ABSTRACT

In 1964, a remote sensing project was initiated at Purdue University. That year, for the first time ever, a multispectral scanner was flown over a non-military target, in this case the Purdue Agronomy Farm. Analysis of the imagery showed that some crop types could be identified, based only on their spectral response. All the imagery was classified as “confidential” because it had been obtained by a military scanner system, so only pencil sketches of what the imagery looked like could be published. It quickly became very clear that a more quantitative method for analyzing the data was needed. This led to the founding of the Laboratory for Agricultural Remote Sensing, or LARS, in 1966. LARS was an interdisciplinary laboratory with students and faculty from many different departments at Purdue University working together to develop effective techniques for analyzing remote sensor data, particularly multispectral scanner data.

Pattern recognition technology was in its infancy at that time, but was believed to be the best approach for developing computer-aided analysis techniques that could be applied to multispectral scanner data. This led to the development of LARSYS, a software package that was ultimately utilized by remote sensing labs throughout the country and even internationally. Early image displays could only be done using computer line printers and symbols, but in 1969, the first digital image display device ever developed was delivered to LARS. It had a black and white display screen with a light pen for interfacing with the data, and cost NASA and IBM $1,000,000 to develop. With the advent of desk-top computers and display devices, this unit was obsolete within about ten years and was then returned to IBM for their company museum.

This paper discusses the beginnings of the research with multispectral scanner data; the various types of data, imagery and equipment used; the analysis techniques developed; and some of the early applications of multispectral remote sensor data.

INTRODUCTION

In the late 1950’s, the Agricultural Board of the National Research Council was concerned about the impact of insects and diseases on crops and forests throughout this country and the world. Therefore, in 1961 a committee was formed to investigate the potential of aerial surveys for monitoring insect and disease infestations in agricultural crops and forests. This committee, called the “Committee on Remote Sensing for Agricultural Purposes” was chaired by Dr. J. Ralph Shay, then Head of the Department of Botany and Plant Pathology at Purdue University. One of the key people on the committee was Dr. Robert N. Colwell, of the Forestry Department, University of California. Bob was an expert in photo interpretation and was considered to be “Mr. Remote Sensing” in the United States at that time. He played a critical role in the activities of the committee. Another key person on this committee was Dr. Marvin Holter, from the Institute of Science and Technology (IST), University of Michigan. He was involved in a research project called Project Michigan, which was a classified military project that included work to develop an instrument called an “optical-mechanical scanner”. Such a scanner could be flown in airplanes to obtain imagery of the ground in different wavelength bands of the electromagnetic spectrum. Dr. Holter believed that this optical-mechanical scanner had good potential for assessing agricultural cover types and conditions. The other committee members agreed that it would be worth evaluating, and Dr. Shay suggested that the Agronomy Farm at Purdue University had many species of crops, with detailed “ground truth” information available, so would be an excellent test site. *

* Much of the work of this committee was ultimately documented in the classic book: REMOTE SENSING -- With Special Reference to Agriculture and Forestry, which was published by the National Academy of Sciences in 1970.
At about that same time, NASA was rapidly developing satellite capabilities and was interested in potential applications of data that might be obtained from satellites. Thus, there was a merging of interests – the need for agricultural information over large geographic areas; the potential utility of multispectral scanner systems; and NASA’s interest in the potential for utilizing spacecraft for various practical applications. A proposal was prepared and ultimately funded by NASA, and in May 1964, an optical-mechanical (i.e., “multispectral”) scanner was flown for the first time over a target that was not primarily of military interest – the Purdue Agronomy Farm.

