Remote Sensing for Agriculture and Natural Resources from Space

by

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Abstract

This paper presents reasons why the need exists for a more effective means by which to gather agricultural and natural resource data for resource management purposes. A research program is outlined to develop techniques for this purpose using aerospace platforms. And finally, the problems arising due to the quantity of data involved are discussed and an example illustrating the promise of remote sensing and automatic data processing is given.

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R. B. MacDonald and D. A. Landgrebe

Introduction. From a technical standpoint, food surpluses in the world are, and have been, non-existant for quite some time. In the last two years we have seen artificial surpluses in this country for all practical purposes vanish. The supposedly tremendous surpluses, particularly those of small grains, have been expended in the attempt to feed a small fraction of the world's population. These facts are evidence that the U. S. Agricultural system cannot feed the world. Conservative predictions indicate a need for (a) further development of our national agricultural system to keep pace with our own needs, and more importantly, (b) steps to insure the development of agricultural systems abroad.[1] A hungry world is not going to be content to live in peace beside a well-fed United States.

This paper describes a research program associated with the Apollo Applications Program to develop techniques for such future agricultural systems.

Why is Remote Sensing Needed. In what way then, can the U. S. Space Program contribute to this great national and international need? One of the major essentials for these future agricultural systems is the availability of information of agricultural conditions on a timely basis. Opportunities for increasing and sustaining the productivity of natural resources and for facilitating product flows in agriculture are identified and measured by accurate, comprehensive and timely information on resource use, availability, productivity, potential, and other characteristics. The lack of such information is a major obstacle to the economic development of the undeveloped regions of the world and a significant obstacle to the formulation of important policies and programs in the more fully developed regions.

Generally, information on characteristics of natural resources and their productivity is obtained from surveys on the ground. These surveys are costly and in the more remote and inaccessable regions of the world are difficult, if not impossible, to take. During the past few years, many scientists have been developing, and to some extent applying, remote sensing techniques for acquiring data from aircraft. More recently, this scientific interest has evolved into consideration of acquiring data from earth-orbiting spacecraft.

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[1] The World Food Budget 1970, U. S. Department of Agriculture, Economic Research Service, Foreign Regional Analysis Division.

Although the range of types of data that might ultimately be acquired by remote sensing techniques from satellite altitudes is not well defined, low altitude experiments tentatively suggest some of the following potential applications: (A) Identification of the use of land, including the ability to discriminate among crop species, (B) identification of major topographic and soils features, (C) detection of unique soils problems, such as salinity, (D) detection of forest fires, (E) determination of the density of plant growth, (F) early detection of plant diseases.

Other potential uses of Earth-orbiting remote sensing systems for agriculture and forestry in various regions of the world may be cited. In monsoon regions, such as India, crop yields are very much a function of the calendar date of initial rainfall preceding the monsoon season. This date may vary up to several weeks over scattered areas. Rainfall patterns of interest cover from 5 to 10-square-mile areas and are characterized by tens of degree surface temperature drops. A capability to efficiently map monsoon regions during the critical period would significantly enhance yield prediction capabilities in those portions of the world.

When temperatures of 100° Fahrenheit or more occur within a period of from several days to a week immediately after corn tassels, pollination is inhibited and crop yields are significantly reduced. Efficient methods to identify regions where tasseling occurs and the subsequent monitoring of temperatures in these regions can provide an important input into yield predictions. Similar phenomena also hold for sorghum pollination.

Timely estimates of agricultural production affect a number of agricultural areas such as transportation, storage, processing, financing, marketing and distribution of food as well as the ultimate price to the consumer.

In the United States, information on crop status is collected and prepared by three agencies:

- The Crop Reporting Board, a unit of the Statistical Reporting Service of the USDA, with statutory responsibility to issue crop forecasts and estimates for major crops, currently maintains 43 field offices engaged in collecting, summarizing, and reviewing this information.

- The Agricultural Stabilization and Conservation Service of the USDA administers and checks compliance with production adjustment and conservation assistance, as well as price and market stabilization programs.

- The Bureau of the Census prepares an agricultural census every 5 years.

It is expected that additional remote sensing techniques will be applied to supplement, accelerate and refine the present systems of information gathering and processing. Remote sensing techniques appear to offer the most economical way to cope with the increased requirement to gather data which will exist in future years.

