ROMANIAN MINICOMPUTER BASED REMOTE SENSING SYSTEM

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ABSTRACT: The paper deals with some aspects concerning the use of Romanian 16-bit minicomputers in developing remote sensing data processing systems. Fast Fourier transform, data compression algorithms based on principal component transform, geographic registration techniques as well as classification strategies are emphasized. Landsat MSS data and test sites as well as ground control points are used as raw data.

1. INTRODUCTION

According to the latest trends in remote sensing and cartography, the Research Institute for Computers and Informatics (ITCI) - the leading institute in computer science in Romania included the application of digital processing technology to remotely sensed data interpretation among its objectives. Consequently, a Remote Sensing Research Group (RSRG) embarked on the design and implementation of the first Romanian remote sensing system.

The RSRG activity focused on making remotely sensed data exploration and map production a convenient integrated and interactive process. In the mapping applications addressed for the time being, the imagery information is the primary tool for accessing and evaluating large amounts of information pertaining to Earth phenomena. The RSRG efforts aimed at both devising effective algorithms and taking maximum advantages of the available hardware resources. Furthermore, future developments in the ever changing environment of the hardware, the systems programmers and the users is taken into account. On this ground modularity and high-portability are intrinsic features of the designed system.

The purpose of the paper is mainly to present the considerations underlying the development of EXOSAT - the first Romanian remote sensing system. To achieve high performant software implementation on the available 16-bit minicomputer architecture is a most difficult challenge. The paper is outlined into five sections.

In the second section we give a general view of the major remote sensing application fields taken up in our country and focus on the original aspects related to some specific problems.

Section three tackles the development of the remotely sensed data processing system EXOSAT laying emphasize on the problems we have solved and the system capabilities resulted in.

The fourth section addresses the future approach based on new hardware and software environment to aim at integrating remotely sensed data processing systems within large geographic information systems.
Finally, we conclude with an overview and some comments pertaining to the development of remote sensing systems on Romanian computers.

2. MAIN APPLICATIONS

Landsat imagery has not gained wide acceptance among Romanian application experts as a tool for resources problem solving on regional scale, yet. However, on the ground that the application of remote sensing technology in our country has a great potential in the inventory of natural resources and in corresponding intelligent management planning, two studies have been undertaken.

The first remote sensing application in Romania involves the Danube Delta, the same region that had been selected for the initial photogrammetric applications years ago. The experience acquired in terrain classification by means of photogrammetry provides control test sites with ancillary data to support a successful remote sensing application.

The Danube Delta is embedded by the three channels of the river: Chilia, Sulina and Sf. Gheorghe. The approximate area is 4343 sq.km. A rich network of inland lakes and channels is scattered amidst marshes and swamps. The soil is generally formed by water sediment loads. Reed, timber, typical steppe plants as well as subtropical vegetation are encountered. Besides, for a few years, large areas have been used for agricultural purposes.

The Danube Delta is a most recently formed land of Romania a perpetual transforming region, difficult to be investigated by means of conventional techniques. Landsat MSS data provide significant input to a wide range of applications: determination of water boundaries and surface water area, measurement of sediment and turbidity patterns, inventory of lakes, discrimination of vegetative types, determination of soil conditions, monitoring of water pollution, classification of land uses, determination of biomass, assessment of fish production, mapping and map updating of wetlands, shoreline changes, land-water boundaries, flooded plains.

One major problem is the impact of the man's activities on the dynamics of the Danube Delta and efforts to monitor water quality of this large ecosystem are undoubtedly required. For the time being, our research group has focused on applications including mapping of wetlands, discrimination of vegetative types, determination of water boundaries and surface water area, inventory of lakes, mapping of land-water boundaries.

Another remote sensing application involves the region surrounding Bucharest, which is typical for the Romanian Plain. The investigations concern delineation of irrigated fields, determination of soil conditions, crop inventory, mapping of drainage networks, land-use classification.

Further applications will consider marine resources and environmental monitoring.

3. IMAGE PROCESSING CAPABILITIES OFFERED BY EXOSAT

Before embarking on a more detailed description of EXOSAT
we should emphasize the design considerations behind our approach.

To offer maximum utility, EXOSAT is designed in a modular fashion: the software is unbundled into a number of packages which may be combined to meet exact application requirements. Additional packages may be easily added any time. Consequently, versatile software assists the application expert to identify and evaluate the phenomena he is interested in.

