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Dr. C. Emmott

Division of Surveying & Planning,
Preston Polytechnic, England.

Dr. W.G. Collins

Remote Sensing Unit,
University of Aston in Birmingham, England.

AIR PHOTO INTERPRETATION FOR THE MEASUREMENT OF CHANGES IN URBAN LAND USE

Abstract

Increasing concern is shown by governments in the use of land for urban purposes. The collection of land use information and the monitoring of changes is difficult but essential.

This research is concerned with the use of aerial photographs for the recording and measurement of changes in urban land use. Tests are carried out to assess the measurement characteristics of line grids and of dot grids on maps and on aerial photographs. Experimental evidence indicates that the optimum system for the measurement of urban land use involves the use of orthogonal dot grid overlays to the aerial photographs.

A methodology is developed whereby computer programmes enable comprehensive land use information to be obtained from simple manual inputs taken directly from the photography.

Introduction

The conversion of agricultural land to urban use and the efficient and appropriate use of existing urban land, are factors of current and increasing concern to planners and geographers. In Great Britain a number of different approaches have been adopted for estimating the extent and composition of the urban area and for monitoring changes in these.

Best (1957, 1968, 1976; Best and Coppock, 1962; Best and Champion, 1970) used the statistics submitted to central government by local planning authorities. At the other extreme of the data gathering spectrum Coleman (1960, 1968, 1978a, 1978b) has been concerned with obtaining land use information by direct ground survey. Intermediate between these extremes, other researchers have collected urban land use data by means of sampling techniques applied to published Ordnance Survey maps. Fordham (1974) applied systematic sampling to each of a random selection of maps in order to calculate the extent and composition of urban land in the U.K. and its regions in 1951 and 1961. Dickinson and Shaw (1977) applied a systematic unaligned point sampling pattern to large scale maps to obtain land use areas for the city of Leeds; these data formed the base line against which changes were determined by direct field survey.

The use of such secondary sources as government statistics and published maps results in uncertainty as to the reliability of the information collected. On the other hand, direct observation on the ground is costly in terms of time and effort and does not yield quantitative data directly.

Aerial photographs may be considered a primary source, in that all objects visible on the ground are recorded on the photographs. Furthermore, air photographs taken at dates in the past yield information not readily available from other sources and, in addition, from a sequence of such photographs land use changes may be measured. The aim of the research reported here was to develop and test a methodology for the use of aerial photographs for the measurement of changes in urban land use.

The methodology was seen as being required for the collection of areal data for the following purposes :

(a) geographical analysis of urban land in terms of :

- (i) areal extent,
- (ii) changes in the size of the urban area,
- (iii) conversion to urban use of previously non-urban land,
- (iv) the internal composition or structure of the urban tract.

(b) provision of basic data for town planning

Broad parameters for the system were formulated as follows :

(a) it should be as simple as possible and make use of readily available air photographs and equipment,
(b) it should yield areal data of adequate and definable accuracy,
(c) it should be capable of yielding land use information at such a level of classification as to be consistent with the requirements of the user, and with the identified land uses assembled in a hierarchical classification so that the data might be handled at the various levels of detail,
(d) it should enable the data to be handled either manually or by computer.

The system was developed and tested with reference to a 70 square kilometre area within which lies the town of Preston. Panchromatic aerial photography at a nominal scale of approximately 1:10,000 taken in the years 1946 and 1973 was used for the project.

Land Use Classification Scheme

A classification scheme was devised which was sufficiently detailed whilst still giving an acceptable level of accuracy in the identification of the various sub-categories on the aerial photographs. Interpretation of stereo pairs of photographs for a 4 square kilometre test area was carried out with land use being identified in as great a detail as possible with no a priori classification. An a posteriori classification scheme was then devised to give the optimum balance between detail and accuracy. This was then used as the a priori classification for the survey of the 70 square kilometre area.

The classification scheme was in four levels of detail, the following being the main categories :

1. Urban Uses
   - 1.1 Residential
   - 1.2 Educational
   - 1.3 Industrial
   - 1.4 Open Space
   - 1.5 Commercial and Public
   - 1.6 Transport
   - 1.7 Services

2. Non-Urban Uses
   - 2.1 Agricultural
   - 2.2 Woodland
   - 2.3 Water

Systems for the Measurement and Representation of Land Use

Broadly speaking, methodologies for the collection of land use data by the interpretation of remote sensing imagery may be grouped as follows according to their output products :

(a) primary and only product - land use map,
(b) primary and only product - areal data,
(c) primary product - land use map; secondary product - areal data derived from the map,
(d) primary product - areal data; secondary product - graphical representation of the data.

