ANALYSIS OF MULTISPECTRAL LANDSAT PICTURES

K. Seidel, W. F. Berg

Department of Photography
Swiss Federal Institute of Technology (ETHZ)
Zuerich, Switzerland

Abstract

LANDSAT satellites are equipped with scanners which record the radiation from the earth surface in four spectral channels. Features on the ground have a "spectral signature": a certain combination of data in the four channels. The records in the four channels represent a four-dimensional feature space, in which each particular feature is characterized by a volume, similar to the CIE color space; the size and location of that volume must be established by identifying that feature on the ground ("ground truth"). The recognition and analysis of features implies the establishment of their spectral signature and a subsequent classification of as many as possible of the picture elements (pixels) into appropriate groups. By means of computer methods, this can be done automatically. The success and the limitations of this procedure will be demonstrated on pictures of snow in the high alpine regions of Switzerland and on land use in the Po valley of Italy.

Introduction

Since July 1972 a satellite launched by NASA circumnavigates the globe with the task of recording data on earth resources. The most useful intrument on board this Earth Resources and Technology Satellite (ERTS-1, since renamed LANDSAT-1) is a multispectral scanner (MSS) shown schematically in Fig. 1[1]. The recorded data are characterized by Tables 1 and 2[2], which show that the satellite travels from pole to pole, the earth turning underneath it, so that a slightly inclined strip of the surface is being scanned (Fig. 2). The MSS data are radioed down to a ground station where they are processed such as to deliver photographic pictures or computer-compatible magnetic tapes, on which the MSS video signals are recorded digitally. The satellite can also store data on magnetic tape if too far away from a ground station, as e.g. until recently over Europe. In a preprocessing stage the data are corrected by a receiving station for satellite-specific aberrations.

The recorded information represents the reflectivity of the earth surface in the four spectral channels of the MSS. A quantitative analysis, such as in our case the "Snow Survey and Vegetation Growth in the Swiss Alps" is best carried out by means of computer methods. In order to check the results, to enable the non-technical user to judge them, or simply for the purpose of display, pictures of photographic quality can be produced on suitable electro-optical process-computer controlled equipment.

Image Processing - Analog and Digital

The volume of the data offered is impressive, and so is the effort to digest them: no fewer than 311 groups of researchers are busily engaged on the evaluation from various points of view (Table 3). Even for a single group, the data have to be carefully handled to be sure that one is not swamped. Fig. 3 shows examples of LANDSAT-recordings in the 4 spectral channels. This is a good illustration of the power of multispectral recording: the pictures are strikingly different, so that it should be possible to recognize features on the ground from suitable combinations of the signals in the four channels. This is "multispectral analysis": the main topic of the present survey. The figure also illustrates the other advantages of satellite imagery

- relatively large sections of the earth surface are recorded simultaneously,
- the point of view from which all picture points are recorded in any one frame or as between successive recordings is identical: orthogonal projection, and
- the same region is recorded successively every 18 days so that dynamic changes on the earth surface can be detected.

From Fig. 3 four "false-color-composites" have been prepared which cannot be reproduced here. For each of them the three channels 4, 5, and 7 have been reproduced in different selected sets of primary colors on integral tripack color paper; in each case the color contrast

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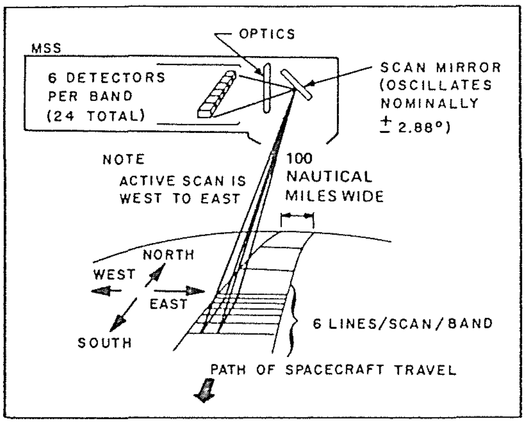