Although an exhaustive study of potential economic benefits has not been completed, there are many specific examples in agriculture and forestry in which the application of remote sensing techniques are expected to reap substantial economic benefits:

- World and U. S. Cotton production in 1964 was 81 million and 14 million bales, respectively (Ag. Statistics, USDA, 1965). Approximately 40 percent (5.6 million bales) of the U. S. production was grown under irrigation. One of the potential applications of remote sensing is the monitoring of soil moisture conditions and the dates to irrigate crops. If this proves feasible, an increase in yield of cotton of only 10 percent due to these techniques would amount to an annual economic benefit of more than $100 million.

- Weed infestations of croplands cause an estimated loss of $3.8 billion to American agriculture annually (Crop Res. Pub. ARS 34-32). Remote sensing techniques could be developed for locating and assessing the degree of weed infestations. If the use of these techniques could contribute a 10-15 percent reduction in losses caused by weeds, the economic benefits would be $300-$400 million per year. Comparable potential benefits would accrue from the application of remote sensing to the detection and definition of insect and disease invasions.

- In 1965 the total number of cattle in the U. S. was reported to be 107 million (Agric. Statistics Report, USDA, 1965). The number of range cattle is estimated to have been 35 million. If remote sensing could be applied to detect and assess nutrient deficiency areas, overgrazing, brush and weed infestation, and other range management problems, it is reasonable to assume that the carrying capacity could be increased by an average of 10 percent on U. S. rangeland. This could mean an annual increase of 3.5 million more calves. At present feeder cattle prices this economic benefit could amount to $350 million annually.

- The annual loss in the United States caused by flooding has been estimated to be $1 billion, about two-thirds of which is agricultural land (Water Facts, USDA, 1957). More than half of this damage occurs in the 12,711 small upstream watersheds. Monitoring of small watersheds by remote sensing in order to locate and identify inadequate surface cover, uncontrolled erosion and other watershed management problems might well contribute a 10 percent reduction in the losses caused by flooding, or an annual economic benefit of $100 million.

- Preliminary studies (USDA Rpt. to NASA, 1966) indicate that remote sensing in the future may be used to determine acreages planted to various crops and to estimate the potential yields of these crops. Although it is very difficult to assign a specific value to the economic benefits of such information, this data is of vital importance in world trade negotiations, planning for transport and storage, and in planning for famine prevention in the food deficit nations. The Food and Agriculture Organization presently utilizes crop yield estimates to determine the needs of food grain import to the deficit nations. Further refinements in potential yield estimates can be of great importance.

- There are 508.8 million acres of commercial forests in the United States. By conventional survey methods the cost of surveying and preparing a national forest inventory for the United States is $10.7 million. The use of remote sensing could reduce the cost of this survey considerably. It is estimated that the use of remote sensing from spacecraft could permit an 8 percent reduction in the area of forests damaged or destroyed by fire. If the capability of remote sensing to detect nutrient deficiencies, forest species, and other information vital to forest management can be established, significant contribution in timber production can be made. If this could increase timber production only a few percent above present yields, its economic benefits would amount to tens of millions of dollars.

The potential other benefits in the application of remote multispectral sensing are countless. Today more than two-thirds of the world's people suffer from hunger or malnutrition. The major political and social concerns of many national governments revolve around the problems of feeding their peoples. A host of international, regional, national, and private organizations are engaged in "food for peace" and "freedom from hunger" campaigns. All these activities have political and social as well as economic implications.

The economic development of African, Asian, and South American countries is highly dependent upon improvement in their agriculture. The Advisory Committee on Private Enterprise in Foreign Aid chaired by A. K. Watson states that "the desperate race between population growth and food production in the less developed countries is so well known and documented that we need not labor it here. So critical is this problem that it justifies the greatest attention of USAID. Where industrial fecsibility studies are concerned, those which relate to expanding the supply of fertilizer or insecticides, or which relates to the transport and processing of foods will merit an especially high priority." On the magnitude of the task ahead the committee states "Over the past months as we worked to relate foreign aid and private initiative, we came to believe that no matter how carefully our aid dollars are invested and no matter how wise and energetic USAID's personnel may be, there is still not enough money nor people to accomplish the vast task the United States has undertaken. It is only through private resources, our own and those of developing countries themselves, where the additional resources are potentially adequate to meet the challenge."

All programs of agriculture development involve data gathering and processing. In the food-and-fiber surplus countries a continual search goes on for refinements and improvements in their survey and analytical methods. In many food-and-fiber-deficient countries, programs are being initiated to develop systems of data gathering and analysis. In both groups of countries remote sensing techniques could greatly accelerate and expand the processes of data gathering and processing.

