-TRUTH CLASSIFICATION.

A subjective approach was required from the interpreter even though the land-use classification was accompanied by detailed operational definitions. It was defined, for example, that areas of fragmented development where breaks in the continuity were less than 50 metres were to be amalgamated. In practice, however, ribbon or scattered development, together more than five hectares in extent, might be mapped where breaks of more than 50 metres occurred or not mapped even though no gaps of this magnitude were present. Precise measurement of all such breaks was impracticable and estimation was by eye. A similar situation existed in relation to the minimum parcel size to be mapped.

Discrepancies between the Landsat classification and the updated aerial survey also arose due to ambiguity in the actual classification or because of ambiguity in what is shown on the photographs. For example, large houses and estates were mapped according to the definition, "Where a large house stands in gardens and parkland only the ornamental gardens will be shown" [as residential]. Clearly, the actual divisions between "ornamental" and "non-ornamental" when judged from 1:60,000 scale photography will often be arbitrary. Similarly, abandoned gravel workings may be industrial land, urban open space, or non-developed depending on the stage of excavation or reclamation.

In a typical instance, where the Reading test area was classified for July 1975, of the total number of discrepancies 10 percent (or 2 percent of the total test area) could be allocated to reasons defined above.

DIFFERENCES DUE TO THE GROUND-TRUTH CLASSIFICATION BEING INAPPROPRIATE FOR USE WITH LANDSAT DATA.

Under the definitions used for the 1969 survey, many land uses are categorized on the basis of relative location as well as use. Reservoirs, golf courses, and motorways are examples of land uses classed as developed only when within or adjoining other development. With the addition of contextural information to the present Landsat classification procedures, it may be possible to approximate more closely the present definitions. Certain differences, however, are unlikely to be reconciled even with improved resolution and sophisticated algorithms for the inclusion of textural and contextural information. Examples include small airfields using grass runways, and camp sites where the number of tents may not be sufficient to affect the spectral signature. In these instances it will be necessary to alter the definition of developed land to match more closely the information content of Landsat imagery. The percentage of the discrepancies which fall under this heading is relatively small (5 percent to 10 percent of the differences) indicating that a high level of consistency between a Landsat classification and the Developed Areas Survey is at least theoretically possible.

"GROUND-TRUTH" ERRORS

These are discrepancies caused by mistakes in interpretation, bad plotting, digitizing errors and changes in land-use between the date of the "ground-truth" and the date of the Landsat imagery. Such errors constitute about 6% of the discrepancies.

ERRORS IN THE LANDSAT CLASSIFICATION

At the present stage of software development this is still the most common cause of discrepancy (~ 75 percent). Errors in Landsat classification may result from poor geometrical rectification of the imagery, inadequate spatial or spectral resolution from the scanner, inadequate ground-truth training, or lack of sophistication in the classification software. The most frequent cause, however, is that certain ground areas (bare soil) have very similar spectral signatures to urban areas.

Careful study of the maps of discrepancies also provides other valuable information of use in improving the accuracy of classification. Ground features which are consistently misclassified (or, conversely, always correctly classified) can be determined, allowing one, if desired, to adapt the classification procedure to these strengths or weaknesses. Similarly, the effect of weather, season, geology, etc., on the classification of different ground features can be determined and taken into account in the classification or the assessment of the classified results. Finally, of course, the discrepancy maps indicate the areas of land-use change between two known dates. The separation of the differences due to land-use change from all the other causes of discrepancy is the major objective of the research.

Results

At present the research has concentrated on six test areas ranging from a small town in rural East Anglia (6,771 ha) to a large area (160,000 ha) west of London containing a number of large towns. Other areas include a coastal site in north-west England and the outskirts of Manchester which included parts of the Pennine Hills. Landsat images for March, May, June, July, and September have been examined.

In broad terms, single date classification using only spectral information produces initial accuracies on the order of 80 percent for Developed Areas correctly classified and 85 to 95 percent for rural areas. On detailed examination of large scale photography and site visits, actual accuracies are 1 or 2 percent higher due to errors in the mapping, digitizing, or raster encoding of the ground-truth.

The comparison of automated classifications with the ground-truth (described in the section on Ground Truth Checking) yielded significant information. Areas which are physically developed in the sense that the ground has been covered by some man-made material and which are grouped so as to cover and area of five hectares or more can be classified as developed with a very high level of accuracy. Two problems exist, however, which mean that such an ability is of little value in itself.

