EXPERT SYSTEMS FOR IMAGE PROCESSING: PAST, PRESENT AND FUTURE NEEDS

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ABSTRACT

Remote sensing technology has advanced significantly during the past twenty years. New instruments, better detectors, more sophisticated ground systems and expanded product types have resulted. Artificial Intelligence and Expert Systems have had a parallel growth during the past two decades. Using Landsat as a baseline for remotely sensed data, this paper discusses both technologies and the need to merge these disciplines where possible for ground processing systems of the future.

BACKGROUND

Landsat Multispectral Scanner System (MSS) digital processing was initiated in the USA two years after launch of Landsat 1. Images placed on computer compatible tapes (CCT) were used to build the first digital archive of processed data. When the worldwide network of Landsat remote sensing countries was established in the late 1970's a concerted effort was expended by NASA to bring these groups together to construct a standard digital data format for the MSS. The format was designed to allow the international exchange of data using CCT. This group evolved into the Landsat Technical Working Group (LTWG). When the National Oceanographic and Atmospheric Administration (NOAA) took over the Landsat program they continued the LTWG as did the Earth Observation Satellite (EOSAT) company when the Landsat program was made a commercial venture.

As users became more sophisticated the demand for digital products grew steadily. In the most recent report to the LTWG it was noted that in 1986 the money spent on digital products in the USA exceeded that spent for film products for the first time in the history of the Landsat project. This new emphasis on digital products was the result of multiple advances in technology that occurred during the 1980-1986 time frame. These include the launch of the Thematic Mapper for Landsats 4 and 5, the growth of hardware and software systems capable of handling large image data sets interactively, the growth of mini and micro computer technology, the ability to interface these systems with mainframes where necessary to extract video information, the development of new and better classification algorithms, and the parallel growth of artificial intelligence and knowledge based systems hardware and software.

The launch of Landsats 4 and 5 initiated the era of the Thematic Mapper. This new instrument provided the remote sensing community with better spectral coverage, better spectral resolution in each band than MSS, and better spatial resolution than available in the past. Due to its unique place in the world of remote sensing a special effort was expended by NASA to define and describe instrument performance and the radiometric and geometric characteristics of TM products (Salomonson 1984, Markham and Barker 1985).

Hardware and software systems were procured by NASA prior to the launch of Landsat 4 that were designed specifically for the extraction, manipulation, and evaluation of Landsat data. This Landsat Assessment System (LAS) was the first interactive system capable of ingesting and manipulating either full frame or partial frame TM data. Applications software for this system included multiple classification schemes, the freedom to manipulate data at the pixel level, and the ability to ingest and cross compare data from satellites other than Landsat.

Many of the features of the LAS can be found in currently available microcomputer based systems. The development of the 80386 microchip, larger capacity memories, and fast input/output data streams for microcomputers makes it possible today to ingest and manipulate TM data using desk-top computers. These systems provide present and future users with the capability to extract, compare and manipulate data from multiple satellites at nominal cost without using large mainframe computers.

As the NASA/NOAA/EOSAT program for Landsat evolved a similar upgrade to remote sensing of earth resources from polar orbiters was introduced by the NOAA Advanced Very High Resolution Radiometer (AVHRR). Recent studies (Clark, Sadowski and Johnson 1987) have indicated that it is possible to generate an MSS like AVHRR color composite through use of a standard mathematical transformation. Similar analyses for MOS-1 and SPOT are currently underway. This has led us to the present where we have an initial capability to process disparate data sets, cross compare data at the pixel group level and generate both photographic and digital products that match one another. However, the complexity of this activity for the user will grow as multiple Earth pointing satellites are launched in the future.

CURRENT AND FUTURE MISSIONS

Table 1 contains information relative to present and future worldwide remote sensing programs and the country responsible for the management of the data and its distribution to users. These data are not exhaustive. They represent only the inputs from members of the Landsat Technical Working Group countries relative to their planned activities in this area in the next decade. In addition the NOAA series of polar orbiting

satellites has been included due to the increasing use of AVHRR for land applications.

