N73-28334

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DIGITAL INTERACTIVE IMAGE ANALYSIS BY ARRAY PROCESSING

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Geophysical and ERTS Data Processing Are Similar

This paper endeavors to draw a parallel between the existing geophysical data processing service industries and the emerging earth resources data support requirements. The relationship of seismic data analysis to ERTS data analysis is natural because in either case data is digitally recorded in the same format, resulting from remotely sensed energy which has been reflected, attenuated, shifted and degraded on its path from the source to the receiver. In the seismic case the energy is acoustic, ranging in frequencies from 10 to 75 cps, for which the lithosphere appears semi-transparent. In earth survey remote sensing through the atmosphere, visible and infrared frequency bands are being used. Yet the hardware and software required to process the magnetically recorded data from the two realms of inquiry are identical and similar, respectively. The resulting data products are similar.

In several decades of evolution, the geophysical data processing industry has become application oriented and cost effective. It is driven by a very intensive competition. This is not the case at this time in earth survey data analysis, which has hardly entered the commercial sector. Therefore, it is interesting and probably beneficial to consider the potential of an existing technology with regard to a developing one.

Detailed Comparison Between ERTS and Geophysical Data

A survey of ERTS-1 investigations discloses several categories of efforts which can be compared with seismic data processing categories. First there are the optical and digital filtering and enhancement techniques,

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which attempt to eliminate noise or improve contrast in the resulting display. With improved processing algorithms, these lead to classification techniques, and to hybrid selection and suppression methods. Then there are highly sophisticated spectral and spatial detection efforts, aimed at low signal-to-noise contrasts, for the detection of subtle shades of grey or the respective color, which represent differences in soils, chlorophyll, stress, infestation, or other manifestations of resources conditions. Because the dynamic range of the information which can be derived from any one recorded element is limited by the number of bits per byte, several spectral or temporal exposures are generally stacked and correlated.

Conversely, seismic processing starts with corrective programs, followed by correlative displays of features of similar reflective, attenuative and conductive properties, which in geological terms are better known as stratigraphy and structure. Over and beyond these fundamental displays, the industry has learned to isolate and enhance, even in color, any combination of variables of value to the explorationist, ranging from velocities, energies, frequency shifts, and reflection coefficients to rock type, porosity, water content, temperature, pressure, and hydrocarbon concentration. The more sophisticated analyses are based on relatively large arrays of data which have been precisely recorded, in as many as 48 channels, under rigid gain control. The reconstruction of the signal characteristics in the computer is possible within a large dynamic range, exceeding 100 db and approaching 180 db. This precision is not available for ERTS data, where acquisition and transmission limitations, and restrictions of spectral and temporal multiplicity leave room for improvement in later, more advanced eras of earth survey.

A detailed discussion of a specific enhancement of hydrocarbon content in gas and oil bearing sediments was recently published by C. I. Craft (Oil and Gas Journal, Feb. 19, 1973, pp. 122-125). Color processes for the display of geophysical parameters have been publicized by several geophysical data processing companies, both in the U. S. and abroad.

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Interactive Mode and Different Service Concepts

Geophysical data services do not limit their attention and competition to a more accurate and useful information content of the final product. They have also devised new ways of meeting and involving the client, and of participating in designing the product of his choice, where and when he needs it. This service approach is today completely outside of the realm of ERTS investigations, where time and costs are still relatively secondary considerations. In geophysical processing, the usual interactive involvement of the geophysicist in the man-machine cycle has been expanded to include the client, who is generally the user of the data. Remote terminals in major user's offices--hundreds or thousands of miles away from the computer facility--allow real time display of intermediate data processing steps, and allow decisions and participation as to further iterations, choices or measures of enhancement. There are two more dimensions of service, however, which are available to the geophysical data user. Some service companies have adapted and standardized their data processing capability so that they can take advantage of existing computer centers around the world. They may, for example, use the "brand X" computer system, and they can make it work wherever a business potential and a computer location coincide, be it Chicago, Calgary, London or Singapore! And in even closer interaction with the field crews, some geophysical service companies are dispatching miniaturized computer centers into the field, wherever it may be, to work literally tied in with the field data acquisition.