First, in classifying the areas covered by 'man-made' materials as developed, other areas which are not developed for urban use are grouped into the same category. Such features are quite varied in type but usually have the characteristic that the vegetation cover is poor or missing. In one test area, fields, where the chalk geology was very evident at the surface, were frequently misclassified. Woodland and heath also were frequently difficult to separate out from urban, especially for the drought year of 1976 when the infrared response was low.

Second, many "developed" features are not wholly, or even largely, brick or concrete type constructions. In areas of suburban housing the proportion of ground covered by buildings, rather than gardens or tree covered paths and road, may be quite small. Many factories and public buildings have substantial grounds surrounding the actual buildings. In such instances misclassification is more likely.

The examination of automated classification of Landsat imagery and visual interpretation of Landsat color composites demonstrated, however, that the accuracy of classification of areas of new development was high. For an automated classification of a test area around Reading (15,665 ha) and monitoring change over a three year period, there were 202 ha of new development representing a growth of 1.3 percent of the total test area. Of this 202 ha, 73 percent of all the new developments of more than 2.5 ha were correctly delimited and 18 percent were left unclassified. In the unclassified areas 78 percent were found from ground checks to be new extended gravel workings. No new development of over 2 ha was wholly misclassified, and the largest single error was 4 ha in a 28-ha new development. These four hectares were in fact "urban open space", but because of the minimum threshold of 5 ha when using the 1969 Developed Area Survey definitions, they are classified with the development in question as industrial. The total classified urban growth was, however, much greater than 202 hectares (1659 ha).

A visual interpretation of an area (47,500 ha) around Northampton gave a similar result when the interpreter made use of existing maps as well as the Landsat scene. In this instance 74 percent of new development over a six year period was identified correctly. Discrepancies, which were partly due to using an unrectified Landsat print, corresponded broadly to those obtained with the automated interpretation.

There are two main problems, therefore, to be solved in improving classification accuracy.

- to improve the percentage of developed areas correctly classified.
- to reduce the incidence of non-developed areas being classified as developed.

It was in meeting the second of these aims that the visual interpretation showed an improvement over the automated classification. This reduction was due not just to the discrimination of tonal differences, but to the interpreter taking account of position, shape, and related land uses. It was at this stage in the research program that the automated classification was extended to incorporate non-spectral information.

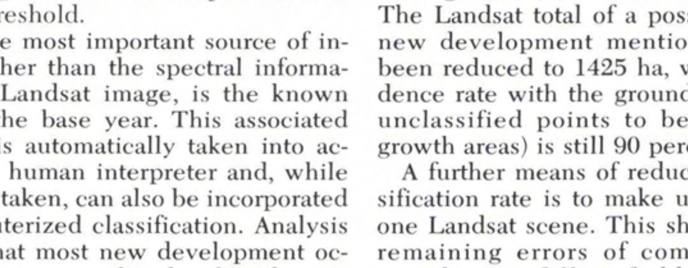
The first and most simple step to reduce the level of misclassification in monitoring change in developed areas was to exclude from the classification all changes of use of less than 2.5 ha. Checks by DOE frequently showed changes of only one or two pixels (100 m × 100 m (1 ha) unless otherwise stated) to be due to rectification errors or due to the limited resolution of the Landsat data. If the change of land use indicated is not spurious, then the new development will be recognized and mapped once the area of contiguous new developed exceeds the 2.5 ha threshold.

Perhaps the most important source of information, other than the spectral information on the Landsat image, is the known land-use at the base year. This associated information is automatically taken into account by the human interpreter and, while care must be taken, can also be incorporated into a computerized classification. Analysis has shown that most new development occurs adjoining or near other developed areas. A simple rule may therefore be devised which (1) accepts a Landsat classification of new development if part of a classified urban area is within X-metres of presently existing developed areas and (2) accepts a Landsat classification of rural from a base classification of urban if part of it is within Y-metres of a presently existing rural boundary.

The idea of only searching for change near the periphery of the developed area boundary obtained from the 1969 survey means that most of the false classifications of new development in the rural areas are eliminated. Also, there is now only the need to search for new urban areas beyond the known urban boundary defined for the base year. Since new urban development is associated with construction work and consequently often the clearance of vegetation cover, genuine change is fairly consistently recognized from the satellite imagery.

