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Educational Image Processing: An Overview

Mainframe, minicomputer, and microcomputer configurations are described.

Abstract: *Digital image processing is often an integral part of a student's education in remote sensing. Such instruction is normally accomplished by (1) providing digital image processing laboratory assignments within the context of introductory remote sensing courses and/or (2) teaching separate classes or seminars specifically oriented toward digital image processing of remotely sensed data. The general course content of such approaches is briefly reviewed. In addition, image processing system configurations to support these scenarios are identified and discussed.*

Introduction

In 1981, there were approximately 691 courses in airphoto interpretation and/or remote sensing taught in the United States (Dahlberg and Jensen, 1981; Lillisand, 1982). This education was performed by various academic disciplines with the social sciences (37 percent), physical sciences (25 percent), and engineering sciences (18 percent) responsible for the greatest proportion. Although detailed statistics are not yet available, it appears that many remote sensing educators try to incorporate digital image processing instruction within the course sequence. This is normally accomplished by (1) providing digital image processing laboratory assignments within the context of introductory remote sensing courses and/or (2) teaching separate classes or seminars specifically oriented toward digital image processing of remote sensor data.

To provide an appreciation of how such digital image processing education takes place, this paper first identifies the fundamental concepts to be mastered. Then, digital image processing system configurations which address this educational need are introduced. This overview provides a foundation for more indepth treatment of the image processing approaches discussed in this issue by Williams, Gunn, and Siebert (1983) of the University of Kansas (p. 1159), Kiefer and Gunther (1983) of the University of Wisconsin at Madison and Computer Sciences Corporation (p. 1167), and Eyton (1983) of the Pennsylvania State University (p. 1175). These are revised papers on educational digital image processing solicited in 1981 for the Conference on Remote Sensing Education (CORSE-81) held at Purdue University and the Fall Technical Meeting of the American Society of Photogrammetry.

Before identifying the fundamental concepts of digital image processing, it is important to ask, "Why is digital image processing of remotely sensed data of practical value to the student who only wants a fundamental knowledge of how to interpret and apply remotely sensed data to Earth resource problems?" There are two answers. First, many of the concepts to be mastered even in an introductory remote sensing course may be communicated and understood better by the student if he or she is exposed to image processing principles. This is especially the case today where much of the data analyzed in remote sensing courses is acquired by multispectral scanning systems and originally provided in a digital format. Second, let us dispense with a myth. Employers rarely hire 'remote sensing specialists.' Rather, they hire people solidly trained in a scientific discipline who may know something about remote sensing (Lillisand, 1982). If the employee has learned the fundamentals of remote sensing and also has experience in digital image processing, then he or she will likely be even more valuable to the employer. Thus, a knowledge of digital image processing

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principles and techniques makes the scientist more marketable (Mead, 1979; Johnson, 1981).

Fundamental Concepts to Be Mastered

The fundamental concepts to be mastered in a remote sensing class inevitably require an understanding of sensor system resolution constraints and preprocessing and classification logic germane to the remote sensing task at hand (Everett and Simonett, 1976). The constraints include the spatial, spectral, radiometric, and temporal resolution inherent in a given remotely sensed image or series of images (Hoffer, 1978). Students must come to understand that, with fixed resources, a change in one system parameter generally requires a change in one or more of the parameters. For institutions which fall in category #1 of the previous discussion, the goal of gradually bringing students to a higher level of conceptual and practical understanding is often accomplished using a carefully structured series of laboratory assignments which supplement the lecture material (Swain, 1981). The assignments generally require students to

- experiment with preprocessing algorithms such as ratioing and filtering in order to understand and reduce system or environmental effects such as high frequency noise, shadows, or atmospheric attenuation. Also, system deformations in the image are made clear to the student when he or she is required to de-skew and/or geometrically rectify remote sensor data to a standard map projection or other base. In addition, other transformations of the raw data such as contrast stretching or edge enhancement serve to communicate the statistical nature of the remotely sensed data and how it might be preprocessed to improve visual interpretability (Jensen *et al.*, 1979).
- use statistics, histograms, and brightness maps to investigate the spectral nature of selected subimages (Gunther, 1981a; Jensen and Hodgson, 1983). This causes students to acknowledge the regional spectral variation of phenomena due to cultural (e.g., land use and tenure) or environmental parameters (e.g., soil type variations). Using large scale aerial photography, students are usually required to 'zero in' on very small regions or features (possibly even one pixel) to determine pixel location and the nature of the physical materials present within the sensor's instantaneous field-of-view (IFOV). This, in conjunction with an analysis of the spectral nature of the scene, drives home the integrating nature of the sensor system and its relatively coarse spatial and spectral resolution (assuming Landsat data are used).
- learn the procedures for supervised and unsupervised feature extraction and feature selection and the significance of sample location, size, and degree of homogeneity (Jensen, 1979). Students are required to grapple with multimodal training statistics and become aware that the interaction of man and computer is critically important in the classification process (Kristof *et al.*, 1976).
- experiment with different classification algorithms in order to determine the advantages and disadvantages of using certain algorithms for specific applications (Hixson, *et al.*, 1980). Students evaluate methods of assessing classification performance and the proper way of validating statistically their results (Rosenfield *et al.*, 1982). They consider absolute and relative performance and determine the feasibility of steps to improve classification performance (Thomas, 1980). Iterative analysis becomes an important learning experience (Kristof *et al.*, 1976).
- summarize their experiences concerning the advantages and disadvantages of machine-assisted land-cover analysis and classification in terms of specific tradeoffs of cost, time, and accuracy, and repeatability versus visual photointerpretation. The visual photointerpretation approach may be judged superior.