A Brief History of Remote Sensing in Agriculture. It is our opinion, however, that at the present time, basic knowledge is insufficient for these applications to yield consistent and acceptable information from aircraft, much less from earth-orbiting vehicles. In an effort to develop this basic knowledge, limited research has been initiated by a number of Governmental agencies, industries, and research institutions. The National Academy of Sciences have stimulated interest in this field of research and serves as a consulting body in research planning and execution.

The National Aeronautics and Space Administration and the U.S. Department of Agriculture are intensely interested in the use of remote sensors from aerospace platforms. These interests embrace not only earth-orientated applications, but also the use of remote sensors to learn more about the physical and biological environments of other planets. Because of these interests, the National Aeronautics and Space Administration is funding remote sensing research conducted by mutually interested governmental agencies, industries, and research institutions.

The present NASA/USDA program has its beginning in two, initially unrelated, activities: One at the National Academy of Sciences, the other at NASA headquarters. In 1961, the NAS-NRC committee on "Aerial Survey Methods in Agriculture" was formed. The purpose of the committee is to formulate plans for and stimulate research to develop improved methods of applying aerial survey methods to agricultural problems such as land use and crop distribution, crop yield estimations, species identification, disease detection, etc. By 1963, the committee had formulated a research program and received academy approval of it. A part of the program was a multispectral crop sensing plan. In 1963 the committee became aware that within NASA headquarters the biosciences and the manned space sciences divisions were formulating experiments to develop techniques for sensing the Earth, Moon, and other planets for the detection and analysis of biological and geological information. A remote sensing program was then formulated and funded to meet the needs of both organizations. Also the U. S. Army, through its electronics command, having an interest in the same type of data, agreed to support the program by making available aircraft and sensing equipment existing under Project MICHIGAN. The Purdue University Agricultural Experiment Station agreed to support the program by making available a number of diverse experimental stations, providing records kept at these stations, manpower, and equipment for making related "ground truth" measurements. This combination of efforts resulted in a minimal airborne remote sensing program in 1964 and included flight missions during the summer growing season over the Purdue experiment stations.

In 1965 the U. S. Department of Agriculture, in accordance with a formal agreement with NASA, established a Laboratory for Agricultural Remote Sensing at Purdue University and a Laboratory for Remote Sensing in Forestry at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California, to assist in carrying out this effort.

A Systems Viewpoint of Remote Sensing Remote Sensing technology is concerned with the determination of characteristics of physical objects through analysis of measurements taken at a distance from the objects. Such information is propagated by:

- o Force Fields
- o Electromagnetic Fields

as

- o Spatial
- o Spectral
- o Temporal

variations of these radiation fields.