Table 1. Landsat and Other Missions for Earth Remote Sensing

ORGANIZATION	SATELLITE	INSTRUMENT
EOSAT	Landsat 4/5	MSS AND TM
EOSAT	Landsat 6	ENHANCED TM
EOSAT	Landsat 7	TBD
NOAA	GOES	AVHRR
NOAA	GOES-NEXT	AVHRR
FRANCE	SPOT	PAN AND MSS
CANADA	RADARSAT	SAR
EUROPE	ERS-1	SAR
INDIA	Indiasat	MSS
JAPAN	MOS-1	MSS
JAPAN	EOS-1	MSS

In addition to these satellites and their associated countries Brazil, China, and Sweden have mentioned the possibility of launching Earth remote sensing systems in the next decade. Assuming the continuance of the open skies policy, established by the United States with the launch of Landsat 1, data from each of these platforms will be available to the worldwide community of remote sensing specialists in the decade of the 1990's. Internally managed remote sensing data can be used by each country to satisfy its national goals. Data from other platforms can be used to satisfy more global requirements within each nation. For example, if there were more than one TDRSS satellite in orbit today it would be possible in the USA to map the entire world using Landsat imagery. Given this lack, the alternative is to acquire video data over regions not covered by Landsat and TDRSS using other satellites. When this type of need arises it is critical that the two satellite sensor types can be mixed and matched to form a coherent image of the world at large. The comparison is nontrivial. It requires the consideration of such things as the differences in local crossing times, orbit configurations, and the performance of new and different sensor/detector combinations in both the spatial and spectral domains.

In addition to these operational land remote sensing systems NASA has planned to launch multiple Earth Observation Systems

(EOS) in the space station era. These data acquisition systems are meant to be research oriented and consist of spectrometers for the remote sensing of earth resources in hundreds of spectral bands, sounders for atmospheric analyses, and other complex instruments designed to highlight special aspects of our environment. One of the more difficult aspects of working with these multiple data types will be the selection of the best combination of sensors for specific applications. In recognition of this information handling problem NASA has been delivered a preliminary plan on how both operational and research sensors to be available in the 1990's can be cross compared (NASA 1987). The focus of the NASA study is restated here. "To meet the paramount need for information, the Working Group focused the proposed applications strategy on providing information to users, rather than on technology or hardware development. The goal of the Applications Strategy is to develop through demonstration projects, by the end of the next decade, integrated information systems that will allow private industry (including value-added industries), operational agencies and the scientific research communities to exploit effectively the data taken by Earth-observing satellites."

This effort to merge data from new instruments not yet characterized with operational systems such as Landsat is recognized as one of the more difficult R&D activities taken up by NASA. It will require the development of many new methods for the data reduction and analysis required to build a self-consistent picture of our evolving environment. Since the instruments for EOS have not yet been characterized, the remainder of this paper will discuss the merger only of different Landsat like data sets and the problems that must be solved for these similar systems.

KNOWLEDGE BASED SYSTEMS -- A SHORT REVIEW

Many texts and journal articles have been devoted to the use of knowledge based systems. Rather than present a comprehensive survey of the literature in this area the reader is referred to Hayes-Roth, Waterman, and Lenat (1983).

Following Hayes-Roth, et.al., the study of expert systems can be broken into the areas given in Table 2. This table of general types of expert systems and their function was developed by the authors after a survey of the field of knowledge based systems. It is intended to be used as an aid in visualizing the multiple activities currently underway in this research discipline.

Table 2. Generic Activities for Knowledge Based Systems

INTERPRETATION	INFER SITUATION FROM SENSOR DATA
PREDICTION	INFER CONSEQUENCE OF GIVEN SITUATIONS
DIAGNOSIS	INFER SYSTEM MALFUNCTION FROM OBSERVABLES
DESIGN	CONFIGURE OBJECTS UNDER CONSTRAINTS
PLANNING	DESIGNING ACTIVITIES
MONITORING	COMPARE OBSERVATIONS WITH PLANS AND POTENTIAL VULNERABILITIES
DEBUGGING	PRESCRIBE REMEDIES FOR MALFUNCTIONS
REPAIR	EXECUTE A PLAN TO ADMINISTER A PRESCRIBED REMEDY
INSTRUCTION	DIAGNOSING, DEBUGGING AND REPAIRING BEHAVIOR
CONTROL	INTERPRETING, PREDICTING, REPAIRING, AND MONITORING SYSTEM BEHAVIOR

Each of these areas has had significant amounts of time, money, and manpower expended in the construction of a variety of very specific hardware and software systems to accomplish unique goals. These systems are called knowledge based systems, expert systems, or rule based systems because of their origins. Normally an expert is found in the area of interest, the expert is asked to respond to a detailed questionnaire, and this is followed by a personal interview where the systems analyst or knowledge engineer attempts to determine the total universe of possible responses by the expert in different situations.

From the set of responses a rule based hierarchy is constructed, code is written, and the software system is expected to respond exactly as would the human being. A few of these systems have had some spectacular success. Others, normally the older systems, are quite slow and sometimes inaccurate. One area receiving renewed interest is that of neural networks. Theoretically these networks can be adjusted or taught to respond correctly to a variety of different inputs. After initialization these "self teaching" systems are capable of responding correctly to new and different input conditions with little or no new adjustments. Neural network computers were offered in the USA for the first time in 1987. Though their future remains unclear, the fact that these systems can now be built is another step forward that parallels the increased sophistication of the remote sensing community.