This scenario may be the most widely adopted method of incorporating image processing into a remote sensing curriculum because only occasionally are special purpose digital image processing courses or seminars offered. In fact, only 40 of the 691 remote sensing courses taught in 1981 could be classified as dedicated courses in digital image processing (Dahlberg and Jensen, 1981). When such instruction does occur, however, a more in-depth treatment of the digital image processing topics discussed above, plus system architecture, logic, and algorithms is required. Consequently, a more sophisticated digital image processing system may be justified so students can experiment with state-of-the-art algorithms and equipment (Scarpace and Kiefer, 1981).

Educational Image Processing Systems

Having concluded that there are basically two methods in which digital image processing is introduced into most remote sensing curricula, the system requirements can now be addressed. Two typical scenarios (1A and 1B) for the digital image processing laboratory approach and a single scenario (2) for the specialized coursework in digital image processing are presented in Table 1. First, note that up to fifty students may desire access to the system at one time in the digital image processing laboratory approach. The requirements of 50 persons performing digital image processing in a structured laboratory environment suggests that either a large mainframe with numerous terminals be available, or that numerous stand-alone systems be provided. Thus, we have a dichotomy in Table 1 between the mainframe and the microcomputer approach.

Mainframe Digital Image Processing

The significance of the mainframe approach is that, for those academic departments just starting to introduce image processing into the remote

TABLE 1. TYPICAL CHARACTERISTICS OF IMAGE PROCESSING SYSTEMS USED IN TWO TYPES OF EDUCATIONAL ENVIRONMENTS

	Type of Use	Number of Students	Type & Speed of Processing: Interactive	Batch	Typical Size of Image to Be Analyzed	Typical CPU Configuration and Cost	Most Typical Compilers	Type of Image Input Device Required	Type of Output Device Required or Available	Typical Peripheral Storage	Typical Cost of Processing per Student
1A.	Image processing laboratory assignments in introductory remote sensing courses using one mainframe computer.	≤50	near real-time	≤1 day	<300 × 300 pixels	MAINframe provided and supported by the University (≥32 bit word; ≥500K memory), ≤$500,000.	ASSEMBLER, FORTRAN, BASIC	Nine track tape drive purchased and supported by the University.	Numerous alphanumeric CRTs or line printers (132 column) and usually a digital plotter (≥100 dots per inch).	hard disk (>100 megabytes)	$3./hour
1B.	Image processing laboratory assignments in introductory remote sensing courses using more than one microcomputer.	≤50	real-time	≤1 hour	≤240 × 256 pixels	MICROcomputer system(s) purchased and supported by dept. (8 to 16-bit word; ≥48K memory), $10,000 to $20,000.	ASSEMBLER, FORTRAN, BASIC, PASCAL	RS232 communications link between mainframe disk and floppy disk to transfer subimages, or EROS 8″ floppy disk format. * joystick/trackball	Low resolution color CRT for Apple to support 40 × 40 or 280 × 190 with 16 colors. Medium to high resolution CRT for S-100 system to support 240 × 256 pixels and at least three 4-bit refresh image planes.	floppy disk (256K to 1.2 megabytes)	$1./hour
2.	Course in digital image processing or the support of graduate research using a dedicated minicomputer.	≤10	real-time	≤1 hour	≥512 × 512 pixels	MINIcomputer purchased and maintained by dept. (16 to 32-bit word; 128 to 512K memory), $30,000 to $100,000. * floating point processor * array processor	ASSEMBLER, FORTRAN	Nine track tape drive. * joystick/trackball * video camera digitizer * coordinate digitizer	High resolution color CRT(s) to support ≥512 × 512 with at least three 8-bit refresh image planes. * matrix printer/plotter * film writer * computer output to microfilm	hard disk (>20 megabytes)	$20./hour

sensing curricula, it is usually the least expensive alternative. Most university computer centers *purchase* and *maintain* the central processing unit (CPU), disk drives, nine-track tape drives, and numerous alphanumeric terminals. Thus, the academic department is not required to invest directly in any capital equipment. Another significant element of this approach is the relatively efficient cost of image processing per student per hour (Jensen *et al.*, 1979; Williams *et al.*, 1981).

