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SPECTRAL LIBRARY ISSUES IN HYPERSPECTRAL IMAGING APPLICATIONS

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Abstract

This paper addresses several key spectral library issues concerning potential and current hyperspectral imaging applications. This emerging technology uses sensor fusion techniques to detect and identify an object through multi-dimensional aspects involving spatial, spectral, radiometric, and temporal data from the combined capabilities of imagery, spectrometry, and radiometry instruments. Applications can range from precision agriculture applications, such as early detection of crop infestation; to medical applications, such as functional mapping of the brain and early detection of cancer (hyperspectral biopsy). Applications to mine detection, search & rescue operations, plume detection, and chemical & biological defense are among the current military applications.

The key spectral library issues addressed in this paper primarily concern the need to have, in the required timeframe, the spectral signatures available to extract the absorption features that tell us the composition and state of the target material in each pixel. This paper considers and expands on the concept of using the Internet as a means for managing digital spectral information worldwide and suggests that everyone can benefit by being more proactive in his or her use of the resulting Web-based Spectral Library Information System (WSLIS) for reward and communication.

Resolving the critical spectral library issues presented in this paper concerning the application of hyperspectral imaging is important because this technology is increasingly becoming incorporated into modern civil and military remote sensing systems and the resultant greater integrated system performance is synergistic to newly evolving commercial, civil, scientific, and military applications.

1. Introduction

The very high efficiencies and extreme flexibility of hyperspectral sensors provide a powerful measurement technology currently being demonstrated with modern airborne and spaceborne hyperspectral systems. However, for this capability to be exploitable, it is essential that a well-populated spectral library exists and be accessible in a user-friendly way by the user of this technology. This will also require the development of faster processing algorithms, better search methods, improved spectral matching techniques, and cost-effective data handling and management structures.

Hyperspectral technology has global applications and is well suited to those applications requiring the detection of optically unresolved subpixel-size objects in an image. The technology is an excellent complement to the large investment in image processing by adding quantitative physical information to each pixel in a scene thereby adding an entirely new dimension for object location, classification, and identification. Applications of this technology are many. Applications can range from precision agriculture applications, such as early detection of crop infestation, to medical applications, such as functional mapping of the brain and early detection of cancer (hyperspectral biopsy), to mine detection, and to anti-terrorists operations among many other applications.

Recent improvements in spectral technology, remote sensors, space power, computers, image processing algorithms, and communication systems suggest that real time detection and identification systems are feasible. Existing operational satellite remote sensors, such as Landsat, Ikonos, and SPOT, have demonstrated their value for Earth surface observations. New spaceborne hyperspectral sensors, such as MightySat II, Hyperion, and Atmospheric Corrector, have the potential to greatly extend our capabilities to see objects of interest on the ground or in the air from earth orbit. A military hyperspectral user who can "see deep" through the Earth's atmosphere and accurately locate and identify objects of interest on the ground in real time, will have a decided advantage on the modern battlespace.

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This paper supports the view that hyperspectral technology can help provide a unique capability to commercial, civil, scientific, and military users.

2. Background

The workhorse U.S. operational satellite system for multispectral imagery gathering has been the Landsat. The Landsat series began with the launch of Landsat 1 in July 1972. Landsat 2 followed in January 1975 and Landsat 3 in March 1978. The first two spacecraft were equipped with Return Beam Vidicon (RBV) cameras and Multi-Spectral Scanners (MSS) while Landsat 3 provided data from a High Resolution Panchromatic (also referred to as RBV) camera as well as from a MSS. The decision was made to use the MSS data as opposed to the RBV data since MSS was in a form that was more adaptable for computing processing. It supplied four bands of data for analysis and a resolution of eighty meters (later sixty meters). The point-to-point fly over for these spacecraft was eighteen days. Landsat 4 was launched in July 1982 with Landsat 5 being launched in March 1984. The point-to-point fly over was sixteen days for these two satellites. They were equipped with the Multi-Spectral Scanners as well as the Thematic Mappers (TM). The TM data was considered superior since it provided seven bands of data as well as thirty-meter resolution. The TM data is about five times more expensive to buy than the MSS data is and even more expensive to process.

The French then launched their first SPOT, in 1986, followed by SPOT 2 (1990), SPOT 3 (failed on orbit, 1996), and SPOT 4 (1998). The start of the Indian Remote Sensing (IRS) program came in 1988. The European Space Agency (ESA) started its ERS-1 and -2 operational series of satellites in 1990 as did the Japanese Space Agency (NASDA), with JERS-1 the same year. Canada launched Radarsat in 1991. In all of these cases, the governments of those countries developed and launched the satellites. However, they arranged for the operation of the data gathering and distribution to be done by existing private companies or ones they created.

