SUMMARY REPORT OF WORKING GROUP II/4
INSTRUMENTS FOR PROCESSING AND ANALYSIS OF REMOTELY SENSED DATA

James V. Taranik

Resource Observation Division
Office of Space and Terrestrial Applications
NASA Headquarters
Washington, D. C. 20546

ABSTRACT

Working Group II/4 in Commission II of the International Society of Photogrammetry is concerned with instrumentation for processing and analysis of remotely sensed data. The Working Group is composed of scientists from Europe and North America who are engaged in the design or utilization of instrumentation for remotely sensed data reduction. Three symposia were held by the Working Group to define the content of the final summary report. The first meeting was held in the United States at the EROS Data Center in Sioux Falls, South Dakota and the second meeting was held at the Canada Centre for Remote Sensing in Ottawa, Ontario. An interim report of Working Group activities was presented at the Commission II Symposium in Paris, France in September 1978. At that meeting a special sub-panel on instrumentation for processing of synthetic aperature radar data was developed. This SAR sub-panel sponsored the third symposium in Frascati, Italy in December 1979.

The costs for central processing units have decreased with development of semi-conductor technology. Array or parallel processors are now employed and they allow large volumes of data to be processed in near real-time. Research needs to be focussed on input and output devices and instrumentation for archiving and dissemination of data. In the near future small economical, compact analysis systems will be routinely employed at remote locations.

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COMMISSION II
WORKING GROUP 4

INTRODUCTION

Working Group II/4 in Commission II of the International Society of Photogrammetry was concerned with the instrumentation for processing and analysis of remote sensing data. The Working Group was composed of scientists from Europe and North America who are engaged in the design or utilization of instruments used in processing and analysis of electromagnetic and potential field remote sensing data. The first meeting of the Working Group was held in the United States at the U. S. Department of Interior's Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota. At that meeting representatives from industry presented recent developments in instrumentation for high-speed processing of satellite remote sensing data. The second meeting of the Working Group was held at the Canada Centre for Remote Sensing (CCRS) in Ottawa, Ontario, Canada. At the second meeting the main subject was the development of instruments for interactive analysis of remote-sensor data. The third meeting of the Working Group was held in Paris, France on the occasion of the Symposium on Equipment for Analytic Photogrammetry and Remote Sensing sponsored by Commission II. The purpose of the third meeting was to share the results of the North American meetings with European scientists. At the third meeting the European scientists suggested a subgroup on instrumentation for processing of synthetic aperature radar data and the organization of this subgroup was finalized in 1979. The SAR subgroup held the fourth meeting at the European Space Agency Earthnet Center in Frascati, Italy in December 1979.

North American Participants	European and SAR Subgroup Participants
J. Taranik - (NASA) Chairman	J. Guignard - (ESTEC) Co-Chairman
F. Billingsley - (NASA/JPL)	F. Brun - (IGN)
P. Chavez, Jr. - (USGS)	J. Cazux - (CNES)
A. Collins - (CCRS)	J. Degavre - (ESA/ESTEC)
S. Francisco - (IBM)	A. Ellis - (MRL)
A. Goetz - (NASA/JPL)	B. Fritsch - (Dornier)
G. Harris - (Western Union)	J. Hollette - (CIMSA)
R. Jensen - (I^2S)	A. Hourani - (LAE)
J. Lent - (ISI)	P. Keller - (CNES)
P. Maughan - (Comsat)	L. Marelli - (ESRIN)
J. Nichols - (ESL)	C. Miller - (Eurosat)
A. Park - (GE)	L. Moussy - (CIMSA)
S. Riffman - (TRW)	E. Nielsen - (C. Rovsing)
W. Rohde - (USGS)	R. Okkes - (ESA/ESTEC)
B. Schrock - (ETL)	D. Parkinson - (ICL)
E. Shaw - (CCRS)	R. Shotter - (Dornier)
C. Sheffield (Earthsat)	F. Sondergaard - (TUD)
J. Smyth - (CCRS)	
M. Strome - (CCRS)	
F. Waltz - (TGS)	
G. Zaitzeff - (Bendix)	

Table 1. Participants in Working Group II/4 meetings and members of WG II/4.