The methodology required for the present project fell within group (d).

The weight of evidence in the literature (see, for example, Colcord, 1972; Grey et al., 1973; de Bruijn, 1974) is in favour of the recording and measurement of land use areas by means of a grid or by systematic sampling, rather than by the recording and subsequent measurement of land-use polygons. Also, grid systems lend themselves to manual preparation of data for input to the computer. The most promising options were considered to be :

(a) the transcription of interpreted land use units onto a base map and the transformation of these units to cellular format for data processing,
(b) recording interpreted land use on a data sheet, cell by cell, directly from the photographs by means of a grid overlay.

Since the primary requirement was for areal data (supplemented by illustrative graphical material) and since an exact map representation was not required it was desirable to bypass the production of a land use map. The most convenient system, thus, would involve the recording of land use data in cellular format directly from the photography. This would form the computer input for the generation of areal data and computer graphics.

In order to determine the optimum system, balancing accuracy against practicability, the following test procedure was adopted :

(a) derivation of an accuracy datum against which to compare the grid systems,
(b) selection of the type of grid to be used, i.e. grid cells or points,
(c) selection of area measurement base, i.e. map or air photograph,
(d) selection of the optimum size of unit cell or grid density.

Accuracy Datum

The interpreted land use units of the 4 square kilometre test area were, by a process of detail inspection, transferred from the photographs onto 1:10,000 scale Ordnance Survey maps. The area of each unit was then measured by means of an Ott disc polar planimeter and a list of category areas compiled.

The disc planimeter is a precision instrument designed for the accurate measurement of small areas (vernier least count 2 sq.mm). Experimental results in the present project together with the work of Zill (1955) and of Frolov and Maling (1969) indicated that areas obtained by planimeter might be expected to be from 6 times to over 16 times as precise (according to the size of unit cell) as those derived from grid or point counting. Thus, any discrepancy between areas derived from sampling techniques and those obtained by planimeter measurements might reasonably by treated as errors in the sampling results.

Grid Type

Two alternative applications of the system may be recognised.

(a) the method of squares, in which a line grid is placed over the tract for which land use areas are required, and the dominant use within each square recorded,
(b) the point or dot counting technique whereby each notional unit cell is represented by a dot at its centre.

It is assumed that either the dominant use or that recorded at the centre dot occupies the whole cell. Areas are then calculated either by taking account of the size of the unit cell, or by considering the cell or dot counts as proportions of the total count, the total area being known.

It was not possible, on literature evidence, to determine the most accurate of these systems since reports are few and contradictory (see, for example, Abell, 1939; Gierhart, 1954). Consequently tests were carried out to compare the accuracies of category areas obtained using the two grid types.

Category areas were calculated from grid square and dot counts carried out on the land use maps compiled for the planimeter measurements. In each case grids of unit cell 100 sq.mm, 50 sq.mm and 25 sq.mm were used, these being equivalent to ground areas of 1.00 ha. 0.50 ha and 0.25 ha at the 1:10,000 scale of the maps. The results were analysed by means of multiple regression using an equation derived from the work of Yuill (1971):

$$(S\%)^{\frac{1}{2}} = A + B \ln X_1 + C \ln (X_2\%)$$

in which $S\%$ = percentage difference between the grid and planimeter area,

$\ln X_1$ = natural logarithm of the total number (X_1) of the grid squares or dots counted.

$\ln (X_2\%)$ = natural logarithm of the percentage $(X_2\%)$ of the total area occupied by the category in question (i.e. the category percentage area).

Multiple regression and correlation yielded the following results :

Grid Squares : $(S\%)^{\frac{1}{2}} = 11.75 - 1.02 \ln X_1 - 1.42 \ln (X_2\%)$

$R = 0.774, \quad R^2 = 0.599.$

Dot Grids : $(S\%)^{\frac{1}{2}} = 11.62 - 1.01 \ln X_1 - 1.57 \ln (X_2\%)$

$R = 0.820, \quad R^2 = 0.672.$

In Figure 1, values of $S\%$ are plotted against category percentage area $(X_2\%)$ for a total count of 100 units. It may be seen that the dot grids produced somewhat better results, particularly for small category percentage areas.