THE FIRST MULTI-SPECTRAL DATA COLLECTION OVER A NON-MILITARY TARGET

On May 3, 1964, two single engine L-19 aircraft flew over the Purdue Agronomy Farm with a system of multispectral scanners and cameras. This was the first time in history that a multispectral scanner had been flown for the primary purpose of gathering information on crops and soils. The scanner system actually consisted of two double-ended scanners. One scanner obtained data in the ultra-violet portion of the spectrum on one end of the scanner and the thermal infrared on the other end. The other scanner collected data in one thermal and three reflective infrared channels. The data were recorded onto analog tapes, and then imagery was generated which could be analyzed using photo interpretation techniques. (Computer-aided analysis capabilities did not exist at that time.). Because neither of the scanners obtained data in the photographic portion of the spectrum (0.4 - 0.9 μm), data in these wavelengths was obtained using a Graflex camera. However, instead of a standard lens, the front of the camera consisted of a piece of plywood in which nine holes had been drilled and a small lens was inserted into each hole. On top of each lens was a thick packet of filters designed to allow only a certain range of wavelengths to be transmitted. The imagery was recorded on 4 x 5 inch I-N Spectroscopic glass plates. The result of the combined scanner and camera system was a set of eighteen wavelength bands of imagery, representing wavelengths from 0.32 μm in the ultraviolet to 14 μm in the thermal infrared (see Table 1).

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<tr>
<th>Wavelength bands</th>
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<td>Kodak Ektachrome Infrared Aero film (or camouflage detection film) and Wratten 12 filter and special infrared color filter</td>
<td>P-2 camera (70 mm format)</td>
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MANUAL INTERPRETATION OF 18 WAVELENGTH BANDS OF IMAGERY

Five missions were successfully flown over the Purdue Agronomy Farm during the summer of 1964. I was hired by Purdue University under a grant from the U.S. Department of Agriculture, Economic Research Service. When I
arrived at Purdue later that summer, my first task was to interpret the imagery obtained on these missions to see if it could be used to identify different crop species and conditions. Of the eighteen wavelength bands of imagery produced, all of the bands obtained by the “optical-mechanical scanner” had a military classification of “confidential” because the scanner had been developed under military contract. As a result, I had to have military clearance to work with the imagery. Since I had just been honorably discharged from the U.S. Army and did have such clearance, it was relatively easy to have my credentials extended to allow me to work with this data. Because the scanner imagery was classified as “confidential”, I had to keep it in a locked cabinet, and no one else could be in the room when I was working with the imagery.

Manually interpreting the differences in grey tone that might identify the various crop types and conditions using eighteen different wavelength bands of imagery proved to be challenging. I used Kodak grey-scale chips to compare against the grey tones of the different crop types and conditions seen on the imagery. Different crop types could be compared in each wavelength band of imagery and “Multispectral Response Pattern” graphs prepared which showed which wavelength bands would be useful for differentiating the crop species of interest. (See Figure 1.) In comparison with today’s technology, this approach undoubtedly sounds like something out of the stone age. However, this crude method of data analysis did appear to hold promise, but also indicated that before we tried to identify agricultural disease or insect infestations, we first needed to determine if we could simply identify the different crop species using such multispectral data. The resulting efforts also indicated the importance of obtaining remotely sensor data at the critical stages of crop development. Some crops could be differentiated at certain times during the growing season, but not at other times.

**Figure 1.** A Multispectral Response Graph for Corn and Soybeans.

It is interesting to note that because the imagery was classified, I could not include illustrations of the imagery in any publications. As a result, I developed “artist’s concept” drawings of the grey tones of the agricultural fields for the various wavelength bands, and illustrated the relative differences in reflectance or emittance in that manner. *(See Figure 2.)* Scanner data obtained on June 25, 1964 over several fields of row crops resulted in some interesting moire’ patterns. These patterns occurred if the scan line was at a slight angle to the row direction, and if the flying height of the scanner was such that the scanner resolution was similar to the distance between the rows of the crop (see Figure 3).

*It was not until 1967 that the scanner system was declassified and imagery obtained from it could be shown to the general public and used in publications.*

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These early, rather crude attempts to manually interpret 18 wavelength bands of black and white imagery led to the conclusion that methods needed to be developed to quantify both the data collection and analysis processes. One approach that was considered involved use of a densitometer to measure the photographic opacity of the film for each agricultural field of interest in each wavelength band of data. This technique would provide a quantitative set of data to which pattern recognition algorithms could be applied. However, before this approach was implemented, the University of Michigan engineers had developed a new multispectral scanner system that collected data simultaneously in twelve bands (ten visible and two near infrared), and these data were recorded onto an analog tape. The analog tape data could be changed later into digital data through an analog to digital converter. It was
this scanner that provided the data for the research needed to develop and test digital pattern recognition techniques, many of which are still in use today.