Fig. 1:
LANDSAT Multispectral Scanner (MSS) and its field of view

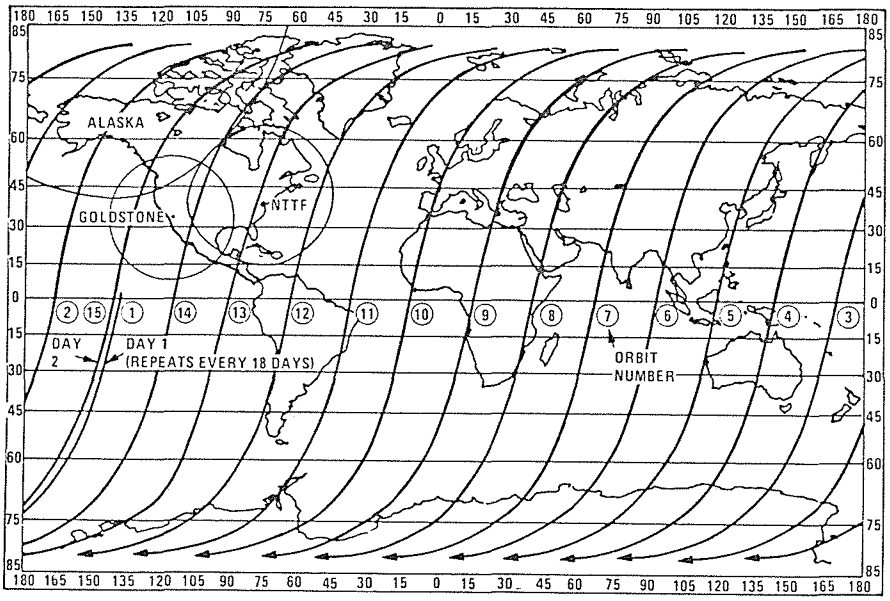

Fig. 2:
Typical LANDSAT Coverage - One day[1]

Table 1: LANDSAT mission parameters

Apogee	917 km
Perigee	898 km
Inclination	99.0 degrees
Anomalistic period	103 minutes
Eccentricity	0.0012
Local time at descending mode (equatorial crossing)	9:30
Coverage cycle duration	18 days
Distance between adjacent ground tracks	159.38 km

Table 2: Multispectral Scanner (MSS) characteristics

Instantaneous field of view	0.086 mrad	Spectral band range: 4	0.5 to 0.6 μm
Earth area subtended	6240 m^2	5	0.6 to 0.7 μm
Mirror oscillation range	±2.89 degr	6	0.7 to 0.8 μm
Mirror oscillation frequency	13.62 Hz	7	0.8 to 1.1 μm
Scan lines per oscillation	6	Number of detectors	24
Cross track field of view	11.56 degr	Sample word length	6 bits
Cross track scan	185 km	Samples per line	3240
Sampling interval of detector output	9.95 μs	Lines per band	2340
		Information per scene	30.4×10^6 bytes