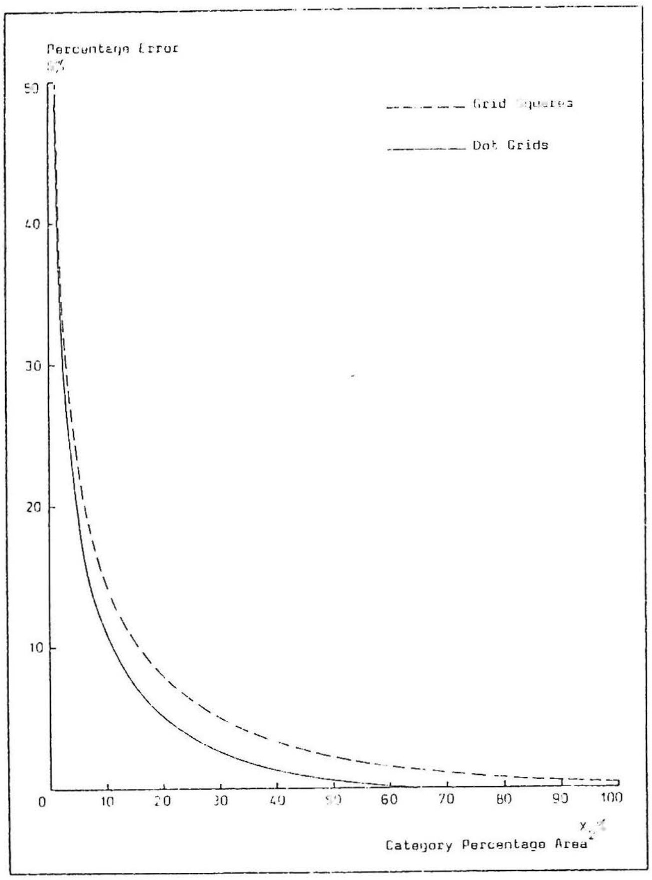

Figure 1. Percentage error against category percentage area for a total count of 100: comparison between grid squares and dot grids.

In addition, the following characteristics of the two grid types, noted during the tests, reinforce the choice of the dot grid as being most suitable.

Grid squares :

(a) categories occuring in small or narrow linear units rarely if ever form the dominant use within a square and, thus, will tend to be omitted or systematically underestimated,
(b) the process of judging dominant use within a square is frequently difficult and always subjective even on a simple chorochromatic map; this difficulty would be very much greater when combining the three processes of photointerpretation, recognition of land use boundaries and judgement of dominant use within a grid cell.

Dot grids :

(a) the relationship of dot count to category depends on the proportion of the total area occupied by each category not on the size or shape of individual land use units; thus there is no tendancy towards systematic underestimation of categories occuring in small units,
(b) no estimations of proportion or dominance are required.

Measurement Base

Category area measurements were then carried out directly upon photo overlays depicting the land use units before transcription onto the base map. The areas so derived were compared with the planimeter values and the results subjected to multiple regression analysis. The equation obtained was :

$$(S\%)^{\frac{1}{2}} = 11.36 - 0.93 \ln X_1 - 1.66 \ln (X_2\%)$$

$$R = 0.822, \quad R^2 = 0.676$$

As may be seen in Figure 2, areas obtained directly from the photographs were very nearly as accurate as those taken from the map. Certainly the very small reduction in error resulting from transcription of the units from the photographs to the maps did not justify the effort involved.

Grid Density

From the plotted curves relating percentage error (S%) and total dot count (X_1) it was apparent that for a category percentage area of 1% there is a marked increase in the rate of change of percentage error against total dot count, for counts of less than 400 dots. This characteristic persists for category percentage areas up to 10% but for areas of 20% the critical value is in the region of 200 dots and falls to 100 dots for a category percentage area of 50%.

These factors together with a consideration of the sizes of the administrative districts (wards) of the study area indicated that the optimum dot grid for the survey would have a notional unit cell of 1.00 ha (approximately 10 x 10mm). This would result in dot counts of from less than 100 in the small town-centre wards to over 400 in the larger wards in the outer areas. Thus, higher levels of accuracy would be expected in the areas of greatest land use change. The predicted errors in category areas, listed in Table 1., were considered acceptable.