**LARS – THE LABORATORY FOR AGRICULTURAL REMOTE SENSING**

In early 1965 the Purdue researchers in the Botany and Plant Pathology Department had learned that faculty in Electrical Engineering were doing work in an area of research referred to as “pattern recognition”. Meetings between Drs. Shay and Hoffer and Dr. Roger Holmes, an electrical engineer, resulted in a plan to form an interdisciplinary team to attempt to apply pattern recognition techniques to this multispectral scanner data. A proposal to NASA from Drs. Hoffer and Holmes was funded for the purpose of “establishing methods whereby various soil and agricultural crop parameters may be determined remotely, through a program of comparative multispectral sensing. Crop and soil parameters to be studied include species identification, state of maturity, disease conditions, soil types and soil moisture conditions.” A companion proposal from Dr. Shay to the USDA Agricultural Research Service enabled the Laboratory for Agricultural Remote Sensing, or LARS, to be established in February 1966. Dr. David Landgrebe, Dr. K.S. Fu, Dr. Philip Swain, and Mr. Terry Phillips, from the Department of Electrical Engineering, formed the core of the data processing analysis team. Mr. Robert MacDonald came from IBM to become the Technical Director of LARS, and Dr. Marion Baumgardner, Dr. Chris Johannsen, and (later) Dr. Marvin Bauer of the Agronomy Department provided expertise in that area. From the beginning, LARS was a very interdisciplinary team. By working together in a single laboratory facility, faculty and graduate students from different disciplines were able to learn from each other and contribute to the common goals in a manner that was much more effective than would have been the case if it had been a multi-disciplinary program. The basic goal of the LARS team, initially, was to develop techniques to digitally analyze multispectral scanner data of agricultural crops. (It should be noted that in 1969, LARS was renamed the “Laboratory for Applications of Remote Sensing” in order to better reflect the broadened research activities of the group in forestry, geology, hydrology and geography, as well as agricultural crops and soils.)

At the same time that LARS was being formed at Purdue University, NASA also funded Dr. Robert Colwell, Department of Forestry at the University of California, to pursue the use of remote sensing technology for forestry applications. Given Dr. Colwell’s expertise in photo interpretation, the research efforts at the University of California concentrated on the use of multi-band photography and manual interpretation techniques for forestry applications. Another grant was given to the University of Michigan to continue development of multispectral scanning systems and to pursue the use of analog methods of data analysis. Dr. Victor Myers, U.S. Department of Agriculture, Weslaco, Texas, was funded by the U.S. Department of Agriculture to assess the utility of remote sensing for various agricultural applications. Research at the University of Kansas focused on the interpretation and applications of radar data was also supported by NASA. Key people in this effort were Drs. Richard Moore, Fawaz Ulaby, David Simonett, and Stanley Morain. Thus, there was a significant amount of research being conducted at several locations around the country, all dealing with remote sensing for agricultural and forestry applications, but with each team of researchers pursuing a rather different and distinct aspect of remote sensing research.

**EARLY METHODS FOR INTERFACING WITH MULTISPECTRAL SCANNER DATA**

At Purdue University, the initial effort concentrated on developing computer programs that would allow the researchers to effectively interact with multispectral scanner data. The data for each wavelength band was first converted from analog to digital format using an analog to digital converter. Then in November 1966, an IBM 360/Model 44 main-frame digital computer was obtained. This was only the second machine of this model to be installed anywhere in the country. The main CPU (Central Processing Unit) was huge, standing about head-high, was about 10 feet long and 4 feet wide, and we loaded data into it via large 7-track tapes or computer punch cards.

* The U-M system was actually a combination of four scanners, obtaining data in a total of 18 wavelength bands. In addition to the 12-band Multispectral Scanner, the U-M system also collected a single band in the U.V. (0.32 - 0.38 Fm) portion of the spectrum; four bands in the middle and thermal IR (1.5 - 5.5μm) region, and one band in the longer thermal IR (8 - 140μm) portion of the spectrum. However, it was the registered 12-band multispectral data that was used for most of the pattern recognition research at LARS.