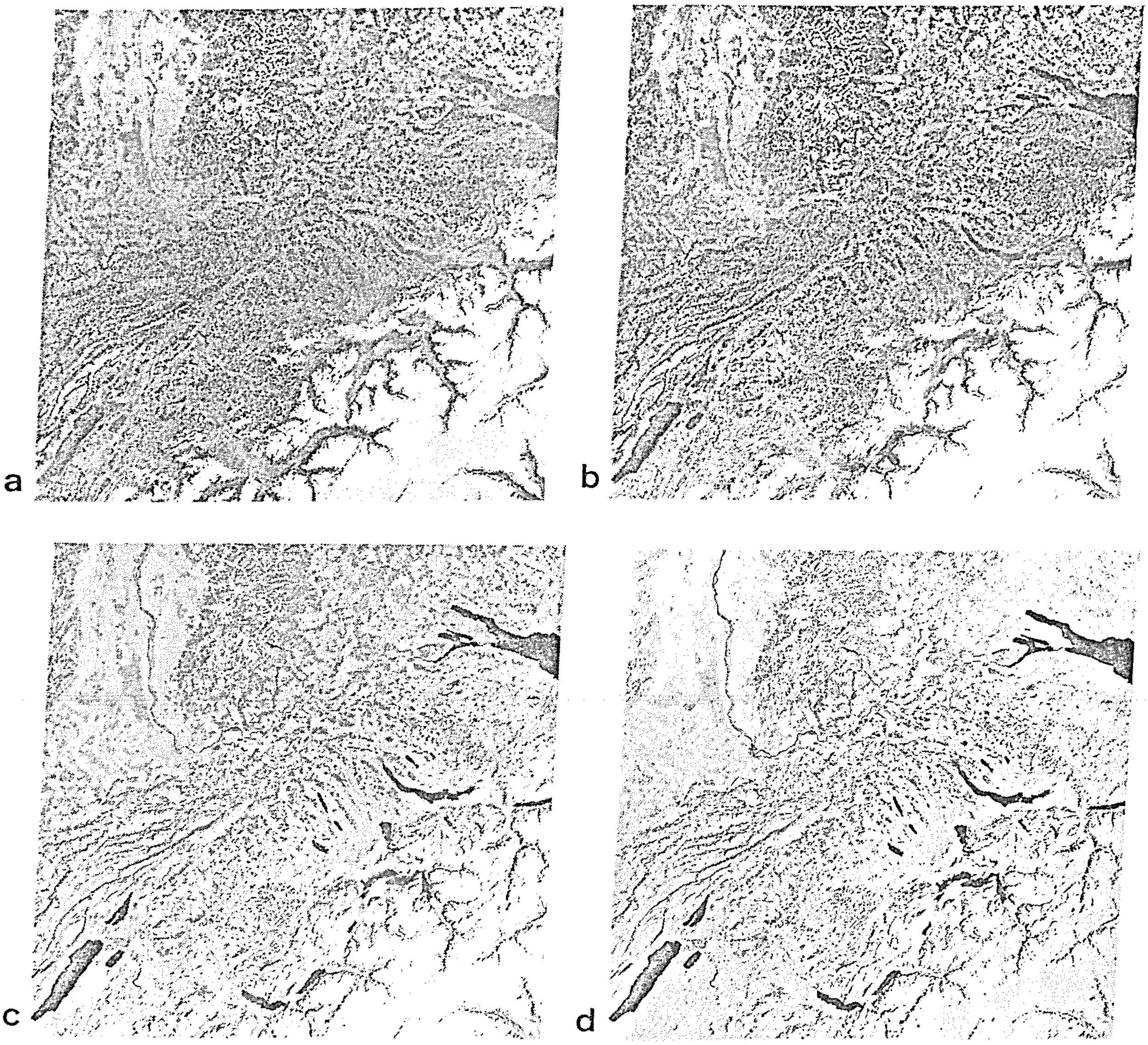

Fig. 3: LANDSAT MSS Recording: E-2091-09382 (April 23, 1975)

The four channels are recorded (a) in channel 4: 0.5 - 0.6 µm
(b) in channel 5: 0.6 - 0.7 µm
(c) in channel 6: 0.7 - 0.8 µm
(d) in channel 7: 0.8 - 1.1 µm

Table 3: Some disciplines involved with satellite imagery

Agriculture	Landform surveys	Land use mapping
Range resources	Marine resources	Geological structure
Mineral resources	Forestry	Water resources
Environmental surveys		

of water has been enhanced by photographic masking. In this way different features of the landscape can be brought out, as e.g. a river valley with its morphogenetic differentiation or similar structures in woody hill country; sites of conurbations; different kinds of soil.

The scene used for this is a good example for "analog image evaluation" such as is practised in conventional interpretation of aerial photographs. The desired information is always taken from the combination best suited for the recognition of features under study by hand, as is were, and transformed to a map.