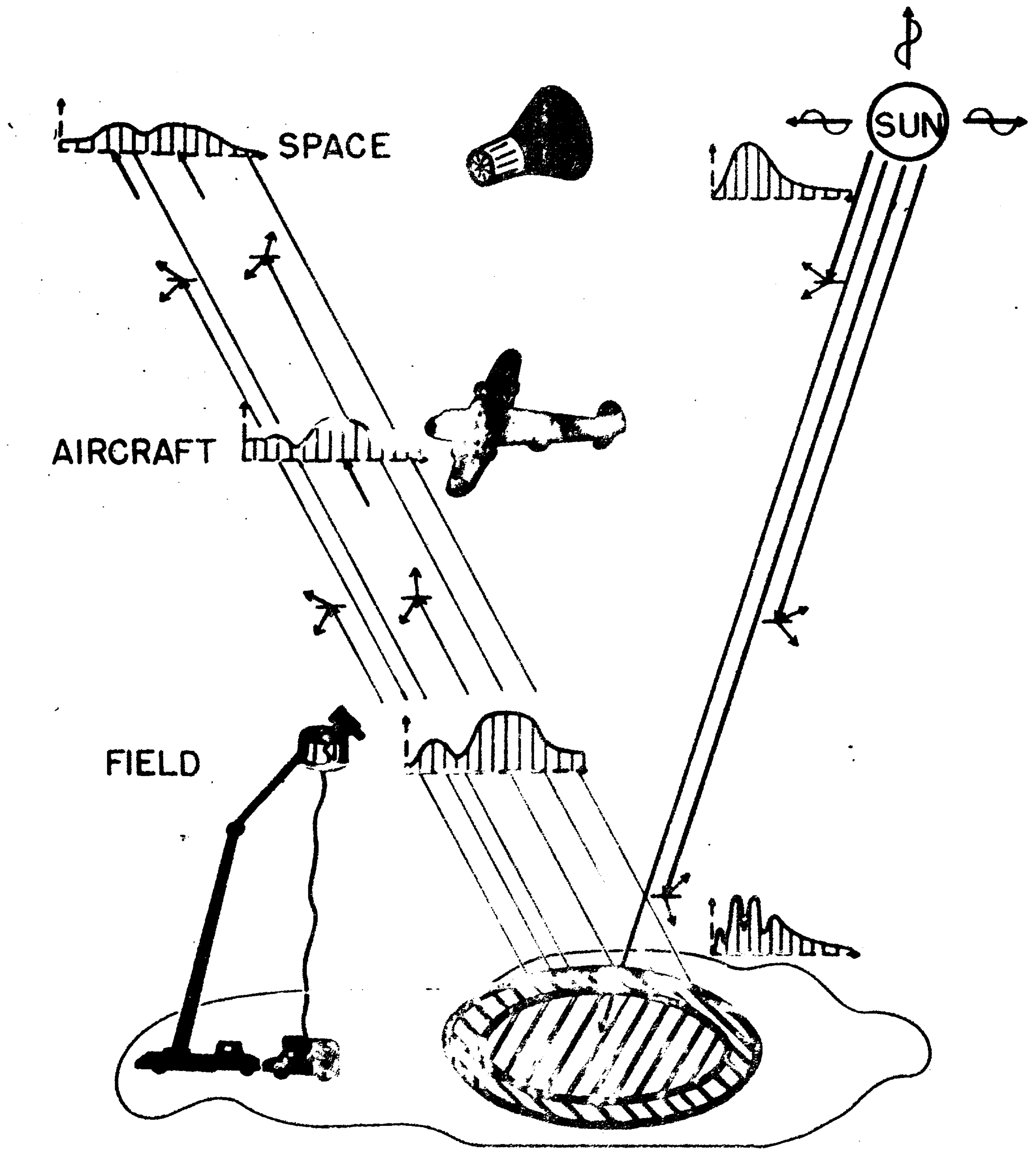
Generally, to apply remote sensing to a particular situation, it is necessary to initially make good measurements of the variations of propagated energy and to in turn analyze the measurements to relate variations to target characteristics of interest.

A simplified sketch of the basic problem in agricultural remote sensing applications is shown in Figure 1. Insolation energy is in part transmitted to the earth's surface through atmospheric transmission windows and in part scattered and absorbed by the earth's atmosphere. Solar energy is both reflected and absorbed by earth surface features. The heating effect of absorbed energy results in the emission of 'thermal' radiation by surface features. This reflected and emitted electromagnetic radiation is propagated into the atmosphere where again it is in part transmitted out through the atmosphere and in part scattered and absorbed by that media.

The spectral, spatial, and temporal variations of this propagated energy are a function of the physical characteristics of the particular radiating target, as well as the transmission characteristics of the intervening atmosphere and of the characteristics of insolation energy. Due to the corrupting influences of the atmosphere on the energy radiated from earth surface features, it is evident that in the research phases data should be gathered and analyzed at several levels of the atmosphere. Analysis of these data assists in distinguishing atmospheric effects from variations caused by the physical characteristics of agricultural scenes.

The Research Program at LARS/Purdue. A functional organization of the research program in agriculture at Purdue is shown in Figure 2. As shown, the five principal research areas are:

- o Agricultural Applications
- o Agricultural Research
- o Aerospace Agricultural Research
- o Measurements
- o Data Processing


SPACE
SUN
AIRCRAFT
FIELD

LABORATORY FOR AGRICULTURAL REMOTE SENSING

RESEARCH PROGRAMS

- **AGRICULTURAL APPLICATIONS**
  - ECONOMIC STUDIES
  - REQUIREMENT ANALYSES
- **MEASUREMENTS**
  - INSTRUMENT DEVELOPMENT
  - CALIBRATION
  - RADIATION PHENOMENA
  - MOBILE DATA COLLECTION OPERATIONS
- **DATA PROCESSING**
  - DATA HANDLING
  - DATA ANALYSIS
- **AGRICULTURAL RESEARCH**
  - STATISTICAL SIGNATURE STUDIES
  - MICROPHYSICAL STUDIES
  - MACROPHYSICAL STUDIES
- **AEROSPACE AGRICULTURAL RESEARCH**
  - OPERATIONAL SYSTEMS
  - EXPERIMENT DEFINITION STUDIES

Briefly, 'Agricultural Applications' studies are being conducted to delineate specific user requirements and to, in turn, estimate potential benefits from such applications. Such estimates, together with other considerations, are to result in a rank ordering for the various application objectives. Various segments of the agricultural community versus their geographic area of involvement are shown by the following three by four matrix table.