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It’s processing characteristics were: 16,434 words of core storage with a 1 microsecond memory cycle time per 32-bit word. It had no monitor or display capability. Therefore, to display the data, a line printer and different alphanumeric symbols were used to represent different levels of reflectance in a particular wavelength band, thus providing a rough grey-scale map of the area (see Figure 4). For example, the letter M or W might be used to represent a low reflecting pixel, while a - , /, or blank would be used to display high reflecting pixels. From a distance of several feet, a person would not see the individual symbols, but only a crude grey-tone map of the area. We would often then use marker pens and color the different symbols to provide a “color image”, and use this for our analysis.

**Figure 4.** (Left) Aerial photo with agricultural crop species and land use indicated, e.g., S = soybeans, W = winter wheat, O = oats, C = corn, R.C. = red clover, P = pasture, D.A. = diverted acres, etc. (Center) Computer line printer “grey-tone” map of the multispectral scanner data obtained in the 0.62 - 0.66 μm wavelength band for a portion of Flight-line C-1 on June 28, 1966. (Right) Printout of the computer classification of winter wheat for the entire Flightline C-1 area. This was the first attempt to use multispectral scanner data and truly automated pattern recognition techniques.

To classify the multispectral scanner data, the line printer output also showed each line and column of the scanner data so that each pixel had a specific set of X-Y coordinates. This allowed the data analyst to define rectangles of known cover types that were used as “training fields”. Using this training data and various pattern recognition algorithms (e.g., nearest neighbor, maximum likelihood, etc.), the spectral pattern of each pixel could then be “classified” by the computer into one of the training classes that had been defined. It soon became clear that there was often not a nice one-to-one relationship between the cover type classes that were identified as training fields and the spectral classes present in the data. This led to an increased focus on understanding the spectral variability of agricultural cover types and crop phenology. A field spectroradiometer proved to be particularly useful in this effort.
VALIDATING THE CONCEPT: THE FIRST CLASSIFICATION RESULTS

In 1966, the University of Michigan flew three flight missions in the vicinity of West Lafayette, Indiana (where Purdue University is located). On February 15, 1967, LARS researchers achieved the first successful application of pattern recognition techniques to multispectral scanner data. The data had been collected on June 28, 1966 over an agricultural area designated as Flightline C-1, south of the Purdue Agronomy Farm. Because of limitations in the analog to digital conversion process at that time, only four wavelength bands of data were used (0.44 - 0.46\,\mu m; 0.52 - 0.55\,\mu m; 0.62 - 0.66\,\mu m; and 0.72 - 0.80\,\mu m wavelengths) in the classification, and nine spectral/informational classes were defined by the training data. A relatively simple classification algorithm was applied to the data. As shown in Figure 4, the classification results could be displayed as a printout in which only the points classified as winter wheat were displayed, using the letter W to represent the winter wheat. One field near the middle of the flightline had oats planted in the middle and wheat around the outside portion of the field, and therefore became affectionately known to many students and visiting scientists in the following years as the "donut field". These results were reported in LARS Information Note (21567) titled “Automatic Identification and Classification of Wheat by Remote Sensing” by David A. Landgrebe and Staff of the Laboratory for Agricultural Remote Sensing, published in March 1967. In the LARS report, it was stated that out of 64,240 total points classified, 5,469 points were classified as wheat, thus indicating the potential for using such computer processing techniques not only for mapping a particular crop species, but also for providing acreage estimates if the size of the scanner resolution element is known. The classification results reported in this publication showed, for the first time, that the concept involving the application of pattern recognition theory to the analysis and classification of multispectral scanner data was valid. This report is thus considered to be one of the milestones in the development of remote sensing technology.

The data from Flight-Line C-1 was also used in a supervised classification for all crops present, and a "classification accuracy matrix" was produced for the first time, based on the use of test fields (as opposed to training data). It is interesting to note that these first analysis efforts used the term Remote Sensing Unit, or RSU, for what is now known as a pixel or picture element.