Analog methods do not lend themselves to automatic evaluation; for this digital methods are available and continue being improved. The principle: the combination of the signals from the four channels is identical with the analog method but now the combination is established for each pixel. Since the data are transmitted for any one pixel one at a time, digital processing would appear to be method of choice where

- automatic evaluation is required and
- the cost of labour is high but computers are available.

Image evaluation comprises a series of well-recognizable stages, as set out in Table 4. The procedure naturally divides into three stages: Preprocessing, Classification and Presentation. In preprocessing some of the treatments are of general nature, others are problem-dependent, as is all the rest.

Image Processing

A certain degree of preprocessing is carried out by NASA before the users get the pictures; this is not of importance here.

The Table 4 sets out operations carried out by the user, not all of which are required in each case. "Mosaicing" is simply the placing of adjoining pictures in their correct geometrical position, where the difficulty of projecting the curved earth surface on a plain represents the real proplem. "Reformatting" is the process whereby the NASA digital data are transformed into the format most comfortable for the user's software. The transformation of the radiometric scale is akin to the choice of a printing paper to match the density scale of a negative. However, a much greater degree of freedom exists: the transformation may be nonlinear, and in general its purpose is to aid in the discrimination of features in the classification to be described below.

Table 4: Image Processing

Image Preprocessing		Image Classification	Image Presentation and Correlation
Image Restauration	Image Enhancement		
-Image restauration (noise abatement, radiometric and geometric correction) -Mosaicing -Reformatting	-Transformation of radiometric scale -Edge enhancement -Spatial filtering	-Decision making technique (on the basis of spectral and spatial information patterns)	-Display of the results -Change and difference detection (comparison with other sources of information)
General	Problem-dependent		

TABLE 5: DECISION MAKING TECHNIQUES AFTER STEINER (1972)

PATTERN DISCRIMINATION

- TRAINING SAMPLES (SUPERVISED LEARNING)
- DETERMINISTIC METHODS
  NO PROBABILITY CONCEPTS
  DISCRIMINANT FUNCTIONS
  DECISION: SAMPLE IN CLASS WITH LARGEST DISCRIMINANT SCORE
- STATISTICAL TECHNIQUES
  PROBABILITY DISTRIBUTION

PARAMETRIC	NON PARAMETRIC
DISTRIBUTION IS GIVEN ANALYTICALLY	UNKNOWN DISTRIBUTION
EXAMPLE: GAUSSIAN DISTRIBUTION	EXAMPLE: POTENTIAL FUNCTIONS, HISTOGRAM METHOD

  DECISION: BAYES' DECISION RULE
  MAXIMUM LIKELIHOOD

PATTERN CLASSIFICATION

- NO TRAINING SAMPLES (UNSUPERVISED LEARNING)
- NATURAL GROUPINGS IN FEATURE SPACE (CLUSTERS)
- DETERMINATION OF SELECTED CLASSES: AFTERWARDS BY GROUND SAMPLING INFORMATION

Image Classification

Table 5 attempts to give a theoretical survey of decision-making techniques. This is based on the fact that the gamut of spectral reflectivities of ground elements as recorded by the MSS: their "spectral signature", represents a four-dimensional "feature space" in which each element is characterized by a single point. Since ground elements of the same type are likely to be close to one another in feature space, classification of any new ground element consists in deciding, which group in feature space it belongs to.

A detailed discussion of the table would take too much time, so that only the most important features can be summarized. In order to classify pixels the feature space must be separated somehow into sub-volumes which correspond to known categories. The main distinction is between the use or non-use of such training samples (training or learning sets or groups): "supervised or non-supervised learning" (s. Fig. 4).

A training sample is a group of picture elements on the ground whose nature is known as "ground truth" from other sources. If a sufficient number of such groups were established, classification of the whole picture should be possible, without any left-overs. Classification without training samples may also be possible, provided the spectral signatures of ground elements of any one of the various types are sufficiently similar to form "clusters" in feature space. An analysis of a whole picture would automatically provide a number of such clusters, which would then have to be identified afterwards by sampling ground information.