	LOCAL	REGIONAL	NATIONAL	WORLD
FARMER				
AGRO-BUSINESS				
GOVERNMENT				

A review of the agricultural requirements in these situations is essential in assessing the benefit to agriculture from the information collecting capabilities afforded by remote sensing systems.

Agricultural Research studies are attempting to relate observed radiation characteristics to the physical and chemical properties of agricultural sources on both microphysical and macrophysical scales.

Aerospace Agricultural programs include studies to define agricultural experiments for future aircraft and space test programs and to effect operational system studies to determine typical requirements of future systems.

A 'Measurements' group has undertaken the task of developing and/or modifying instrumentation and related facilities to allow the collection of reliable data for laboratory and for field research studies.

The 'Data Processing' program is organized to carry out investigations in the following five categories:

- o theoretical pattern recognition studies
- o applied pattern recognition
- o statistical studies and modeling
- o data handling research
- o data handling operations

Remote sensing situations generally increase in complexity with the inclusion of additional factors that arise by proceeding from laboratory conditions to those found in an aerospace environment. This philosophy has led LARS to conduct research at three different levels. These are:

- o Laboratory
- o Field
- o Air/Space

A good example of this can be found in looking at the problem of applying remote sensing techniques in soil temperature determinations. If this information is to be obtained from measurements of radiation emitted by soils at spectral wavelengths from 8 to 14 microns, it is necessary to know factors such as the emissivity of the radiator. In determining the feasibility of this approach one needs to determine the characteristic values of this parameter under various important conditions. In the laboratory, emissivity values can best be measured for different soil types at different temperatures, moisture levels, etc. Certainly such phenomena continue to occur in the field situation. With this information in hand, field programs are required to determine effects of soil surface conditions, etc., on emissivity values. Other new effects of the intervening medium are kept at a minimum with field station measurements. With the understanding accrued through these efforts, a researcher is hopefully prepared to attempt to continue feasibility studies from aircraft platforms.

On the Data Problem. One of the chief problems in developing a system capable of providing the type of information necessary for resource management on a nation-wide or world-wide basis is the great quantity of data which must be dealt with. A little consideration of the agricultural situations leads one immediately to the conclusion that the type of information needed requires the gathering of data to a resolution of at least a few hundred feet. We need not labor the point here that to map any area as large as a country to a resolution of this size results in tremendous quantities of data regardless of the method of analysis planned. A major contribution being made by the Laboratory for Agricultural Remote Sensing is the development of data handling and data analysis systems capable of reducing these large quantities of data to information useful to agricultural scientists.

In discussing this work, we intentionally used two terms --data handling and data analysis--to describe this effort. The term data handling refers to the various types of data manipulation (e.g. editing, formatting, analog-to-digital conversion, and the like) which are necessary with data of this sort in addition to a capability for continually monitoring data quality.

The term data analysis refers to the algorithm by which the data will be reduced to useful information. Examples would be automatic pattern recognition, statistical analysis and the like.

As an example of the use of these two terms, consider the case of data gathered in photographic form. The term data handling would be applied to the techniques necessary in the photographic darkroom to provide a usable image. The term data analysis would be used to describe the processes used by the photo interpreter in extracting the desired information from the photographs.

The need for research in data analysis methods is fairly obvious. We wish to suggest here that research in data handling, even basic research, has not been given proper emphasis since techniques in this area are lagging. Previously, in situations of this nature, the researcher has received access to vast amounts of data presented in inconvenient forms. A major objective of our effort has been the development of means to provide access to these vast quantities of data in such a manner that they may be conveniently reviewed for rapid identification and extraction of selected portions. It is crucial for a researcher to be able to readily communicate with his data. Thus considerable efforts at Purdue are being expended in this area.

The large data quantities in a program of this type imposes restrictions on data analysis methods as well. Entirely automated data analysis algorithms are mandatory at least for the first level of data reduction. There are many ways in which data from ground surface areas can be collected. Of these, the most amenable to automated analysis methods appears to be the measurement of energy radiated from elemental ground areas as a function of wavelength. Note that in this approach no geometric information is necessarily involved. It turns out that this fact appears to greatly simplify the data reduction algorithm required.