Landsat 6 never made it to orbit because of a ruptured hydrazine manifold. Landsat 7 was launched on April 15, 1999, from the Western Test Range at Vandenburg Air Force Base, on a Delta-II expendable launch vehicle. The Enhanced Thematic Mapper Plus (ETM+) instrument on Landsat 7 is an eight-band multispectral scanning radiometer capable of providing high-resolution imaging information of the Earth's surface. The Landsat primary ground station, the data handling facility and archive, are located at the USGS/EROS Data Center in Sioux Falls, SD. The first three Landsats are no longer operational. Ikonos, with its 1-meter spatial resolution panchromatic image and a 4-meter spatial resolution multispectral image was launched in September 1999.

The hyperspectral era began with airborne mineral mapping in the late 1970s and early 1980s. In 1989, a major advanced occurred with the arrival of the NASA/JPL Airborne Visible/IR Imaging Spectrometer (AVIRIS).[1] The AVIRIS system flies on an Extended Range U-2 (ER-2) and other airborne platforms. It collects imagery in 224 spectral bands over the spectral range from 400 to 2500 nm. Spurred by the success of this instrument, other hyperspectral instruments came into being. Some other examples of hyperspectral sensors in operation are Aurora (APTI), HYDICE (NRL), AISA (Specim Ltd.), CASI (Itres Research, Canada), DASI (NASA/Ames), DAIS (GER), MISI (RIT), AIS (JPL), PHILLS (NRL), MIVIS (Daedalus), Probe-1 (ESSI), TRW Hyperion (EO-1), MightySat II (AFRL), TRWIS III, and many others. Unfortunately, the Orbview 4 satellite launched on 21 September 2001 with what was to be the first commercial hyperspectral sensor on board (Warfighter-1) failed to achieve orbit. Two spaceborne hyperspectral sensors to be launched later include the Naval EarthMap Observer (NEMO), sponsored by the Office of Naval Research (ONR) and ARIES (Australia).

The Digital Array Scanned Interferometer (DASI) was specially designed to operate from the Pathfinder, a high-altitude remotely piloted aircraft (RPA). The instrument has been used to acquire imaging interferometric data of the Hawaiian Islands as part of NASA's Environmental Research Aircraft & Sensor Technology (ERAST) program.

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3. Spectral Signatures

Spectral research is the study of the phenomenon of spectra and its underlying principles. Atoms and molecules are constantly communicating with us and sending us messages. They sign their names with their spectral signatures or spectrum. Spectroscopic techniques can be used to read the spectral signatures and decode the massages. The signature of an object is a characteristic, or combination of characteristics, by which a material or an object may be identified on an image or photograph. Considerable work in the area of spectral sensing is being conducted worldwide to identify and collect the specific signatures of objects and to develop the spectroscopic techniques best suited to the task. Scientific advances in the area of spectral research are opening new technological opportunities to develop an increased capability to perform surveillance and target acquisition tactical missions. Universities and workshop organizers are increasingly offering excellent training opportunities in the subject of hyperspectral imaging technology.

4. Spectral Analysis and Atmospheric Effects

Spectral analysis is the investigation of transmission, absorption, reflectance, or emittance of electromagnetic radiation as a function of wavelength or frequency to attribute specific physical characteristics to spectral features of measured objects. The effect of the atmosphere on electromagnetic (EM) waves is a problem that complicates the use of spectral sensors for many applications. Molecular absorption, molecular scattering (Rayleigh), aerosol absorption, aerosol scattering (Mie), non-selective scattering, optical turbulence, reflection, refraction, and atomic processes all affect EM propagation through the atmosphere. There are certain spectral regions, referred to as "atmospheric windows", where gaseous absorption is at a minimum. Most sensors operate primarily in these window regions. The amount of radiation reflected from a surface depends on the wavelength band under consideration, its angle of incidence with the surface, the orientation of the sensor in relation to the surface and the illuminant, the material's molecular composition, and the surface structure.

The source spectrum must also be considered when performing corrections to observations of a source for the effects of absorption by the atmosphere between the source and the sensor. Since most actual sensors do not have a spectral resolution adequate to separate individual lines in the apparent radiance spectrum, these atmospheric corrections will also depend on the spectral resolution of the sensor.