Complete classification without training samples may be just an impracticable dream: it has certainly not been carried out so far. The method may, however, eventually become useful com-

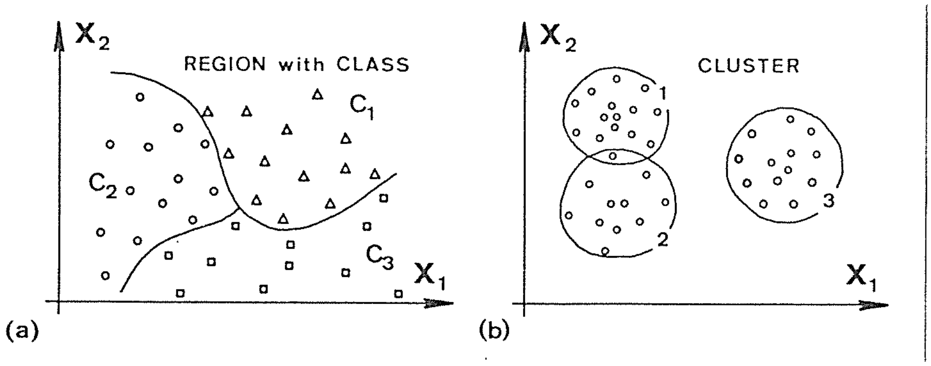

Fig. 4: Schematic Feature Space (a) with well defined regions
(b) with natural groupings (clusters)

bined with supervised learning. As result of a supervised classification, a number of pixels may remain unclassified. The cluster method may then help to discover whether other clearly definable groups of pixels exist (which would, of course, have been classified before if the appropriate training groups had been chosen). The method may also be used to discover whether any of the learning groups should be divided into sub-groups.

More elaborate classification routines take into account not only the spectral signature of each pixel but also those of the neighbouring ones. This concept implies that one would try and sort out in the picture not just the individual pixels, but groups or areas of similar pixels: "per field classification".

In our own work we have applied methods of supervised learning. Here the success entirely depends upon the correct choice of training samples. The better we know our feature space the more likely we are to assign the pixels correctly.

The training samples are naturally subject to statistical fluctuations. For any one sample the larger the number of pixels and the closer together they are the more definitely is the position of their center of gravity defined. In the method of "stepwise linear discriminant analysis"[3] we have used, one assumes that the training samples are normally distributed and from that, as a first step one derives a set of discriminant functions. As the second step one classifies all picture elements according to these functions.

The basic principle of decision making as to which learning group any one pixel is to be assigned is that of "maximum likelihood": it is assigned to the nearest group in terms of distances in feature space. To aid discrimination we may be using distorsions such as the adjustment of radiometric scales described above or even the introduction of new synthetic axes; as an example the ratio-variables may be mentioned.

There will always be cases where a pixel is too far away from any one learning group in feature space to make a sensible assignment. A step of thresholding is introduced by which such pixels are classified as unassignable.

Various calculating programs are in use for putting into effect the classification procedure outlined above. The choice will depend both on the computer available and on the exigencies of the problem to be solved. Thus for example if the number of pixels is relatively small it will be economic to work out directly all the distances from neighbouring training samples. For a feature space of few dimensions it is advantageous from the computing point of view to construct a "look-up table" on the basis of which the pixels are sorted out. A similarly simple method in terms of computing effort is to subdivide the feature space into parallelepipeds into which the pixels are placed; here the effort goes into the preparation of the necessary limits, and the classification itself is simple.