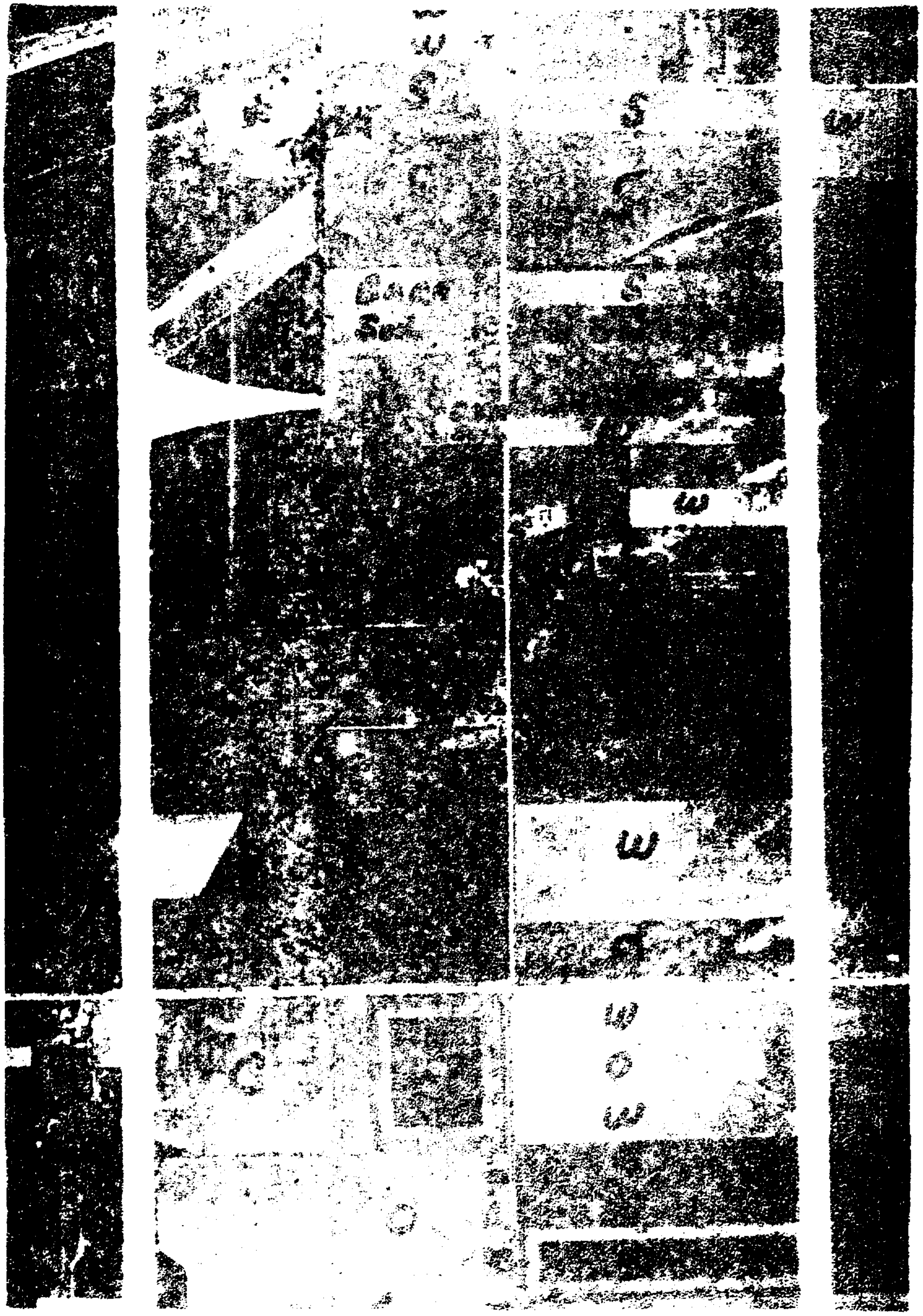
A disucssion of data handling and data analysis techniques beyond the above is outside the intent of this paper. However, we wish to conclude by presenting one or two early results in this area in order to illustrate the promise of this approach. In this particular study, an agricultural area several miles in extent was overflown by an aircraft carrying a multispectral optical-mechanical scanner. The output of any given channel of this particular scanner at any given instance is a voltage level related to the radiance of the scene in the current ground resolution element and a given optical spectral band. The scanner is arranged such that by simultaneously sampling all channels of the scanner, one obtains a set of numbers related to the radiance in each of the available spectral bands from the same resolution elements on the ground. Currently data is available from 18 bands between .32 and 14 microns, although for the study to be discussed below, due to temporary equipment limitations, only four of the 18 bands were available to the researchers. Further, it was not possible to include any of the thermal infrared spectral region in the four bands used.