Various atmospheric correction codes for use with hyperspectral data are available, e.g., ACORN and HATCH In the absence of aerosol size distribution measurements, we must presently rely on aerosol models such as those found in MODTRAN4 to calculate the effects of aerosol on atmospheric transmittance and background radiance using measured meteorological parameters as inputs. These aerosol models were developed to be as representative as possible of different atmospheric conditions. However, they cannot be expected to exactly reproduce the optical properties in a given location at any specific time. Better methods are needed for proper selection of these aerosol models. The Electro-Optics Systems Atmospheric Effects Library (EOSAEL) is more appropriate to use for the case of anthropogenic aerosols. The EOSAEL is a product of the U.S. Army Research Laboratory.[2]

In performing detection and identification applications, it is widely recognized that it is the background, rather than the object, which limits our ability to perform detection and identification missions. The background includes the effects of the environment in which the object is located. A good understanding of background and object spectral signatures and their dynamic behavior in realistic environments is essential to the exploitation of spaceborne and airborne hyperspectral imagery to support applications in a real-time mode. To achieve this level of understanding, the user has to address atmospheric effects, atmospheric back-out corrections, autonomous intelligent processing, spectral signature database usage, sub-pixel unmixing retrieval techniques, scene generation models, and other spectral research topics. Probably the most vital component in all of this is a good spectral signature library.

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An effect of photon absorption is luminescence. There are materials that can absorb photons of one frequency and emit photons of a lower frequency, without any significant increase in temperature. These materials are said to be luminescent. Luminescence can be one of two kinds, fluorescence and phosphorescence. They can be differentiated by how long does the light last after the excitation energy is turned off. This is called the decay time. In fluorescence, the decay time is very short (less than 0.003 seconds). In phosphorescence, the decay time is much longer.

There are three basic problems in spectral analyses that need our attention, namely: (1) measurement of wavelengths, (2) measurement of intensities, and (3) interpretation. It is much more difficult to measure intensities accurately than it is to measure wavelengths accurately. Calibration techniques need to be well understood and mastered in these measurements. Also, it is very difficult to work in the infrared part of the spectrum because all objects are heavily radiating and exchanging energy with each other. Although electromagnetic radiation at an individual frequency or wavelength can be measured, the most common practice is to measure energy coming from a range of frequencies, referred to as a band. Acquiring information from a band requires (1) procuring a sensor that reads or gathers information exclusively from that band, and (2) displaying the information in a form that can be interpreted. There is, of course, also the problem of spectral mixing. Fortunately, if we can identify the endmember spectra, we can then deconvolve (unmix) each pixel's spectrum or exemplar spectra to identify the relative abundance of each endmember material. Of course to accomplish this, we need the pure spectra signature of the endmember material, hence the need for well-planned spectral library information system.

5. Spectral Analysis Software Issue

A number of image-processing systems are currently available. These systems are being used to investigate vital research areas, such as the spectral and spatial processing functions and spectral/spatial tradeoff issues. Systems such as the Land Analysis System (LAS), Comprehensive Hyperspectral Analysis and Processing System (CHAPS), Spectral Analysis Manager (SPAM), Hyperspectral Image Processing System (HIPS), and others have been used. The industry (de-facto) standard hyperspectral processing software is the Environment for Visualizing Images (ENVI). Atmospheric models like FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes), ACORN (Atmospheric Correction Now), ATREM (Atmospheric Removal), MODTRAN4, and HATCH (High Accuracy Atmosphere Correction for Hyperspectral Data) are used with ENVI. There are many other tools that work with ENVI like the OKSI Hyperspectral Toolbox (www.techexpo.com). Free software is always available. The Multispectral Image Data Analysis System (MultiSpec) is available at web site: (http://ece.www.ecn.purdue.edu/~biehl/MultiSpec). The U.S. Army Topographic Engineering Center (TEC) is offering HyperCube at the following website: (http://www.tec.army.mil/Hypercube/index.html). USGS offers ISIS, a comprehensive, user friendly, portable tool for processing, analyzing, and displaying 3-D data hyperspectral cubes from imagers and spectrometers (http: //wwwflag.wr.usgs.gov). For advanced image processing users that are willing to pay, the ERDAS IMAGINE Professional provides a comprehensive remote sensing package (http://www.erdas.com). There's the Hyperspectral Distiller, which is a product under development by Applied Analysis, Inc. and geoPiXCL, which is a product of VYSOR Integration Inc. When you add the Hyperspectral Image Tools offered by Applied Coherent Technology (ACT) to the above list as well as to other software by many other companies and government agencies, you find that it can get overwhelming as to which ones you should use. And this is not taking into consideration what other countries have to offer. Our neighbor to the north offers the PCI Enterprises' Hyperspectral package. The Canada Centre for Remote Sensing (CCRS), offers the Imaging Spectrometer Data Analysis System (ISDAS). A spectral library information system that can help deal with this problem, of which software to use, would be nice.