PRESENT AND FUTURE APPLICATIONS OF KNOWLEDGE BASED SYSTEMS

Prior to dealing explicitly with the use of knowledge based systems in remote sensing one should note that the issues faced by researchers in the fields of AI and Knowledge Based Systems are nontrivial. Many times it has been found that the development of a particular system - for example one used to simulate vision - is totally inappropriate for other more mundane tasks such as automatically sorting large lists of data by different attributes. This has caused some very specialized languages to be built and implemented for the sake of efficiency in performing one task very well rather than addressing the universe of applications possibilities.

The application of knowledge based systems to remote sensing can be illustrated in the generic sense through Table 3.

Table 3. Knowledge Based Systems Areas for Remote Sensing

INTERPRETATION	IMAGE CONTENT ANALYSIS
PREDICTION	EPISODAL EVENT PREDICTION
DIAGNOSIS	IMAGE CONTENT ALERTS
DESIGN	SYSTEM CONFIGURATION FOR DATA PROCESSING
MONITORING	PERFORMANCE MONITORING
PLANNING	PRODUCTION PLANNING
DEBUGGING	REAL TIME ANALYSIS
REPAIR	IMAGE RECONSTRUCTION
INSTRUCTION	TRAINING
CONTROL	QUALITY CONTROL, PRODUCTION CONTROL, etc.

As illustrated in Table 3 it is relatively easy to transfer the generic types of categories of knowledge based systems over to the realm of image processing.

IMAGE PROCESSING AND EXPERT SYSTEMS PRESENT AND FUTURE

In the following paragraphs the discussion of image processing will deal with the generic categories defined by the expert systems theorists and illustrated in Table 3. Where possible very specific examples of present activities will be provided that exploit these methodologies.

Image interpretation has never been possible using only the

digital product. Though some knowledge based systems exist that can classify different types of crops and their relative health, determine the lineaments in geological data, and separate other features through principal components analysis, there is no single, all-encompassing logical system that will allow the user to read in the data, select the type of information expected in the scene, and have the system return information relative to the characteristics of the features desired. Some attempts have been made in this area. However, they will require significant upgrades if they are to be applied to the decade of the 1990's with the expanded set of multispectral and multispatial instruments available. Moreover, their speed must be upgraded by a significant amount. Systems that work well on small segments of data are at present incapable of the analysis of hundreds of scenes of TM each day. This represents a challenge to the fields of AI and Knowledge based systems experts, and to image processing experts. The problem will be solved only through a synthesis of activities from these two areas.

Prediction is another facet of image interpretation. Given a hypothetical system capable of evaluating image content, it should be possible for this system to warn of upcoming problems such as drought for those interested in monitoring the health of different crop types. These predictions require a full scale merger of Landsat like data, weather satellite data, ground truth weather conditions, and other inputs. Data of this type are normally input to multi-level Management Information Systems (MIS). As these MIS become more complex new predictive tools must be built. Technologies available from the fields of AI and ES are natural candidates for upgrading predictions made using combined remote sensing data with other MIS attributes. This represents a significant challenge to each of the disciplines involved.

Diagnosis requires a very specialized merger of AI/ES with Landsat to produce an image interpretation capability. Landsat has been used for flood control activities through the determination of the snow depth in the USA for selected sites every winter (Salomonson 1983). However, there are other areas where the applications are not as well established. Using Chernobyl as an example, the extent of the damage could not be determined using TM until the site was identified, the suspected temperature of the reactor was determined, and the correct infrared band was selected to view the image. No operational satellite other than Landsat had the combined spectral and spatial resolution required for this job. Furthermore, neither standard color photographic products nor imagery displayed on high resolution color monitors with the data in the normal band sequence used for red, green, and blue would allow the full extent of the damage to be assessed. However, the use of the proper infrared channels in different band combinations highlighted the damaged area immediately. This is a case where early image analysis relied upon the

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expertise of multiple individuals across several disciplines. No existing system could have done this job automatically.

Design reflects potential system configurations for data processing, data base management, management of multiple archives of data, image processing requirements, and data format records relative to structure from one satellite to another and from one country's product to another. Multiple applications are possible here. One limited application for the future would be the build of a unified system capable of reading data from multiple sources on different formats using different media e.g. tape, CDROM, WORM, Optical Tape, etc., with no operator intervention.