The 2.5 hectare rule and the spatial elimination rule have been applied to the classified Reading test area shown in Figure 2. The results are seen in Figure 3. Since many of the unclassified points were associated with growth, they were considered as possible growth during the spatial elimination. The elimination rules are very effective in rural areas at eliminating falsly classified thinly vegetated and fallow fields as urban, but they do not overcome the problem of false growth around the urban periphery. The Landsat total of a possible 1659 ha of new development mentioned earlier has been reduced to 1425 ha, while the coincidence rate with the ground truth (allowing unclassified points to be considered as growth areas) is still 90 percent.

A further means of reducing the misclassification rate is to make use of more than one Landsat scene. This should reduce the remaining errors of commission corresponding to fallow fields or where the



■ Ground Truth rural - classified urban
Ground Truth urban - classified urban

■ Ground Truth urban - classified rural
Ground Truth urban - classified urban

FIG. 2. Classification of Reading Test Area (8/6/76) with respect to 1973 ground truth using (1) only spectral information.

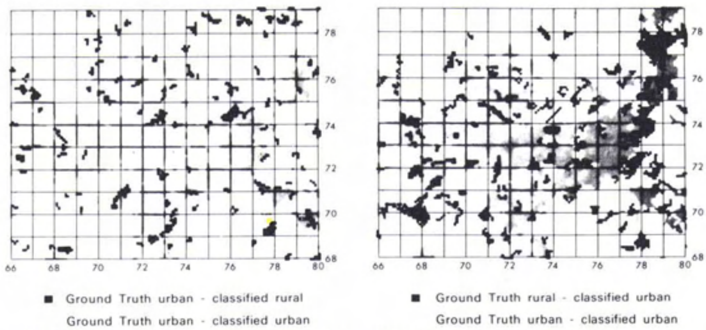


FIG. 3. Classification of Reading Test Area (8/6/76) using (1) spectral information, and applying (2) 2½ ha threshold for inclusion of new development and (3) 1973 ground truth (x = 200 m, y = 100 m).

ground cover was very thin. The approach to multitemporal classification was not, however, to move from a 4-channel to 8-channel multispectral classification, but to clarify each scene separately and to use the second Landsat scene to check for consistency areas classified as new development in the first scene. On this basis only those areas which meet the following three criteria would be considered as new development:

- the contiguous area of change (parcel) comprises an area of > 2.5 ha, RULE 1;
- the parcel meets certain locational criteria in relation to the existing land-use data base, RULE 2; and
- two independent Landsat classifications agree of the change in land use, RULE 3.

The use of a second Landsat scene (6/9/76) is demonstrated in Figure 4. In this example classified growth from the scene of 8/6/76, which is beyond the 1973 outer boundary (Figure 3), is only accepted if it is also classified as urban in the second scene. The overall amount of classified growth has been dramatically reduced to 358 hectares, showing the potential of this check. In addition, on detailed checking at least 159 hectares of this total, which was thought to be wrong on comparison with the ground truth, was found to correspond to mineral extraction areas, motorways, etc. Hence, Landsat is picking out all areas of "bricks and mortar," and the definitions of "developed" areas must be amended to allow for this. These new rules are now being applied to much larger test areas in order to determine their effectiveness in enabling the growth to be accurately determined.

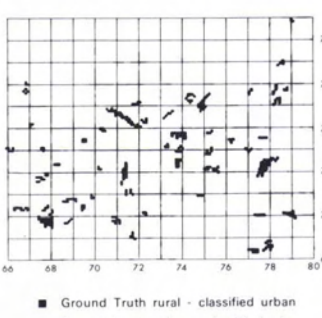


FIG. 4. Classification of Reading Test Area (8/6/76) using (1) spectral information, and applying (2) 2½ ha threshold for inclusion of new development and (3) 1973 ground truth (x = 200 m, y = 100 m) and (4) a second Landsat scene (6/9/79).

FUTURE WORK—REFINEMENT

The above model for classification is still over-simplified, and a number of adjustments and refinements will be necessary as test results are checked for validity. Optimal values for the restricted search area for new development must be estimated as must the optimal threshold size below which areas of land-use change will be ignored. Classification is also more complicated than the given examples in that, at present, land use is classified not only into rural and urban but also water and woodland, with further categories expected to be added in the future.

Areas which are identified as new development from their spectral signature and which also satisfy the necessary criteria laid down in Rules 1 and 2 of the basic model (6.11) may still be discounted on the basis of Rule 3, i.e., the two independent Landsat classifications give conflicting results. It would be possible to make use of the specific deviation of the pixel intensities from the land-use class means in order to improve conflicting results, if the necessary increase in computing time can be accepted. Additional refinement may also be achieved if from experience one can assume a correct classification of urban areas at some times of the year more than at others. Thus, the incorrect classification of pixels as "developed" may be less likely from June imagery than from September imagery. On the basis of the above comments, a more correct classification would be obtained by applying Rules 1 and 2 plus a weighted result from two separate Landsat scenes. The weighting would be a function both of the variance of the pixel from the land-use class mean and the season in which the imagery was acquired.