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6. Data Handling and Interpretation Issue

Progress toward developing a capability to extract spectral information from hyperspectral imagery (HSI) to support user's needs is accelerating. The driving overall objective of the current situation is the development of a hyperspectral exploitation system. Since HSI systems like MightySat II and Hyperion will generate tons of data; we need to have a reliable system that can handle the data. TEC currently has under development a spectral signature database for its own internal topographic and DoD mission use.[3,4] TEC has generated considerable spectral data. There are other similar databases available within the DoD, government civil agencies, intelligence community, industry, and university communities. They all would benefit from the realization of good data handling system, better interpretation procedures, and the development of a worldwide Internet spectral library. They are, of course, currently addressing these problems within their respective communities. However, we need a clearinghouse to tie it all together. With the threat of terrorists at hand, we need all the data available on laboratory spectral signatures of chemical and biological materials that could be exploited for the remote spectral sensing of chemical and biological agents in the field. Other applications include the location of mobile rocket launchers by detecting fuel leaks at launch, the discrimination of missiles by their plume spectra, the spectral detection of narcotic-related agents, and the detection of pollution sources through their spectral signatures. Success in the use of this quantitative measurement technology would provide a quantum leap in enabling U.S. Global Information Superiority during peace through war.

Instrumented test sites have been constructed at various locations to acquire data in a continuous mode for establishing radiation and meteorological databases. For example, at TEC, a temperate site (humid subtropical climate) located at Fort Belvoir collected data since 1983. A sub-humid site (semiarid to arid climate) located at the Jornada Experimental Range (USDA), Las Cruces, New Mexico and an arid site located at the Yuma Marine Corps Air Station, Goldwater Range, Arizona were also used to collect data. Data has been collected at the Jornada site since 1986 and at the Yuma site since 1988. These last two sites were both solar/battery powered remote sites using GOES telemetry with 6 min, 12 min, and 60 min data averaging. The Jornada site was a cooperative site with USGS and USDA. The Yuma site was a cooperative site with USGS. The types of data collected at all these sites include global short/long wave incoming/outgoing radiation, wind speed profile, wind direction, soil temperature, cumulative precipitation, air temperature profile, barometric pressure, soil heat flux, surface radiometric temperature, soil moisture, and other housekeeping measurements.

Data from these test sites and others, e.g., Desert Radiance I & II, Littoral Radiance I & II, and Forest Radiance I & II, are being used to develop physical models and algorithms that evolve into mathematical models. These models can and have been used to support target and background predictions. They can also be used to support synthetic image generation work. Laboratory spectral measurements (reflectance, emittance, and luminescence) of natural and man-made materials have been published and are available in hard copy and soft copy. Laboratory spectral measurements at TEC have produced special spectral databases for the intelligence community and other customers. This included spectral measurements of altered vegetation, camouflage materials, and paints. The Remote Sensing Field Guide - Desert (co-op with USGS) published by TEC has been a great success in light of Operation Desert Shield.

The bottom line is that the amounts of spectral data are increasing and we have to pay attention to how we are going to handle it, distribute it, assess it, store it, and interpret it for our benefit. These are not the only sites.

7. Standards Issue

The spectral signature database is intended to serve as the spectral user’s starting point and ready reference. The Web-based Spectral Library Information System (WSLIS) that needs to exist should be designed with an open architecture so that every user can help populate it.

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An unbiased organization needs to step up the plate and organize and maintain the WSLIS web site for everyone else. Presently, this would include populating it with existing unclassified spectral signatures and spectral information that are available worldwide. The database will grow over time as it is updated and this library activity grows. The database will need to be updated frequently to capture the user's most recent experience and potentially address sensor and modeling issues.

Standards are a must if we are to populate the library with useful data. Data integrity is a must. Standards are also needed to be able to develop models and software that work with the database entries.

Guidelines for preparing inputs for the spectral signature database need to be developed and distributed. It is anticipated that the list of guidelines will grow and/or change with time, and there will be a need to solicit, from all spectral signature library users, suggestions of additional categories of spectral information to include in the database. Standardization of the database effort will prove important to facilitate use of the database and as an aid to users searching for examples of previous spectral experience in particular areas. This should also help tremendously in the development of models and software packages.