The specific classification study carried out was aimed at making a green vegetation map of the area overflown. One can easily think of applications for this kind of a capability from space. For example, with this capability it may be possible to advise a developing nation what currently undeveloped land to next put into agricultural production by determining the vigor of the naturally occuring green vegetation. Or it may be possible to use this technique in the midwest to make an early wheat acreage measure since during the month of December, the portion of the ground cover in this area which is green is predominantly winter wheat.

Actually, for these types of applications a more specific question which must be asked is to what extent must the ground be covered with green vegetation before a given resolution element on the ground can be correctly classified as green from an aerospace platform. Figure 3 shows an ordinary panchromatic air photograph of one of the areas overflown. A portion of this flight line covered by the scanner is also indicated. Figure 4 shows a computer printout of the results of applying the classification technique to a portion of this data. The categories established for the classification were green (indicated by 'G') bare soil (indicated by 'X') water (indicated by 'I') and a fourth category (left blank on the printout) for ground resolution elements not logically falling into any one of the three. Since the data used was gathered in late June, this fourth category was established chiefly for mature wheat and other similar types of ground cover. The letters marked on the flight line give the actual type of ground cover as determined from ground observations as follows:

C - Corn	W - Wheat
O - Oats	P - Pasture
R - Rye	RC - Red Clover
S - Soybeans	FS - Farmstead
	BS - Bare Soil