Because the mainframe hardware is often in place and basically out of the instructor's control, the most crucial element of this approach is the selection of the image processing software to be used. There exist numerous image processing software systems which operate interactively or in batch mode and have been written for either FORTRAN or BASIC compilers (e.g., Bauman, 1981; Eyton, 1981; Jensen, 1981; Turner, 1981; Williams, 1981; and COSMIC, 1980). Consequently, there is little need to write new software unless one wants the experience. The implementation of software which was developed elsewhere usually requires the interaction of a systems level programmer (perhaps available from the computer center) and a remote sensing applications programmer who understands what the software is to do. Implementation generally takes six months.

Turn-around time is another important consideration. Depending upon the type of compiler available, the nature of the operating system, and the image processing software implemented, all students may be able to either (1) submit remote batch jobs, or (2) conduct interactive time-sharing image processing within a laboratory environment. The turn-around time for batch jobs is usually slow, e.g., hours or even days. However, late in the quarter and in the afternoon of each day it is not unusual for time-sharing, interactive systems to also slow down. Thus, slow turn-around time for the mainframe approach in either batch or interactive mode is not uncommon because of demands on the system by numerous users (Williams, 1981).

Because so much of the digital image processing education in the United States is performed on mainframe systems, it is useful to identify various approaches. In this issue Williams *et al* (1983) discuss the interactive, time-sharing, image processing system operating on the University of Kansas Honeywell Level 66 multi-processor. They describe system hardware, software, and cost characteristics and the advantages and limitations of image analysis instruction in a time-sharing mainframe environment. Also in this issue, Eyton (1983) discusses a hybrid instructional image processing system operating in batch mode which makes use of special purpose FORTRAN and SAS (Statistical Analysis System) software to process remote sensor digital data on an IBM 3033. These two papers concur that the mainframe approach is the best for introducing a large audience to the fundamentals of digital image processing in introductory remote sensing courses.

MICROCOMPUTER DIGITAL IMAGE PROCESSING

Numerous researchers (e.g., Cady and Hodgson, 1981; Gunther, 1981b; Harrington, 1981; Wagner, 1981; Hsu, 1982) and commercial vendors (e.g., Masuoka *et al.*, 1981; Egbert, 1982) provide image processing software for microcomputer systems. When as many as 50 students are involved, it becomes necessary to purchase several independent systems which are modestly priced ($10,000 to $20,000), or attach numerous work station terminals to the microprocessor CPU, i.e., network the units. Networking also requires a special operating system. Obviously, the amount of data to be manipulated (e.g., size and number of matrices) may not be competitive with the larger mainframe capabilities (Table 1). This may be offset, however, by the microcomputer's ability to provide a color, interactive environment with real-time response. Also, because the students are divorced from a University accounting system, the cost of the image processing session per student per hour is a function of the initial cost of the equipment and its maintenance. Thus, as the same equipment is used by more and more students, the cost of the image processing continually decreases.

A major stumbling block for the microcomputer based systems has been how to get the raw data resident on a nine-track tape onto the floppy disk of the microcomputer system. Almost all microcomputer image processing systems still rely on a mainframe computer, disk drive, and nine track tape drive from which the data are transmitted via an RS232 communications link onto the floppy disk. Some vendors do provide a program for the mainframe which will perform this function (Egbert, 1982). Fortunately, the EROS Data Center now provides portions of Landsat digital images on 8-inch floppy disks, hopefully solving the problem (U.S. Geological Survey, 1982; Holm, 1983).

A final attraction of microcomputers for remote sensing education is that a department can enter the field with a relatively modest investment ($10,000 to $20,000) and then add peripherals, memory, etc., as additional resources become available.

Thus far, the majority of image processing performed using microcomputers (i.e., 8-bit CPUs) have been on either Apple IIs or Z-80 microcomputers which operate on an S-100 bus. In this issue, Kiefer and Gunther (1983) review the characteristics of five image processing systems written for the Apple II computer, including the Apple II Digital Image Processing System (A/DIPS), Apple Image Processing Educator (AIPE), Oklahoma Landsat Training Program System, Apple Personal Image Processing System (APPLEPIPS), and Mini-LARSYS. They identify the advantages of cost and portability for introductory digital image processing and the disadvantages of having a relatively small image size and small color pallet.

Software written for microcomputers operating on an S-100 bus offer quite a different set of options (Hsu, 1982; Wagner, 1981). Such systems typically incorporate an image processor with refresh graphic memory which provides 240 by 256 by 8-bit pixel resolution in the black-and-white mode and 240 by 256 by 12-bit resolution in the color mode. This may allow approximately 4096 colors to be displayed on the screen at one time. Thus, false-color composites with up to 4096 colors and black-and-white brightness maps of up to 256 shades of gray (8-bit) can be viewed on a high resolution monitor.