Within the next decade the rapidly evolving maturity of aerospace remote sensing for observations of the Earth's atmosphere, oceans and land will levy increasing requirements on the development of instruments for processing and analysis of remote sensor data. The challenge for development of new technology in data processing is related to the increasing requirements for reduction of larger amounts of higher spatial and spectral resolution data, storage and rapid dissemination of this data in standardized formats, and rapid interactive analysis of multiple data sets. Working Group II/4 focussed on developments in instrumentation for onboard signal processing, data transmission, initial raw data reception, raw data re-transmission, data preprocessing to apply radiometric and geometric corrections, data storage including film and magnetic media, data dissemination by transmission through telephone lines or using domestic satellites and finally instrumentation for data reception by users. A second area considered by Working Group II/4 was instrumentation for analysis of remote sensing data including digital and analog interactive analysis systems, optical analysis systems, and stereoscopic viewing systems.

INSTRUMENTATION FOR REMOTE SENSOR DATA PROCESSING

Near the close of the last decade the United States had two Landsat satellites, a Seasat satellite with synthetic aperature radar, and a Heat Capacity Mapping Mission (HCMM) satellite which had a combined data rate of close to 2×10^6 bits per second. Ground systems for handling this data were based on hardware not specifically designed for that purpose and, even now, the Landsat ground data handling system has almost a year backlog for preprocessing of data! The United States may have land observing systems in orbit by the end of this decade which will produce 10^9 bits of data per second and the annual total of data received may exceed 10^{16} bits by the end of the decade. The European and Asian free-world countries are planning satellite systems which will collect visible, infrared, and microwave multispectral data on a global basis with at least 10 meter ground instantaneous field of view resolution. World wide data collection could reach 10^{18} bits annually by the end of the decade. Clearly there is a need to develop instrumentation which will limit the amount of data transmitted to the ground for processing, and to develop instrumentation specifically designed for processing and archiving of large volumes of remote sensor data.

Onboard Signal Processing

Radiometric and geometric corrections could be applied to remote sensor data if sensor responses were calibrated, atmospheric conditions (particularly presence of water vapor) were known, and the position and attitude of the sensor with respect to the Earth's surface were known to 1/3 of a ground resolution element. These flight parameters could be input to onboard processors and the data could be formatted to images in standard projections. Solid state imaging technology should allow improved detector calibration and geometric correction. Satellite position determinations systems planned for later in the decade should provide the necessary position and attitude data. Atmospheric analyzers will have to be developed for measurement of atmospheric parameters during data collection. The Working Group felt that microprocessor technology was still in a developmental stage and this technology would not be available for on-board signal processing until later in the decade. Data compression techniques, however, could be utilized now to transmit only changes in radiometric values between picture elements, rather than the values themselves. Data compression could also be used to transmit only differences between spectral bands for a single picture element. Onboard spectral pattern recognition could be used to detect scenes dominated by cloud cover and this kind of image data could be eliminated from the data stream if desired. In the long term, development of techniques for onboard data correction and compression could allow relatively unsophisticated users to receive image data directly from geosynchronous data relay satellites or could allow the data to be stored directly in data archives with a minimum of ground processing.