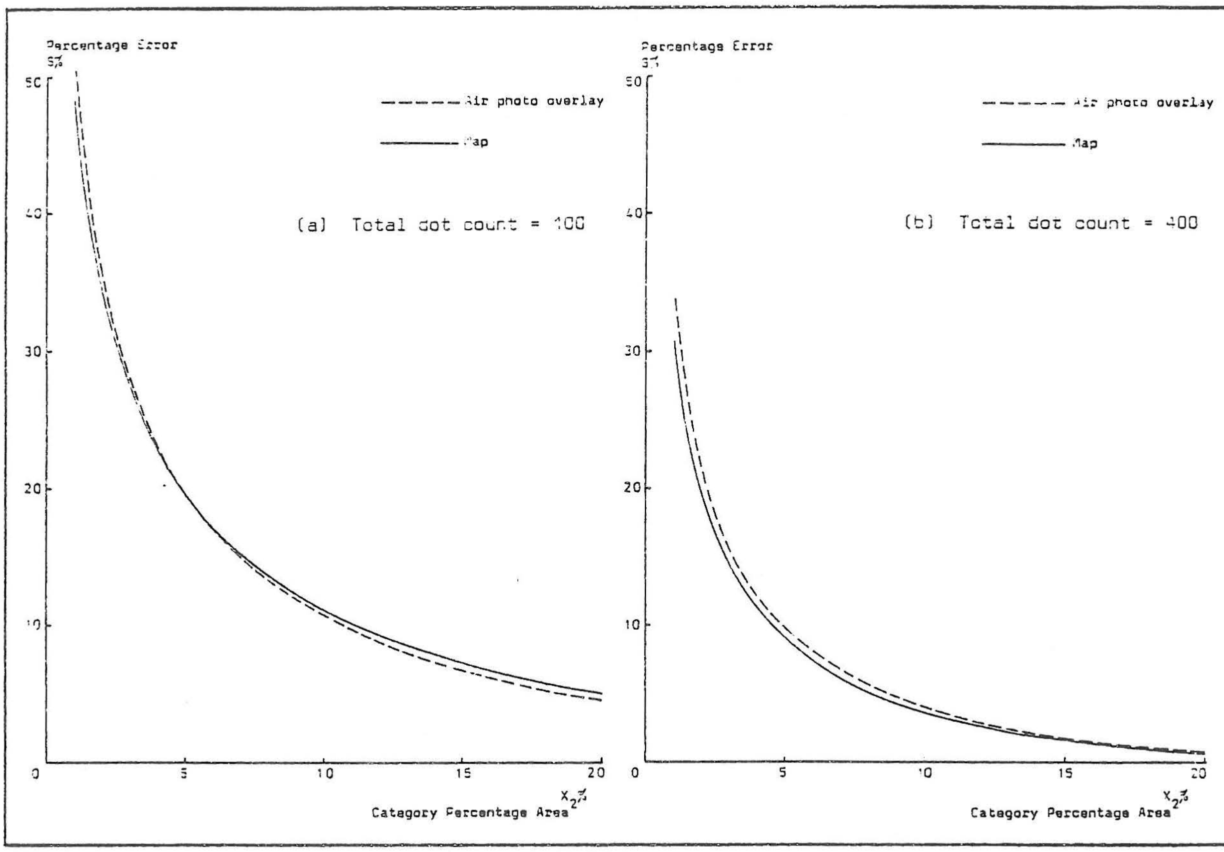

Figure 2. Percentage error against category percentage area: comparison between measurements made on air photo overlays and on maps.

CATEGORY PERCENTAGE AREA ($X_2\%$)	100 ha WARD				400 ha WARD			
	% ERROR (S%)	ERROR (S)	CAT AREA ha	ERROR ha	% ERROR (S%)	ERROR (S)	CAT AREA ha	ERROR ha
1	50.38	0.50	1.00	0.50	33.80	0.34	4.00	1.36
5	19.56	0.98	5.00	0.98	9.35	0.49	20.00	1.90
10	10.70	1.07	10.00	1.07	3.95	0.40	40.00	1.60
20	4.49	0.90	20.00	0.90	0.70	0.14	80.00	0.56
50	0.36	0.18	50.00	0.18	0	0	200.00	0

NOTE: $X_2\%$ = Category area expressed as percentage of ward area

S = Error in $X_2\%$

$S\%$ = Percentage error in $(X_2\%) = \frac{S}{(X_2\%)} . 100\%$

Table 1. Actual error in category area corresponding to values of percentage error and category percentage area.