Image Presentation

The results of the classification of a picture will have to be presented for inspection and comparison with other sources of information. Present-day standard computers are ill-equipped for this type of output, and specialequipment is required for presentation on, e.g. a color TV monitor (RAMTEK and COMTAL units). We have been using an electro-optical drum scanner and writer (PHOTOMATION P 1700 by OPTRONICS INT.) for this purpose which records pic-

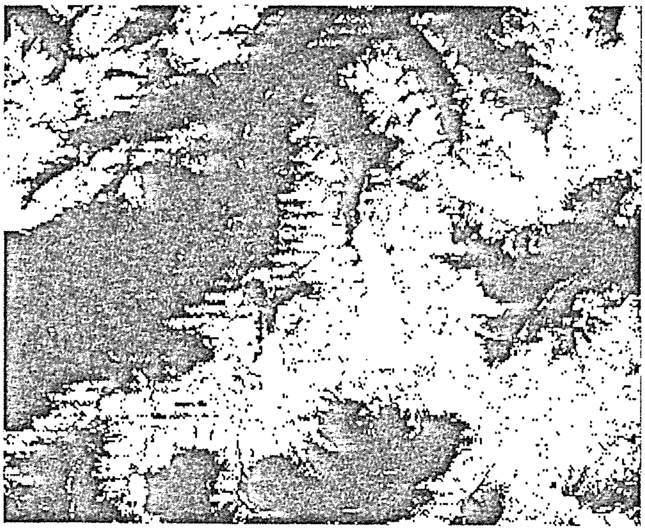

Fig. 5: Snow Classification BERGELL[4]
white: snow in bright sun, in shadow, in melting zone
black: background

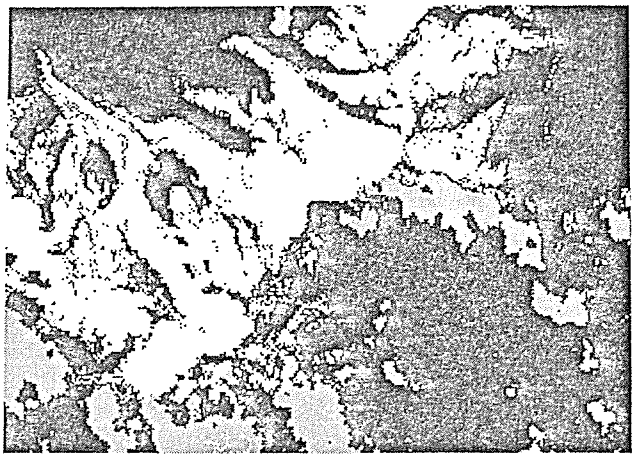

Fig. 6: Snow and Cloud Classification from SKYLAB MSS Data[6]
white: snow - gray: clouds
black: background

tures pixel by pixel on a sheet of film. Interactive systems have great advantages and should be so designed that the subject-oriented, but computer-wise unskilled researcher would be able to utilize it. This calls for sophisticated software and in turn for a considerable effort to create it.

An ideal system would both be interactive and provide a practically instantaneous hard-copy output. The hardware components for such a system do in principle exist, and to acquire them is simply a matter of finance. This would not, however, solve the problem of fast automatic picture interpretation. An enormous software package would be required, and at our present state of evolution one does not see a way of obtaining this with a reasonable effort.

Thus the final arbiter and interpreter even of the classified data remains the human mind. No automatic method is in sight which would be capable of making choices and decisions at a higher level and would replace the mind in its ability both of interfering interactively at the early stages and judging the final results.

Examples

The following pictures are to demonstrate applications of multispetral analysis and illustrate both the power and perhaps some of the limitations of the method.

Fig. 5 is part of a NASA project "Snow Survey and Vegetation Growth in the Swiss Alps". The purpose of this continuing job is to determine the degree of snow coverage at different times, to follow the regions where melting snow adjoins open earth and the resulting changes in vegetation. This is important for the hydrology and the water household in the alpine regions.

Snow occurs in different forms, each with its own spectral signature, which fortunately turned out to be well distinct from that of any other feature in the landscape. The picture shows all the snow white and the background black, in generally good agreement with ground truth.

One of the difficulties in carrying out snow analysis is the similarity between snow and clouds. Whilst we have no trouble in separating snow and clouds by inspection on the basis of shape, this has not so far been possible by any automatic method, especially since the spectral signatures are very similar in the four LANDSAT channels. A further infra-red channel (1.55 - 1.75 µm), such as has been provided by SKYLAB and is hoped to be installed in one of the later LANDSAT satellites, will supply the additional information required.