Data Transmission

Because large amounts of data will be acquired by future satellite sensors, onboard tape recorders are currently not feasible. Therefore, data will have to be transmitted in real-time to relay satellites in geosynchronous orbit. Geosynchronous relay satellites eliminate the need for articulating antennas for satellite tracking. Thus, a relatively unsophisitcated user could point a small receiving antenna to a location in the Earth's equatorial plane and could receive satellite data directly if the data were formatted to imagery by onboard processing. In the first part of this decade, the United States plans to utilize a tracking and data relay satellite system (TDRSS) with Landsat-D. Unprocessed data collected by the instruments on Landsat-D will be transmitted to TDRS satellites and then will be relayed to White Sands, New Mexico where the data will be recorded and later played back at a slower rate to a communications satellite. The communications satellite will relay data to a Landsat-D processing and dissemination facility now planned to be at Goddard Space Flight Center. Data could then be again relayed to other government data dissemination facilities using the same commercial satellite. Currently, the limitation on data rate through TDRSS is 300 megabits per second and several satellites planned for this decade will have data rates in the 300-800 megabit per second range. Thus, new technology will be required for relay of data at these rates.

Instrumentation for initial data recording

The current method in raw data handling is to record satellite data on Wide-band Video Tape Recorders at high data rates and then play the data back at lower rates for transmission through commercial satellite links. If onboard signal processing and data compression techniques are utilized, satellite data could be transmitted through relay satellites directly to the preprocessing facility where the data could be read directly on magnetic disks or to some other storage medium. Once on magnetic disks, the data could be readily preprocessed and relocated on magnetic disks for transmission or for direct recording on film, on computer compatible tape, or optical disk.

Instrumentation for data preprocessing

The main developments in general preprocessing instrumentation are the development and implementation of array processing technology. Array processors are highly flexible instruments which can work with 496 bit arithmetic instead of 8 bit arithmetic. Such processors are capable of high performance on low precision data and they permit the use of unique transforms and specialized arithmetic functions. Most processing problems are now defined in terms of serial arithmetic and processing software will have to be reorganized to take advantage of parallel architecture. Large parallel processors like the Goodyear Massive Parallel Processor and the

United Kingdom CLIP-4 processor have such high data throughput that most data transfer buses cannot transmit data fast enough to meet their demands. Thus, new technology will be required to interface data storage devices to large parallel processors. In this regard, fiber optic data buses are being tested for their high throughput capability.

Data recording and storage

Data recording is now done on film and magnetic tape. High density digital tape (20,000 bpi) technology is probably now at its limit. Problems with HDT's include tape stretching and decay with time. Most data archives are now considering magnetic disk storage as an interim solution and probably bubble memory and optical disk devices will be the solution to almost permanent records by the end of this decade. The use of high-resolution linear array technology to record data digitally on high-resolution film is also being considered as a method for storing digital data permanently and in a convenient manner. Film chips with digital data when processed would provide an almost permanent digital record which could be conveniently shipped by mail or compactly stored. Reading of digital data sorted on film into digital memory could be accomplished also using a linear array and, fiber optic data bus interfaced to a CPU.

Data reproduction and dissemination

Within the next decade it may be possible for users at remote locations to query and receive data from data archives using portable data reception terminals. All that would be required will be an antenna for data transmission and reception, a transmitter or receiver, a terminal with cathode ray tube display and keyboard and a data recording device. Using such a system a user would set up his portable antenna and aim it at a geosynchronous relay satellite, query the data base to determine what is available, order the required data by the picture element, and have the data transmitted over the same link. The data could be recorded in real time in digital form on a high density storage medium. This digital record could then be read into an analysis device which would reconstitute the data as an image. For users requiring less rapid data dissemination, digital film chips or video disks could be mailed without any concern for their electronic destruction or delay.

Direct film recording and film duplication still remain an art. There is need for development of a high-speed device which will record multispectral data on 241mm or wider film in color. Monochromatic laser beam recorders appear to be adequate for black and white film recording at production rates. However, there is a need for development of black and white high-resolution devices capable of recording on 122cm wide film or paper directly. This would allow direct recording of image data at a variety of scales, instead of enlargement in the photographic laboratory.