Although highly automated, the system provides considerable flexibility via its user friendly interactive interface. The dialogue between the user and the system is performed through command menus in connection with the terminal keyboard. The displayed menus supply a rich set of processing techniques to meet requirements of various applications. The choice of one technique over another is dictated by the problem at hand. The user can make decisions based on his knowledge and experience in the domain he currently works and then interpret the results presented to him by the system. Besides the commands to perform specific image processing tasks in support of the remote sensing application, the user can apply for processing session history records to document end results of operation. Furthermore, he can take advantage of a set of utility programs to handle common service functions. The data entered by the user are checked for completeness. For doing all these, the user needs neither programming knowledge nor prior computer experience.

The software consists of processing modules involved in most image processing tasks. The algorithms are already well-known in the literature (Gonzalez 1977), (Nieman 1981), (Pavlidis 1982). Our efforts focused on the efficient implementation of the algorithms in accordance with the available hardware environment based around a 16-bit minicomputer architecture. The major problems confronting us were related to processing large amounts of data (which can only be accessed a segment at a time) with varied operations which provide heavy processing loads to the computer. High performance was to be achieved in terms of accuracy, reduced overall system response time and little storage space used. Our approach includes a fairly sophisticated buffering technique, several core storage saving schemes and various tricks to speed-up the algorithms.

The major system capabilities are: image enhancement, image statistics, image registration, image display and information extraction. It goes without saying that the user is supposed to be familiar with the image processing technology. The system nicely guides the user into the realm of histogram equalizations and specifications, Karhunen-Loève and Fourier transforms, color composites, filtering techniques, and classification. But the user must be aware of the suitability and effect of each image processing method. This task is going to be taken over by an appropriate expert system that will be included in our next version of EXOSAT.

The programs were developed 90% in FORTRAN to ensure high portability to new computer hardware environments.

In the following sections we present the main image processing techniques offered by EXOSAT.

3.1. Image display

Image display is one powerful tool for image analysis.
Visual examination of both original imagery and especially output data provided by specific image processing algorithms is undoubtedly required.

We developed a series of algorithms to control the operation of various devices such as matrix dot printer, monochrome and color display, plotter. The algorithms handle image windows of 640 by 640 pixels with 512 by 512 pixels actual access and scrolling facilities. The basic techniques involved are digital halftoning, density slicing and contour detection.

Furthermore, a wide range of preprocessing techniques to make the image more informative have been included, namely image enhancement by histogram modification (equalization or specification), contrast stretching and thresholding.

The above mentioned features make image display a considerably useful capability of EXOSAT. On one hand, without any sophisticated image processing, based only on associated monospectral radiances, image display alone would be enough to help one detect a certain phenomenon under study by providing gradual thematic images. On the other hand, image display used in association with specific complex image transforms extends the reach of the involved technique itself. This is the case of color-composite images based on the Karhunen-Loève transform and of Fourier image spectra.

3.2. Fast Fourier transform

The Fourier transform has played a key role in image processing and continues to be a topic of interest in theoretical as well as applied work in this field. We do not intend to give detailed descriptions of mathematical formulations related to the Fourier transform as the literature abounds in comprehensive information (Gonzalez 1977), (Rosenfeld 1976). Rather, we address the implementation of a Fast Fourier Transform (FFT) algorithm within EXOSAT and its wide range of applications in remotely sensed data processing problems. The theoretical framework and strategy of implementation of effective filtering techniques based on FFT in support of geomorphic and structural mapping of mineral and petroleum exploration targets were presented in (Roman 1985a).

EXOSAT includes the following capabilities:
- computation of the two-dimensional Fourier transform of N x N Landsat sub-scenes (N ranging from 16 to 512 pixels) by means of the FFT algorithm requiring 1/2 N logN multiplications and N logN additions;
- analysis of the frequency-domain signature of the Landsat sub-scene, that is: computation and display of the power or energy Fourier spectrum, spectrum shift to the frequency-domain center, spectrum log operation to bring out low-level information, local pattern arrangement analysis to point out characteristics such as periodicity, busyness, bias, textural properties analysis;
- design of high-pass filter, that is the transfer function type and the associated cut-off frequency are established according to the image frequency-domain signature;
- application of high-pass filter enhancement to the Landsat sub-scene;
- computation of the inverse two-dimensional Fourier transform, by addressing the same FFT algorithm in association with the complex conjugate of the image Fourier transform.