Fig. 6 results from a SKYLAB recording and shows the categories "snow", "clouds", and "background" clearly separated by a parallelepiped classification routine.

Fig. 7: Land Use Classification MILANO[5]

Original classification result in color: blue: water - violet: city
red: suburban areas - magenta: bright reflecting areas
white: dead vegetation - yellow: living vegetation - green: forests

Here the 3 gray tones represent: black: city - gray: suburban areas
white: rest

One of the most widely practiced applications of LANDSAT data is land-use. Fig. 7 shows the region around Milano, Italy.

Ideally, the complete classification would be presented in color, which cannot be done here; we achieved the following categories: Water - City - Suburban - Bright (reflecting areas) - Dead vegetation - Living vegetation - Forestry. Thus some partial classifications are presented in 3 tones of a gray scale (Fig. 7): black = city; gray = suburban; white = rest.

The picture bears evidence of some misclassification: the small white spots in the inner city (classified as water). To improve this discrimination between other categories would suffer, and where, as in this case, the misleading information is obvious, no harm is done.

An interesting procedure could again be demonstrated in color only. This would be a comparison of a discriminant analysis (into two groups only: live and no vegetation) with a much simpler scheme of using the ratios of the signals in channels 7 and 5, where a value larger than 0.5 denotes vegetation and less than 0.5 its absence. By overlay of two monochrome-films resulting from these two ways of analysis even an insignificant amount of misclassification can be recognized and localized.

Conclusions

It may fairly be stated that investigators have been overwhelmed by the flood of data supplied by the remote sensing capabilities of satellite imagery. Methods of analysis had not been prepared in advance, and investigators' outlook was often somewhat pessimistic. This has changed largely because the availability of the data strongly stimulated research into methods of analysis. There is a strong temptation to set up such methods for their own sake, but this must be resisted: the real fascination lies in the interdisciplinary aspect of image analysis, calling for work in teams of system analysis with project-oriented researchers.

Although the results presented here as well as other experiences have made us optimistic regarding the potentialities of multispectral analysis of satellite imagery, it must be realized that we are still at a stage of initiation, devoted to the study of techniques. The analyses have been confined so far to relatively small areas of a satellite frame. Thus, e.g., we know that identical training samples cannot be used over the whole of a satellite frame, let alone on the neighbouring ones, which are recorded a day apart, or repeat frame 18 days later, since atmospheric conditions will vary both locally and temporally.

These, however, are not principal difficulties; they merely require an increased effort. Thus we reckon that the way has been paved for the solution of large-scale problems such as can be tackled by satellite imagery only.

Acknowledgements

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References

1. ERTS DATA USER'S HANDBOOK. Greenbelt, Maryland, NASA Goddard Space Flight Center, 1972.
2. R. Bernstein: "Digital Image Processing of Earth Observation Sensor Data", IBM J.Res.Develop. 20, 40-57 (1976)
3. W. J. Dixon: "BMD Biomedical Computer Programs. Berkeley, Los Angeles, London, University of California Press, 1973.
4. R. Gfeller: "Untersuchungen zur automatisierten Schneeflächenbestimmung mit Multispektral-Aufnahmen des Erderkundungssatelliten ERTS-1". Dissertation Zürich, 1975.
5. R. P. Binzegger: "ERTS-Multispektraldaten als Informationsquelle für thematische Kartierung (Landnutzung im Raum Mailand)". Dissertation Universität Zürich, 1975.
6. R. Muri: "Digitale Auswertung multispektraler Erderkundungsdaten (SKYLAB-EREP)". Diplomarbeit Universität Zürich, 1976.
7. D. Steiner et al.: "Automatic processing and classification of Remote Sensing Data", chapter 3 in Geographical Data Handling, ed. R. F. Tomlinson, Vol.1, IGU Comm. on Geogr. Data Sensing and Processing, Ottawa/canada, 1972.