INSTRUMENTATION FOR ANALYSIS OF REMOTE SENSOR DATA

In the last decade the number of companies offering interactive digital analysis sytems has increased while the market for such systems has changed substantially in response to new technological developments, increased user sophistication, and lower costs for total systems. At the beginning of the decade remote sensor data in computer compatible tape (CCT) form was generally available to only select research groups. In the United States and Europe most users worked mainly with remote sensor data in film form. Research in the late 1960's with multiband cameras defined the need for multiband analysis instruments which would allow several bands of data to be compared simultaneously. The planned launch of a multispectral data collection satellite (Landsat 1) stimulated several companies to develop and market optical instruments for combined analysis of multiband data. At the same time systems for electronic scanning of film data were developed with the hope of providing semi-quantitative analysis of film density. Such devices were extensively utilized for analysis of thermal data because of the almost direct relationships between film density and apparent temperature. When the first interactive digital analysis systems were introduced in the early 1970's only a few sophisticated users could afford the high costs or had the in-house capability for software development to acquire such systems. These systems were based on available computer technology and utilized a specially designed interactive display console with built-in hardwired functions. Rapid developments in semi-conductor technology, the introduction of parallel processing hardware and high-speed magnetic storage devices has allowed the size, complexity, and costs associated with such systems to rapidly decline. Increased sophistication in software development has also allowed the design of interactive systems which do not require highly-trained users and which allow highly-interactive analysis. At the same time the user community has become more familiar with routine computer processing and CCT data are now universally available on a world-wide basis. Interactive digital and analog analysis systems have now replaced multiband viewing instruments and density slicing equipment as the main tools used by analysts of remote sensing data.

Multiband Optical Analysis Instruments

Most multiband viewing instruments utilize 70mm size film chips or 4-band multispectral camera data registered on 241mm wide film. The light source in these devices is usually placed behind an optical lense system which directs collimated light on the film chip. A gelatin or glass filter is often inserted below the film chip for color reconstruction and the images are directed to a mirror which allows them to be registered on a frosted screen. The images are usually optically enlarged from three to ten times and this usually results in a 25 to 35 percent degradation in optical resolution. Vignetting is another serious problem which has been somewhat mitigated by the use of variable density filters. Multispectral viewers have been found to be invaluable for the teaching of multiband concepts and the principles of color perception in the classroom. These devices provide a low cost method for analyzing multiband data in a qualitative manner.

Instruments for Analog Image Processing

Analog image processors utilize hard-wired modules which are designed to accomplish specific functions. The instruments usually consist of a video camera which scans a transparent image which has been placed on a light table. The image is focussed onto a videcon tube which has a light sensitive phosphor screen. The electronic voltages detected by the camera are synchronized, amplified and displayed using a color cathode ray tube. Some devices use a video disk to record multiple sets of input data so this data can be displayed in combination with other data on the CRT. These instruments have been used for "density" or level slicing and color encoding of the various levels, for first-order edge enhancement, and for isometric projections. Analog processing has some distinct advantages over digital processing and these include increased processing speed at video rates, reduced processing costs, and reduced training for analysts. Some limitations include problems with registering film chips of slightly different size, lack of optical linearity in scanning images, cannot analyze pixels, difficult to upgrade modules when new processing functions are desired, and data sources must be in analog format for processing.

Instruments for Digital Image Processing

Digital image processors utilize a combination of hard-wired modules and software programs to enhance, transform and classify digital remote sensing data. Input devices used with these systems usually consist of digital magnetic tape drives, video cameras, and point digitizers. A mini-computer is used for data manipulation and these minicomputers are interfaced to some kind of solid state, tape, or magnetic video disk refresh memory. Some systems use general purpose disk storage in addition to the refresh memory. A major part of interactive systems is the interactive display console which allows the operator to control the system, view displays of the data in memory, and introduce processing functions to specific areas in the displayed image. Output devices usually consist of the display monitor which can be photographed, tape drives, disk drives, film recorders, paper printers, and drum or flat bed plotters. Recent additions to digital systesms consist of parallel (or array) processors and high speed data buses.