For image processing the monitoring task is one of recording and monitoring production system hardware and software performance to aid in failure prediction and preventative maintenance. For the image applications specialist monitoring is used to evaluate multitemporal data for changes in crop health and analysis of flooding and storm damage. This element of AI/ES is just evolving.

Planning encompasses the routine activities for daily production, system engineering, and the potential for emergency response to specialized scenarios. Current systems use automatic schedulers and specialized data bases both for the flight segment and the ground processing segment of Landsat. These schedulers have been developed using the philosophy of expert systems in that they were developed by and for experts in each area to be capable of response to any contingency. As the Landsat system has evolved its scheduling systems have been updated to reflect those unique rules associated with the operation of each satellite. The image acquisition scheduler merges user requests with instrument power requirements and other critical satellite performance parameters to generate the best schedule for the next imaging scenario. Automatic queuing at each processing step, information exchange between data bases, and work order generation are common to the current system. These systems have worked well. However, in some areas, the original software has been replaced by newer, more efficient expert systems.

Debugging requires the analysis of product and production problems both in real time and using off-line systems. In addition, new software builds, special scheduling, and system performance analysis fall into this category. The advent of special hardware and software used in Computer Aided Software Engineering (CASE) is one example of recently developed systems capable of both design and debug activities.

Instruction relates to the training of individuals and systems to assure that they respond properly in a variety of situations. In the expert systems world this pertains to training an individual using a computer that has already

captured the essence of human knowledge about specific activities. When in the training mode the student works interactively with the computer. In this mode he is given a set of problems to solve in real time. His response to specific questions is graded relative to that of the expert used to build the system. As the student learns he is subjected to progressively more complex examinations developed to illustrate the levels of proficiency required to take over standard operational tasks on a daily basis. This training is the first of a series of certification steps prior to allowing the individual to operate some of the more complex computer systems.

Control is one facet of image processing that is extremely important to each production step. Quality control, for example, must be applied at each completed production phase to assure that the intermediate and final products meet QC standards. Most image processing systems have control built into them. For example, given that there has been a problem with the telemetry for Landsat, the data processing system has a feature that allows it to flywheel through the time code, separate the good data from the bad, and use the good data to establish boundaries for the excursions taken for those small segments of time where the time code does not meet specification. This is an expert system.

Another area of control is image data quality. In the early days of processing Landsat data the effort required many image inspectors. Pictures were made of all scenes, scenes were subjected to a two times visual inspection for very specific features impacting quality, and data were passed or failed on the basis of the quality levels assigned to the pictures. When the NASA all-digital era was started (Landsat 3 - 1978) there was a local transfer of emphasis from film inspection to digital quality control methods. These involved the extraction of data samples, the evaluation of samples, and the monitoring or tracking of response differences from scene to scene on a detector by detector basis to assure a uniformity in the quality of the Landsat product. This was accomplished off line using path/row data sets specially selected for scene content variations that conformed to the limitations of this early expert system.

Obviously no single hardware and software package is currently capable of performing each of these general functions. Furthermore, the attempt to unify or combine the functions into a single global AI/ES package would not be an efficient approach in the short term. However, the examination of each of these functions separately in the context of future mergers of specialized AI/ES based hardware and software with remote sensing problems present and future would be of significant value.

MERGER of EXPERT SYSTEMS WITH REMOTE SENSING FOR THE FUTURE

In order to fully exploit the data captured locally by each land remote sensing system of the future it will be necessary to invest in better expert systems hardware and software

capable of new and more complex activities. In addition, a more global activity must be expended by those organizations interested in multi satellite and multi sensor applications.

As the complex of new land remote sensing systems is launched in the decade of the 1990's it will be very important for users to understand the relationships between data types so they can extract the correct data for their application. If algorithms can be constructed that allow the global cross comparison of digital data from one sensor type to another it will be possible to fill data gaps in geographic coverage, accrue enough data to map the world using a variety of sensors, and assure that the impacts of episodal events detectable by satellite can be properly assessed.

FUTURE CHALLENGES

Current image processing production systems have been structured using a very limited approach to the merger of AI and Expert Systems with Land remote sensing. Similarly AI/ES researchers have neglected the extremely complex problems associated with the daily production of remotely sensed image data. Merging these disciplines provides a multifaceted challenge. We must be capable of handling data from many platforms, we must develop algorithms to cross-compare data, we must develop data base systems that are capable of indicating to the new user the best complex of remote sensing data to use for particular applications, we must update and upgrade this data base as the complexity of cross comparisons amongst different sensor types increases, we must develop better and faster hardware systems, better and faster software and specialized knowledge based systems that allow us to exploit, for Landsat, the advances made by those in other fields.

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