We mention that the frequency-domain analysis is sensi-
ve to overall changes in the original image gray scale (e.g., if the gray scale levels are multiplied by a constant c, the power spectrum values and hence the characteristics derived from them are multiplied by c; other types of changes in the image gray scale have more complicated effects). For an analysis invariant under gray scale changes, the image gray scale must be previously normalized. Therefore, image enhancement by histogram modification techniques should be undertaken along with the Fourier analysis. This capability is provided within EXOSAT.

An idea of the potential of the Fourier analysis in image processing is given by considering the various operations calling for the Fourier transform: registration, filtering, feature extraction and classification, data compression. Spatial registration of multispectral and multitemporal imagery is based on an array correlator. The correlation is a form of convolution and convolution is more efficiently carried out in the frequency-domain via the FFT algorithm. Filtering is an effective means of preprocessing allowing for enhancement of certain properties of interest, noise reduction and correction of distortions. Here again the FFT algorithm makes the frequency-domain filtering an extensively used approach. Feature extraction and classification on the basis of spatial texture is used for automatic image interpretation. Data compression may be efficiently carried out with some encoding technique considering the most relevant Fourier transform coefficients.

3.3. Principal component transform

Because high correlation between the different spectral images of the same terrestrial area is expected, a means of transforming the original set of images into a new, less correlated one is required. Such a transform brings about an important reduction of the original data redundancy. Hence, significant computational process improvement is achieved.

The principal component transform, also known in the literature as the Karhunen–Loève transform (Dave 1982), (Santisteban 1978), successfully accomplishes this task. Our first results concerning the application of Karhunen–Loève transform to Landsat MSS data processing were reported in (Roman 1985). The idea behind this approach is to rearrange the information content of the original multiband image such that most of it be concentrated in the first principal components. The new images are uncorrelated to each other. The results we have obtained proved that more than 95% of the total information in the original set of images was loaded in the first two principal components. Consequently, this approach leads to a low dimensionality representation of Landsat data with the least degradation in the mean square sense, of the radiometric accuracy.

Our study used as test sites two areas, each of 40.53 by 40.53 sq.km located in the Danube Delta and, respectively, in the agricultural region surrounding Bucharest. The former is characterized by channels and shallow waters, the latter shows typical agricultural land-use. Each original set of data contained four 512 by 512 pixels images corresponding to the four Landsat MSS bands (bands 4 through 7).

The two principal components of the Danube Delta imagery contained 95.9% of the total information, while the agricultural test site offered 96.7% of the total information in the
first two principal components. In both cases the remaining two components consisted almost entirely of noise.
Beside the data compression performed by the principal component transform, other two important applications come to the fore:
- display of color-composite images based on the first three principal components;
- perform image classification on a reduced amount of input data, namely the first two principal components.

3.4. Geographic registration techniques
The raw data consists of Landsat imagery geometrically corrected and mapped into a Universal Transverse Mercator (UTM) zone.
The first step in mapping the raw data into a desired projection system is the data resampling into a convenient grid, according to the actual distances derived from the Ground Control Points (GCP) considered by the registration procedure. Then, the GCP are used to compute the appropriate transform coefficients. The coefficient standard deviation is also estimated.
The system enables the definition and simultaneous use of at most ten ellipsoids. Due to the poor resolution of the Landsat MSS data, the ellipsoid does not affect in any way the registration accuracy. But, when interpreting raw data with better resolution, such as aerial MSS data, the ellipsoid should be used with discretion.
The mapping relatively small areas into a local projection system, the orthogonal (Helmert) transform is provided. The registration process was carried out on several test sites of 128 by 128 pixels using eight GCP per scene, on the average. The small registered areas are to be joined to get the 640 by 640 pixels scene.

3.5. Classification
MSS information could be interpreted in many ways, but the huge amount of input data made computer assistance necessary. Theoretically, each object class ought to have a unique multispectral signature. Unfortunately, the situation is almost never this simple. Many natural perturbative agents affect the sensed multispectral signature. Therefore, the identification of a certain phenomenon considerably relies on the expert knowledge.
The problem might be stated as follows: knowing both the radiometric levels corresponding to each pixel in a multispectral image and the radiometric ranges related to a set of phenomena (classes of objects) under study, each image pixel must be identified as belonging to a certain phenomenon (object class). The classification algorithm we implemented is one solution to this problem.
Pattern recognition offers a variety of means of classification of images into pixel classes based on remotely sensed information. Two criteria should be taken into account when considering digital classification methods:
- whether they are deterministic or not;
- whether the object structure is explicitly taken into account or not.
Three categories of methods have been fully accepted:
decision functions (deterministic and non-structural), probabilistic models (non-deterministic and non-structural), and syntactic methods (structural). A rich variety of algorithms
based on several classification strategies can be found in literature (Tou 1974), (Duda 1972).