When the first systems were developed in the late 1960's and early 1970's they were based largely on existing hardware and such systems commonly cost between a half and one million dollars. Within the last decade the systems have become more specifically designed around the needs for digital image processing and the costs have decreased with new developments in semi-conductor technology.

Input Devices. The principle device used for input of digital data is the magnetic tape drive. Most users are now routinely using drives capable of reading 1600 bit per inch (BPI) data at speeds of 75 inches per second (IPS) or faster. Some users have the capability of working with 6250 BPI data and a few users can read 20,000 BPI data at 30 IPS. Because new sensors will produce data at higher spatial and spectral resolutions there is a need for new input devices designed to read data at high speeds. Such devices should be able to read data in a variety of formats and override errors in recording and formatting. Ultimately, new compact instrumentation will evolve that will take advantage of laser disk technology for input of digital data. One laser disk is capable of storing the same amount of data recorded on 300 CCT's in 1600 BPI format. Laser disks and film chips offer a considerable advantage over magnetic tape because they are very stable, do not decay with time, and are not subject to stretching.

A second area that will expand with interactive digital analysis systems will be the area of real-time data reception and storage. Devices will be required that will allow users to receive data over telephone lines or from portable antennas. Portable antennas will allow data to be recorded directly in memory at transmission rates, provided the data bus is capable of handling such rates. Once data are on magnetic disk, or in some other memory medium they can be permanently recorded at reduced rates on magnetic tape, or real-time rates on laser disk.

Computer Processing Units (CPU). The entire area of computer processing technology is undergoing a revolution which has taken it from a revolution which has taken it from units the size of several storage cabinets to systems with advanced capabilities having the size of a hand-held calculator. Developments in very large scale integration (VLSI) technology will doubtless continue this trend and decrease costs for CPU's in interactive systems below the $50K level. Probably the major area of concern is the development of high speed data buses to be used in conjunction with state-of-the-art CPU's and array processors capable of handling data at 500 mega bit per second rates.

Digital Data Storage Devices. The current trend in bulk data storage is to magnetic disk recording. Early in the last decade disk storage was limited below 100 mega byte (MB) capacity and multiple disk units were arranged to handle data volumes. Early models of large capacity (greater than 200 MB) magnetic disk devices cost more than $100K. However, now $300MB disk units are routinely being employed which cost less than $50K. Bubble memory devices are still in the developmental stage and their costs are prohibitive for all but experimental systems. However, bubble memory devices may be the data storage devices which will be routinely used by the end of the decade. Laser disk recording and playback holds promise. However, more development will be required before lasar recording systems are routinely used.

Data Transfer Systems. High-speed data buses are now being employed which can operate in the 50 to 100 MPS rnage. However, parallel processors, high-speed high density tape recorders, and direct read-out instrumentation will require handling of data at half to one gigabit rates by the end of the decade. In this regard, cryogenic and fiber optic data buses are being tested in an experimental mode.

Array Processors. A variety of array processors are now routinely employed with interactive digital systems. A current approach to increasing throughput is to use several array processors in parallel in conjunction with a high-speed data bus and large capacity disk. Several new large "parallel" processors are under development and such devices will allow multiple processing functions to be applied to data at greater than 500 MBS rates. Prior to the use of parallel processing maximum liklihood classification of a 512 x 512 by 4 channel would require 8 hours of core time. Use of a single array processor cuts this time to less than 3 minutes. Reduction in processing time greatly increases the interactive nature of digital processing devices. Array processing technology also allows new approaches to software architecture which in turn speed processing and introduce more flexibility.