Service at Low Costs - A Goal for ERTS Users

Some day, similar customer services will exist in earth survey data anlaysis as are described above. Indeed, the multi-user possibilities of ERTS data promise even cost savings over the generally specialized geophysical data utilization. A data center has quoted rates as low as $0.02 per km^2 for image data correlation, based on two compatible frames. This low unit cost results from the use of special purpose equipment which is attached to the computer for the more efficient handling of large amounts of data. For the geophysical data industry, such equipment and the corresponding software were developed by the Shell Oil Company.

Other Applications in NASA Earth Observation Programs

So far, only ERTS data were addressed. One other application of geophysical data technology is in the Skylab/EREP program. This is particularly appropriate because the data recorded in manned missions need not be restricted as much as ERTS data, as far as data intensity is concerned. From such applications of geophysical methods, changes may result in the design or performance characteristics of later generation earth survey data acquisition systems.

Mutual Technology Transfer

The parallel between geophysical and earth survey data analysis is hampered at this point by insufficient "channels" of ERTS data available to us. Therefore, most of our efforts were based on geophysical data, in the same format as ERTS CCT's. We can interchange seismic and ERTS data in government and industrial processing facilities. And we expect that this work will benefit the geophysical data industry as well, as evidenced by the introduction of false color processes in seismic data displays.

Potential of High-Speed Processes for ERTS Data

In summary, the array processor is introduced as an instrument to free the investigator from data processing chores, so that he can use his time more efficiently for the interpretation and utilization of the data. Conversely, data products are made available to users who are not investigators. The service, patterned after the commercial seismic data processing industry, will therefore increase the potential for the application and utilization of ERTS data. Further details of the two discussed data industries are being pursued.

Appendix - Array Processor Capabilities

This section describes the array processor, developed by Shell Oil Company, which is used in conjunction with a medium to large computer center. There are several brands of processors and computer systems on the market, which may have similar capabilities.

The AP, as the array processor is called for short, performs specific instructions in memory independent of the central processing unit or CPU. This makes the AP similar to a multi-processing system, except

that the AP has a hard-wired instruction set of about 21 operations which are most common in geophysical data processing. These operations need not be detailed in the programming software, step by step, but are executed instantaneously by one command.

Initially, the AP was used for multiply/add operations which it performs effectively in 250 nanoseconds. About 25% of all geophysical calculations were done in the hardware algorithm modules. Today, many other mathematical functions have been utilized or adapted, and the AP is typically employed for about 70% of the geophysical calculations. The instructions available include the following:

vector inner product   partial matrix multiply
sum of squares   sum of vector elements
scalar multiplication   vector element by element multiply
scalar add   vector element by element sum
complex vector element multiply   fast Fourier transform
convolving multiply   limits readout
interpolations

Many of these instructions are common to image correlation, enchancement and analysis.

The single most effective instruction is the convolving multiply. The improvement realized by using the AP versus the CPU is better than 20 to 1. The instruction is used in filtering, auto-correlation and -convolution, cross-correlation, and auto-statics. These geophysically oriented processes are mathematically applicable in image correlation, correction and classification.

The interpolation instruction is another heavily engaged AP favorite. Improvements in processing time are better than 9 to 1 over the CPU. This instruction is used in fiducial and statics correction, stacking and resampling of data. Functionally, these processes correspond to the stretching or compressing of data, either linearly or in time. In image analysis of ERTS data, similar instructions become important in dealing with registration and boundary problems.

The partial matrix multiply instruction yields improvements of 4 to 1 and is used in calculating the Z transform filters by polynomial division, recursive filtering, velocity determination, and for preparatory sine and cosine function generation for the fast Fourier transform algorithm.

The fast Fourier transform is widely used to convert between the time and frequency domains, so as to expedite the processing. Savings of better than 5 are realized in using the AP versus the CPU.