The above refinements may also be a partial solution to the problem of isolated developed areas which, through new development, exceed the 5 ha threshold. A rule may be built into the model which states that, even if a group of pixels do not meet Rule 2 for new development (i.e., they are ≥ 200 m from existing developed areas), they may still be classed as new development if the weighted classification from two separate Landsat classifications suggests a high probability of change. The spectral criteria for such isolated parcels to be classified as new development would be much more stringent than for those parcels meeting the Rule 2 requirement.

Three further refinements may be made by weighting the classification decision on the basis of information about

- the shape of new development,
- the size of new development, and
- the texture of new development.

It has been shown by the Department of Environment, from examination of Landsat images and their automated classification, that rectangular shaped areas classed by the automated interpretation as urban are liable to be fields which have been recently harvested, burnt, or ploughed. Manual interpretation of enhanced imagery also encountered the problem that these fields appeared to be spectrally indistinguishable from some urban areas. The human interpreter will, however, frequently make the correct classification because of the characteristic shapes of these parcels, their isolated locations, i.e., not adjoining previous Developed Areas, and the unlikelihood of such a large (>>5 ha) new development appearing between the last base-date and the re-survey date. It is also the case that such parcels are spectrally more similar to inner urban areas rather than suburban areas or expanding villages. Where large new developments do occur it has been observed that compared to fields they are less consistent in tone and often shape, with the component parts of the new development—road layout, large buildings, and cleared ground—giving a much more textured appearance.

It is likely that, even after all such refinements have been implemented, some new areas of development (or areas which have returned from developed use to rural) will not be correctly identified from Landsat images. While representing only a small proportion of the total area of new development, they may become significant over a number of years. To overcome this problem it may be necessary at five yearly intervals, to print-out from the computer classification records all areas for which there is even a low probability on the basis of spectral and contextural information of a change in land use. Manual up-dating could then be applied by reference to other sources of information, e.g., maps and photographs for the specific low probability areas. Because of the information available from satellites, however, such updating could be far more selective and therefore quicker than full re-survey from aerial photography.

Finally, a problem exists in the monitoring of urban open space. While it is possible to measure the loss of urban open space from the 1969 base year, the recognition of new urban open space presents a difficulty. Once an area becomes totally contained by development, it should be possible to class the contained area as urban open space though this itself is not a trivial problem. Manual up-dating, therefore, for new peripheral urban open-space may also be required at periodic intervals.

Summary and Conclusions

The U.K. Department of the Environment is concerned with collecting information on the rate at which land is being taken up by development and the location of the land-use change. The use of Landsat imagery should offer advantages in availability, cost, data processing, and statistical analysis.

The use of single date supervised spectral classification techniques with the Landsat data enables the recognition of developed areas with an accuracy of typically 70 to 80 percent. This level of accuracy is inadequate for the Department of Environment's monitoring requirements.

Since new development is itself fairly well recognized (plus a great deal of falsely classified growth), it appears sensible at the present state of development to limit the search for growth to an area around the periphery of the developed areas already mapped from a previous aerial survey. This ensures that, at the time of the new survey with Landsat, over 90 percent of the total developed area is already accounted for and all that is required is to recognize the last few percent. Since much false growth may still be picked up, it is suggested that this can be eliminated by confirming the growth on more than one Landsat scene of the same area.

The paper indicates that to monitor land-use change by Landsat will require the use of spectral, textural, and other geographical information combined and weighted to give a confident classification for each pixel. To improve the accuracy of monitoring, research must proceed with equal emphasis on both theoretical development based on *a priori* reasoning and empirically derived concepts based on experience from the examination of Landsat imagery. Detailed ground-truth checks of classifications now being made and an understanding of the factors influencing change of land use will assist the further development of classification software.

Results presently obtained suggest that the Landsat's present 79 m instantaneous field-of-view (IFOV) is compatible with the requirement to map areas of 5 hectares or larger and that further development of the techniques described will allow the monitoring of land-use change for national and regional planning purposes. Accuracy levels may also be expected to improve as higher resolution data (both spectral and spatial) becomes available. Aerial photography will continue to be needed to provide land-use information for more detailed planning and to enable more detail land-use distinction to be made.

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