Interactive Display Consoles. The first display consoles were large units the size of several 6-foot high instrument racks. Usually hard-wired functions, the cathode ray tube (CRT) display, and interactive controls were mounted into the large cabinets. Today's consoles easily fit on a desk top in modular form and usually consist of a keyboard, a television monitor and interactive marker for controlling data analysis. Some keyboards are also interfaced to a small cathode ray tube display or paper printer so entered commands and statistical analyses of data in refresh memory can be evaluated. Many systems use the keyboard CRT or Printer to display menus of programs and prompt user response. The most recent addition to display consoles has been the light pen wand which allows the user to interact with data displayed on the color monitor. Light pens, tracker balls, and joysticks are used to configure electronic cursors for data manipulation. Of the three methods for controlling cursors, the light pen is by far the superior one. Display monitors that were used early in the last decade were limited to 512 by 512 resolution in color and 1024 by 1024 in black and white. Now 1024 by 1024 resolution color monitors are routinely employed and image distortion with such monitors has been minimized. However, there is still a need to improve the resolution and geometric fidelity of color monitors along with reducing their size and complexity.

Output Devices. Microdensitometers, flying spot scanners, facsimile and line printers are the main output devices used in conjunction with interactive digital analysis systems. Microdensitometer systems utilize a modulated light source which scanned on to film placed either on a flat bed or on a rotating drum. The spotsize of the light source can vary from 10mm to 100mm. The main limitations with such systems are mechanical wear and relatively small format size (about 25cm by 25cm). Flying spot scanners consist of electron beam, laser, and cathode ray tube devices. Electron beam devices require an evacuated recording chamber and usually data must be recorded on film not wider than 10cm. Cathode ray tube recorders are somewhat limited to small formats and dynamic range. Although microdensitometer recorders are now most commonly employed with interactive systems, laser beam recorders are being utilized to record images on large formats (24.1 cm or larger). Such laser recording systems are expensive and cost between five and ten times more than microdensitometer systems. Most laser systems record directly on black and white film and color composites must be reconstructed in the photographic laboratory. There is a clearly defined need for instruments which will permit direct recording in color on large formats.

Facsimile recorders are essentially line scanning systems which use photographic, electrostatic, and electrolytic recording methods. The photographic facsimile recorders use incandescent, CRT or laser light sources which are intensity modulated. Electrostatic recorders have 2 or 3 styli mounted on a belt which is driven at a constant speed to scan horizontally. A pulse width modulating technique achieves gray levels by varying the area of each pixel. Electrolytic recorders use a paper which requires no processing because the recording density is proportional to the current passing through the paper.

A standard line printer records digital images using characters to represent gray levels. Sometimes character overprinting is done to give better gray scale representation. The major problems with a standard line printer are speed and aspect ratio. A matrix printer-plotter system can be arranged to output images by representing each pixel by a matrix of dots. Line printers offer hardcopy at the lowest equipment costs because electrostatic printers are more difficult to interface to computer components.

CONCLUSIONS

Within the next decade increased developments in computer processing hardware and digital data storage will make very compact and inexpensive systems possible for the processing and analysis fo remote sensor data. Major technological developments will be required to reduce the size, complexity and costs of input/output devices. If these technological objectives are achieved, then it is not unreasonable to expect that image processing systems will be of a size not larger than a small trunk or large suitcase and may cost less than $10K. It is not inconceivable that by the end of the decade users at remote locations may be able to query data bases using portable telecommunications links to determine what data is available. These remotely located users may be able to receive desired data over the same telecommunications link and may be able to process and analyze the data on a small portable device.

FUTURE RECOMMENDATIONS FOR WORKING GROUP ACTIVITIES

The diversity of instruments for dealing with the processing and analysis of remote sensor data that Working Group II/4 had to deal with was probably too great. In the future it is suggested that separate working groups within Commission II deal with the following areas:

1. Instrumentation for onboard signal processing of remote sensor data.

2. Instrumentation for remote sensor data transmission and reception.

3. Instrumentation for general remote sensor data processing. This would include radiometric and geometric rectification of data to common formats.

4. Instrumentation for data storage and dissemination.

5. Instrumentation for remote sensor data analysis and interpretation.