This latter approach is used by the Remote Image Processing System (RIPS) developed at the EROS data Center (Wagner, 1981; Borrell, 1982). The RIPS system is being installed in various government agencies as interactive, low cost, remote image processing stations (Yost, 1983). Such a hardware and software configuration provides an image processing capability often found only on dedicated minicomputer image processing systems.

DEDICATED MINICOMPUTER IMAGE PROCESSING SYSTEMS

Few social or physical science departments are fortunate enough to purchase a minicomputer-based image processing system. The majority are found in the engineering sciences or at specialized institutes or laboratories (Lindenlaub, 1973; Andrews, 1977; Danielson, 1981b). Numerous systems built around a minicomputer were summarized by Carter *et al.* (1977). Such systems are ideal for state-of-the-art instruction in digital image processing theory and application. A major advantage is the interactive analysis of relatively large image segments. Such images are normally viewed on one or more high resolution color monitors. The monitor(s) are usually driven by digital refresh memory with a resolution of 512 by 512 by 24-bits per pixel (Table 1). Thus, a pixel may be assigned one of over 16 million colors. In addition, several graphic overlay planes are usually present for line drawing and annotation. Of course, there are more sophisticated systems with 1024 by 1024 and 2048 by 2048 capability, but these are still relatively rare in educational environments. Finally, the existence of a hard disk drive supports the rapid retrieval and storage of large image segments.

Data input is normally performed using the system's nine-track tape drive or a vidicon digitizing camera which converts hard copy imagery into digital data files. A trackball or coordinate digitizer is usually interfaced to the system to input ground control coordinates for geometric rectification and/or training site coordinates. Hardcopy image output of the CRT display is often produced on relatively expensive devices such as a film writer.

Numerous vendors offer turn-key image processing systems built around a minicomputer (e.g., Curran, 1982; Flynt, 1982; Hall, 1982; Jordan, 1982; Stone, 1982; Strickland, 1982). Most cost between $30,000 and $150,000. However, another approach is for departments to acquire a minicomputer and then write software and append peripherals as resources become available (Mulder and Donker, 1977; Gunn, 1981). The minicomputer based system provides graduate students with a state-of-the-art education in digital image processing which may be useful in the remote sensing job market. Unfortunately, relatively few systems are in existence.

In 1981, Scarpace and Kiefer discussed the characteristics of dedicated minicomputer image processing and contrasted its utility with the mainframe and microcomputer approaches. They concluded that "there is little doubt that access to a dedicated image analysis system is preferred if computer programming is involved in the course. The most important aspect of a dedicated facility is the ability to view the results of a change in the algorithm very quickly." Also, the display of high resolution color graphics is deemed very important. They pointed out that unfortunately, ". . . the system has the limitation that only one person (or small group) at one time can use the system." This can be a serious limitation when course enrollment is high.

ADDITIONAL OPTIONS

Of course, it is possible to conduct classes or seminars in digital image processing using either the mainframe or the microcomputer based systems discussed. However, the size of the area to be analyzed and viewed, speed of turn-around, and general ability to appreciate the significance of a dedicated minicomputer-based image processing system may not be available to the student.

Still another option is the use of remote analysis stations (RAS) configured around a high resolution color terminal. Such stations communicate via phone link with an image processing system at a central facility (Rogers *et al.*, 1981; Buis and Bartolucci, 1981). The slow rate of data transmission via the phone line may be a serious constraint. Nevertheless, this is a realistic alternative if the host institution continues to support the remote terminals indefinitely.

Finally, no mention has been made of the interface of a geographic information system (GIS) with the digital image processing system (Gunn, 1981). Most remote sensing educators realize that interpreted remotely sensed data fulfills its potential best when used in conjunction with other ancillary data. Fortunately, there are some systems which incorporate both image processing and geographic information systems (e.g., Seidman, 1977; Berry, 1980; Faust and Jordan, 1980; COSMIC, 1980). However, the level of program complexity, computer resources required, and cost of such systems may also increase.

Summary

This preliminary survey has identified the principal educational mechanisms by which digital image processing is introduced into remote sensing curricula. Several image processing system configurations have been discussed. Most students will continue to receive their digital image processing experience via a mainframe environment, due simply to the lack of departmental equipment funds. However, advances in microcomputer technology and image processing software are rapidly providing alternatives (Welch *et al.*, 1983). Image processing systems configured around a dedicated minicomputer are still relatively rare and are likely to remain beyond the grasp of most social and physical science departments. This is unfortunate because such systems provide students the optimum digital image processing experience. Also, these are the systems that industrial users of remote sensing are employing in contrast to mainframe-based systems.

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