The bold faced numbers on the computer printout indicate approximate percentage ground cover as determined by ground measurement at a few sample points in the field. Also indicated on some fields of the computer printout is the height in inches of the ground cover. The area shown in Figure 4 can be located in Figure 3 by using the two bare soil fields in the upper portion of the flight line for orientation.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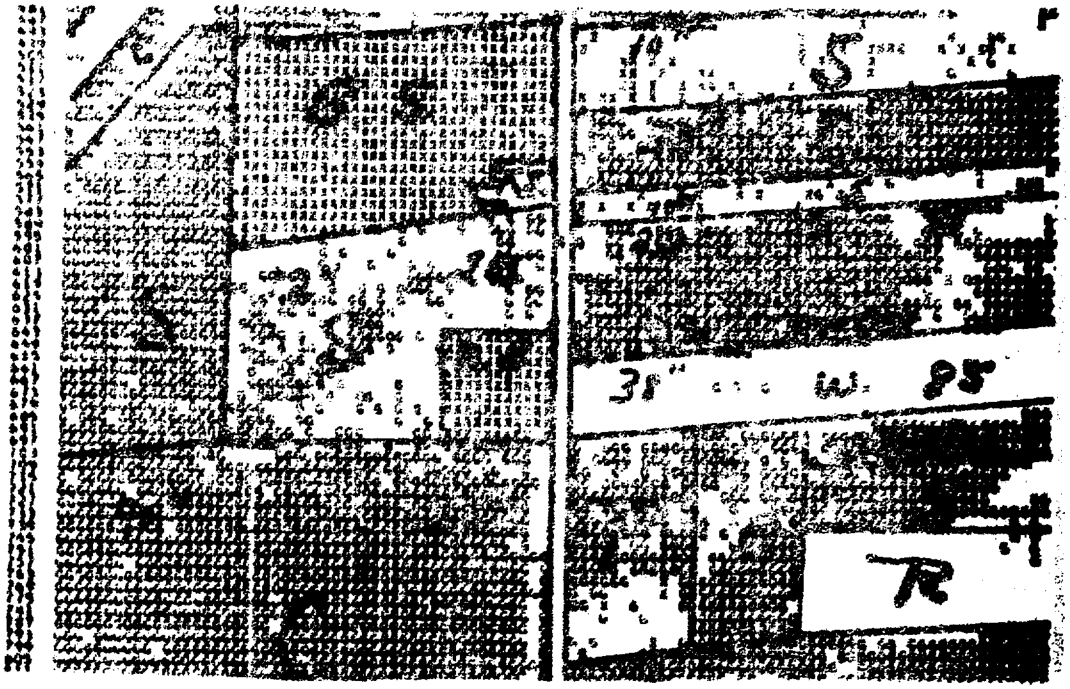
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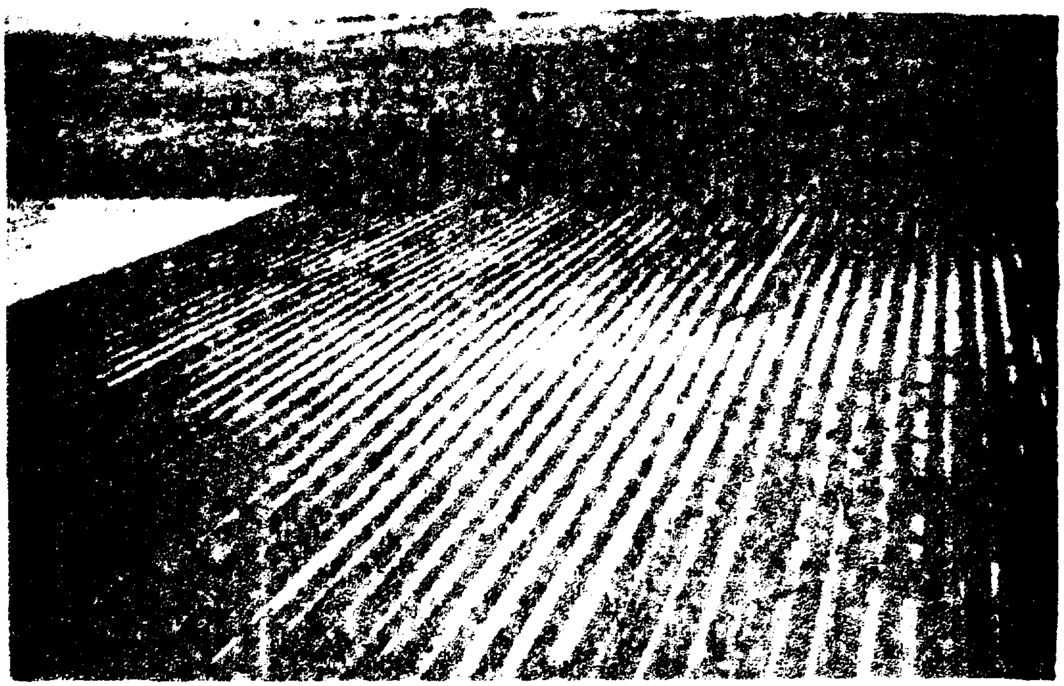

In this test it will be noted that there was no difficulty in correctly classifying resolution elements of bare soil. Consider now the green vegetation category. A detailed analysis by agriculturalists of the results of this classification indicated that for the parameters used in this classification, areas with 15 to 20% or more of green vegetation ground cover were classified as green. As an example, notice the soybean field to the left of the center line at row number 625. A photograph taken at the same time the area was overflown is also shown in Figure 4. The photograph was taken from the road at about line number 619, looking west-southwest. Notice that there is a weed condition in the soybeans. It is possible to correlate the points classified 'G' in this field with the location of the weeds. That is, the additional green ground cover provided by the weeds is just adequate to change the classification of the point in the field thus indicating the 15 to 20% ground cover threshold mentioned. By changing the parameters of the classifier, it is possible to adjust this threshold point to some extent.

Additional studies of this type in species identification have also been carried out. They also show very promising results.*

Closure. In conclusion, it is our opinion that future decisions as to the uses of land, water and other related natural resources will become increasingly critical; future decision making can be greatly enhanced through use of information systems based on tomorrow's remote sensing technology.

We have recommended the development of a second generation spectral sensor that promises vast improvement in our data collection capabilities. We are also of the opinion that future research activities be oriented toward meeting actual requirements associated with a typical geographic region. Such an orientation would help ensure that researchers in the program are working towards realistic solutions to realistic problems. Research would initially be conducted through use of aircraft using procedures and instrumentation systems that would be forerunners of those to be used in later space systems. The region used for this phase of the research would be an excellent test site for subsequent space experiments in that an abundance of ground truth information would be available. Several possible geographic areas for future applied research efforts are presently being studied.

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*See for example "Automatic Identification and Classification of Wheat by Remote Sensing", LARS Information Note 21567, Laboratory for Agricultural Remote Sensing, Purdue University, Lafayette, Indiana.

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