The Recording and Measurement of Land Use

In outline, the system employed was as follows :

(a) a range of 1.00 ha dot grids was constructed to allow a close matching of grid scale to mean photoscale; five scales were required, ranging from 1:12,000 to 1:10,500,
(b) by reference to corresponding map and photograph details a dot grid of the appropriate scale was placed in coincidence with the National Grid transferred from map to photograph,
(c) with the 1973 stereopair under a Wild ST4 mirror stereoscope (8 times magnification) the land use category at each dot was recorded on a data sheet which indicated the position of each dot and the 4 figure numeric land use code,
(d) the procedure was then repeated with the 1946 photographs of the same administrative unit.

The advantages of this method are, firstly, that land use is recorded at identical points for each year; thus the changes noted are real rather than apparent resulting from lack of correspondence between the dot positions. Secondly, land use maps may be produced which are comparable point by point and which may be combined to cover the whole study area without gaps or overlaps. Thirdly, the land use information is compatible with other data referenced to the National Grid or the administrative units, e.g., population census figures.

Computer Processing and Presentation of Land Use Data

For each grid point a four-digit land use code had been recorded in its correct relative position. In this form the data can be processed either manually or by computer. Computer programmes were written in FORTRAN to produce listings of land use areas, land use change matrices and computer maps of land use and changes in use.

Tables of category areas contain a great deal of information regarding total land use at the two dates of survey. Also, comparison between corresponding tables for the two dates yields information of net changes. However, information relevant to the study of land use changes and which cannot be obtained directly from these tables concerns the detailed changes between categories which have resulted in the net changes. In order to obtain such detailed information land use at the two dates must be compared point by point. The programme written for this purpose produced change matrices as exemplified in Table 2. Computer maps were produced to illustrate land use and land use changes. The ease with which the programmes enabled data to be sieved for the production of selected multiple or single theme maps was seen as an important advantage of the use of a cellular format.

Conclusion

The direct recording on data sheets of land use interpreted from aerial photography is a simple and rapid system which produces a data set of useful accuracy and amenable to processing either manually or by computer. Computer handling frees the researcher to concentrate on those stages in the system which he, rather than the computer, can best carry out, i.e. photointerpretation, analysis of the land use information and correlation of this with other variables.

In the project reported here, the land use data obtained were correlated with population data and significant relationships recognised.

PRESTON LAND USE 1946/1973 CHANGE MATRIX

PRESTON STUDY AREA

		1 9 7 3										
		1100	1200	1300	1400	1500	1600	1700	2100	2200	2300	TOTAL (1946)
1100		1004.36	3.00	3.12	33.17	41.46	2.94	0.00	7.01	1.01	0.00	1096.06
1200		1.99	40.77	0.00	0.94	0.00	0.00	0.00	0.00	0.00	0.00	43.70
1300		2.00	1.08	187.95	17.86	63.28	0.98	0.00	10.13	0.00	1.05	284.34
1400	1	83.23	14.97	11.02	383.41	35.02	13.09	0.00	15.69	0.00	0.00	556.42
1500	9	3.02	3.16	2.97	2.08	212.89	4.08	0.00	0.00	0.00	0.00	228.19
1600	4	0.98	1.08	0.99	17.67	6.96	193.68	0.00	0.95	0.98	0.00	223.32
1700	6	10.85	0.00	0.00	5.90	0.00	0.99	23.56	23.71	0.00	0.00	65.01
2100		539.70	127.62	55.75	228.21	49.66	85.51	0.00	2781.08	19.21	0.00	3886.74
2200		4.03	0.98	0.00	3.09	2.07	2.03	0.00	2.03	163.20	0.00	178.32
2300		0.00	0.00	0.00	2.04	0.00	0.00	0.00	0.00	0.00	121.85	123.89
TOTAL (1973)		1650.16	192.66	261.81	695.25	411.33	303.31	23.56	2840.62	184.41	122.90	6686.00

Table 2. Land use change matrix for the Preston study area.

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