We selected the parallelepipedic classification (deterministic and non-structural method) on account of the suitability of the theoretical frame to our application and the expected computational performances. The algorithm seeks to recognize Earth objects using four observations of one attribute: color. The argument behind this approach is that when considering the spectrum as a whole, different objects have different patterns of reflection and emission. Further it is assumed that these spectral signatures are sufficiently unique to make consistently distinguishable from one another.

Each object class of interest is rendered by a set of multispectral ranges given in terms of a set of radiometric couples (the lowest and the highest radiometric levels) corresponding to the investigated phenomenon.

The method was found to have some drawbacks. First among them is the treatment of ambiguous situations generated by overlapping classes.

EXOSAT V1.0 successfully carries out the classification in a supervised manner. During the preliminary training stage the application expert supplies the description of the object classes to the system. The assumption that the representatives of each object class of interest are properly indicated is implicit in the process of classification. It follows that wrong object class descriptions result in wrong classifications. An alternate approach is to include clustering techniques to take over the task of deriving the representatives of distinct types of phenomena. Such techniques will be implemented in our next version of EXOSAT.

The classification algorithm was applied to data of a test area in the south-western part of the Danube Delta and the resulting classification indicates sand dunes, shallow waters, forest cover and agricultural land. The input data consisted of the four-band Landsat 512 by 512 pixels subimage. The results are summarized in table 1.

<table>
<thead>
<tr>
<th>Type of surface</th>
<th>% of total study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand dunes</td>
<td>17.31</td>
</tr>
<tr>
<td>shallow waters</td>
<td>46.95</td>
</tr>
<tr>
<td>forest cover</td>
<td>10.73</td>
</tr>
<tr>
<td>agricultural land</td>
<td>3.25</td>
</tr>
<tr>
<td>ambiguities</td>
<td>5.23</td>
</tr>
<tr>
<td>unclassified</td>
<td>16.53</td>
</tr>
</tbody>
</table>

4. FURTHER DEVELOPMENTS

Nowadays we witness considerable interest and rapid ad-
Advances in the research and development of large geographic information systems (GIS) all over the world. On this account, integration of remotely sensed data processing systems within GIS seems naturally predictable. The role of man in such systems will consist of an interesting interaction with a large data base and phenomena models.

Under these circumstances an improved hardware environment ranging from display devices through a new computer architecture is required. We intend to embark on the development of a new computer architecture based on parallel processing and multiresolution ability to cope with ever more complex tasks. The design of such an architecture must comply with the latest trends opening out the future in computer technology, namely the fifth generation of computers.

Besides, to increase software productivity is a most interesting challenge. New image processing capabilities including improved feature extraction techniques, texture analysis and image enhancement are to be worked out. Image registration, clustering techniques and image coding are our next topics of interest.

The lack of high technology and qualified experts are the most embarrassing factors delaying social and economic advancement in developing countries. Our efforts concern the development of a user friendly system. The following objectives are to be accomplished within the next version of BXOSAT: an integrated data collection approach will handle data acquired at various altitudes from different platforms (space, aircraft, ground) at different viewing angles and times, physical phenomena models will allow more reliable prediction of future events, and last but not least, an expert system will guide and support the neophyte user on the realm of remote sensing technology and image processing sciences.

5. CONCLUDING REMARKS

This paper is an account of the efforts at developing the first computer aided system dedicated to the interpretation of the remotely sensed data in Romania. Needless to add, the problem is far from solved. For the beginning, research focused on the design and implementation of the basic capabilities of such a system on the available hardware environment in our country. The 16-bit minicomputer architecture and the associated peripheral devices are at the back of a number of drawbacks of the implemented system. Therefore, the unsatisfaction generated by the above mentioned hardware environment and the state of the art of computer systems all over the world make compulsory the research in the area of the new generation of remotely sensed data processing systems.

The results achieved thus far by processing remotely sensed information are quite encouraging and consequently, the Romanian remote sensing community enlarged. The increasing interest and growing efforts at solving the problems related with the development of a Romanian remote sensing system are motivated by the challenge of the problem and the expected applications.
REFERENCES