In 1967, multispectral scanner data was obtained over a one mile wide, 70-mile long flightline in central Indiana, and classifications of spectrally simple cover types such as bare soil, green vegetation, and water were shown to be feasible using limited training data. Again, long sheets of computer printout paper with different symbols were used to display the classification results. A very small section of these classification results are shown in Figure 5, along with a color photo of the area for comparison purposes. The blank areas on the printout are pixels that were thresholded and not displayed in any of the designated classes because they had such a low probability of belonging to any of the designated spectral training classes. Most of these thresholded pixels were either mixed pixels along the edge of a field or were actually highway. Spectral differences in soils were also mapped and analyzed over this 70-mile flightline, resulting in maps showing soils having high, medium and low levels of reflectance, generally due to differences in organic matter content. These results clearly showed the effectiveness of computer classification of such spectrally distinct cover types, even for relatively large geographic areas.

**Figure 5.** Computer classification of a portion of a 70-mile long flightline classified in 1967 into the following classes: bare soil (-), green vegetation (I), or water (M). An aerial photo is shown for comparison.
In considering the use of line printer displays of the scanner data, one might think that there should have been a better way to do this, but computer monitors such as we know today were simply not available – they hadn’t been invented yet. Some sort of monitor or display device was clearly needed. Consequently, NASA and IBM collaborated to develop a display to use with remotely sensed data. NASA contributed $500,000, and IBM matched it with another $500,000. This first digital display unit, developed by IBM and installed at LARS in early 1971, had a black-and-white screen -- not very large; only about 12 by 15 inches – and a “light pen” that was connected to the display with a fiber optic cord. (See Figure 6.) The analyst simply pressed the light pen against the glass screen of the display and the pixel under the light pen would be high-lighted, thus allowing the analyst to designate the four corners of a training or test polygon. In comparison to what we had been used to, this was a marvelous advancement and offered a tremendous improvement for interfacing with the imagery.

It was this display unit that was used to analyze the very first frame of ERTS-1 (i.e., Landsat-1) imagery in 1972. Obviously, computer capabilities continued to develop, and within about seven or eight years the display unit was obsolete. Shortly thereafter, IBM asked if it could be returned to them to put it in the IBM Museum. Thus, within a period of less than ten years, this very first digital display device went from being a “one million dollar state-of-the-art” piece of equipment to being a museum display.

**LEARNING THE BASIC PRINCIPLES OF SPECTRAL REFLECTANCE**

One of the things that became quite evident during these early studies was the need to develop a basic understanding of spectral reflectance. Dr. Charles Olson, Jr., from the University of Michigan was heavily involved in spectral reflectance research, and he had developed a very effective field spectrophotometry lab. A small house trailer held a Beckman DK-2A spectrophotometer that could measure reflectance in the ultra-violet, visible, near-infrared, and middle-infrared wavelengths (up to 2.60 μm). The reflectance was recorded on computer punch cards at frequent spectral intervals, thus allowing one to record and analyze the reflectance of various crop types very effectively. Dr. Olson graciously loaned the DK-2 spectrophotometer lab to Purdue in the fall of 1964 and for the entire 1965 growing season. This allowed my graduate students and me to record several hundred spectra, representing many different types of vegetation and soils. For each of the vegetation samples, we measured the moisture content, and for about ten percent of the samples, a cross-section of the leaf was also obtained. These cross-sections gave us excellent insights about why differences in reflectance might exist. For example, a corn leaf has a very different internal cell structure than is the case for a soybean leaf. Such differences in cell structure of the leaves often...
resulted in statistically significant differences in leaf reflectance at certain wavelengths. Analyzing this spectral data, along with the associated moisture and cross-section data, allowed us to gain some excellent insights concerning the potential to spectrally separate various cover types. These DK-2 spectral data also provided a better understanding concerning reasons for variations in the spectral response of various crops, such as what is happening (spectrally) when vegetation becomes diseased or stressed because of drought conditions. I felt then, and still do, that understanding the spectral reflectance of various types and conditions of vegetation and soils is the real key to effective interpretation of multispectral scanner data. Many of the insights gained from these studies were documented in Chapter 5 of the book *Remote Sensing: The Quantitative Approach*, published in 1978.

The development of a field spectroscopy program at LARS was a major factor in gaining a better understanding of the spectral response of earth surface features. This effort, led by Dr. Roger Holmes, allowed researchers to obtain a variety of spectral data from a height of about fifty feet above the ground from a cherry picker bucket. By obtaining spectral data from this height, the vegetation and soil being “seen” by the spectroradiometer was integrated into a measurement that might simulate the area of a pixel in aircraft (or eventually, spacecraft) data. Additionally, the researchers could take photos of the area being measured and obtain detailed ground measurements, so they would have excellent reference data to go with the spectral measurements. The knowledge thus gained from the analysis of the DK-2 and field spectral data proved to be crucial in learning how to interpret multispectral data obtained from aircraft and eventually, from satellites. This knowledge also played a key role in the recommendations that several of us on the LARS staff provided to NASA concerning the number and spectral location of the wavelength bands to be incorporated into the ERTS-1 and later, the Landsat Thematic Mapper scanner systems.

**EXPANSION OF DIGITAL ANALYSIS CAPABILITIES**

The late 1960's and early 1970's were an interesting, exciting time of developing a better understanding of how to interpret and apply pattern recognition theory to multispectral scanner data. There was considerable emphasis on the development of effective analysis techniques such as the use of “supervised” and “unsupervised” training techniques, and various methods of evaluating the classification results. The LARS data processing group developed a set of software, named LARSYS, that was the first software system capable of processing multispectral scanner data. In 1970, the LARS computer facility was upgraded to an IBM 360 Model 67 mainframe computer, one of the larger machines available at the time. This computer was a timeshare system, and allowed other remote sensing laboratories to connect directly to the LARS computer via leased lines, thus providing them with data analysis capabilities that would have otherwise been unavailable. Figure 7 shows the sites that used the Purdue/LARS Remote Terminal System. Sites as far away as Australia used the system on a dial-up basis. The LARSYS software was also given away to any research lab that wanted it. Eventually most of the locations indicated in Figure 7 had their own computational capabilities and installed LARSYS on their own system, thus eliminating the need for the leased lines and the central computational facility at LARS.

Largely because of the pioneering research in computer-aided analysis of multispectral scanner data and the interdisciplinary nature of the work at LARS, the lab became very well known, both nationally and internationally. As an indication of its interdisciplinary character, at one time there were over 100 faculty, grad students and professionals from seventeen different departments on campus. In addition to the remote sensing research, LARS had a very good educational program, with many short courses and a visiting scientist program that attracted people from all over the world. The slide and tape Remote Sensing Mini-Courses and other educational materials developed as a result of the research activities at LARS were utilized throughout the US and the world for many years.
SUMMARY

The scientists and engineers at Purdue/LARS were heavily involved in many of the major, early national remote sensing activities. In addition to all the research activities in the mid- to late 1960s, in 1971, at the request of the U.S. Department of Agriculture and NASA, LARS coordinated the Corn Blight Watch experiment to monitor the extent and severity of the corn blight disease throughout a seven state area of the cornbelt region. In 1972, LARS researchers analyzed the very first frame of digital ERTS-1 data obtained, and were very actively involved in several LANDSAT-1 and 2 and Skylab experiments in the 1972 - 1975 timeframe. These activities involved several different disciplines, including agriculture, forestry, geology, water resources, general land use applications, and others. The early work by LARS scientists and engineers also allowed them to provide significant input to NASA concerning the spectral location and number of wavelength bands on the MSS scanner on ERTS-1 and later, the Thematic Mapper multispectral scanner.

Over the past half-century, there clearly have been many advances in our ability to obtain and analyze multispectral scanner data and to utilize it for a variety of applications throughout the world. It has been a wonderful experience to be part of, and to observe, the changes that have taken place in remote sensing technology since 1964 when I first became involved in this fascinating discipline.

REFERENCES