8. Spectral Libraries Issues

Spectral technology is increasingly becoming incorporated into modern commercial, scientific, civil, and military systems and the resultant greater integrated system performance is synergistic to newly evolving applications. It is imperative that we harness this technology and not waste efforts in performing unfocused work. Our spectral signature database systems are currently inadequate. The high efficiencies and extreme flexibility of new emerging hyperspectral sensors provide a powerful measurement technology not presently available in conventional sensor systems. This technology has global applications and is well suited to those applications requiring high sensitivity and time resolution such as space reconnaissance missions. This technology is an excellent complement to the large investment in image processing by adding quantitative physical information to each pixel in a scene thereby adding an entirely new dimension for object location, classification and identification.

Government civil and military agencies, industry, universities, and other countries have already collected a large amount of valuable spectral information. However, these data are often not disseminated beyond the organization or group for which it was collected. This results in other groups not having knowledge or access to this information. Some agencies that regularly collect and maintain these data have made them accessible through the Internet or CD-ROM. The most accessible library of this kind is the ASTER spectral library. It includes data from three other spectral libraries: the Johns Hopkins University (JHU) Spectral Library, the Jet Propulsion Laboratory (JPL) Spectral Library, and the United States Geological Survey (USGS) Spectral Library. The ASTER spectral library is available on CD-ROM at no cost to the requester at (http://speclib.jpl.nasa.gov). However, these libraries, which are directed primarily to a geologic community, contain relatively few signatures (approximately 500 for USGS and about 1000 for the combined JPL/JHU).

The spectral information that has been collected by TEC, NSEC, NICOLET, SITAC, ERDEC, LILIAN, ASU/TES, GMU, PNNL, MARC, and others may or may not be readily accessible to the public. Moreover, these libraries do not conform to a single format, are not necessarily available in soft copy format, and most lack the capability to be queried or manipulated by the Internet user as with modern databases. They are also very focused as to the applications in mind.

At the present time, there is no single Internet place for spectral sensing users to turn to gather comprehensive data on spectral signatures of materials that are available worldwide for their field of study. Currently the user can not perform advanced queries, apply provided statistical software to perform value added calculations, defined and established "spectral signature exemplars" , and have the data be accessible through languages such as Structured Query Language (SQL), and obtain other spectral information to use in their applications.

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As a result, spectral sensing users must spend considerable time gathering spectral data and identifying knowledgeable points of contact as they try to answer such questions as: Has this type of work being done before? If so, what specifically was done and how does it relate to the application of interest to us? Who did the work, for what application, in what timeframe? How did the user evaluate the spectral sensor's performance? Without a single reference source to help answer these types of questions, the spectral user will not only be less efficient, but will risk the possibility of not exploiting key and relevant experience in the field. The image analyst will be less productive. This deficiency exists at a time when the spectral technology is emerging as an enabling key technology in many military, civil, scientific, and commercial remote spectral sensing applications.

To help solve this problem, this author proposes the development of an online worldwide Internet-based unclassified database of spectral information to include spectral signatures, models, instrumentation descriptions, and lessons learned histories. No one agency can do it alone. Consider that the USGS determined that budgets, time, and available equipment limit what they could do. They figured that it takes them about one person-week to complete an entry of one spectral library sample. And that is when they have the data entry down to a science. So, they say, the entry of their 444 samples would take 8.9 person-years (http://www.usgs.gov/reports). So, the bottom line is they do not have all their samples fully characterized. There must be a better way to do this, and to have thousands of people helping. This database should be designed as a user-friendly tool for the spectral community to help determine what spectral data are available, find out how reliable it is and find out who owns it. People must be allowed to participate in the expansion of the database and a process should be in place to monitor the integrity and quality of the data.

The library can be used to determine what models are available, who developed them, and how good they are. It can also be used to find out who else is doing similar work, and what is going on worldwide in this field. This spectral database should be maintained by a not for profit organization and updated frequently. The spectral library concept must consider all kinds of users: Earth environment scientists, biologists, physicists, geographers, medical professionals, and others who rely on this spectral information in their field will use the information.

Effective utilization of spectral technology requires a balanced set of activities, including analytical modeling and simulation, laboratory research of fundamental processes, development of instrumentation, flight of the instruments on aircraft and satellites, collection of in situ ancillary or validated data, and scientific analysis of the data. The general approach is to develop a technological capability with a strong scientific base and then to collect appropriate data, through remote and in situ means, which will address specific mission objectives. The major goal of this spectral library effort should be to develop a spectral signature database architecture based on the Internet and to demonstrate how such information technology can be used to meet user requirements. The spectral library effort will also provide cost-effective methods to acquire information to assist in the development of standards for models and data. New techniques like "Spectral Signature Exemplars" can be further developed and applied.

Objectives

The spectral library concept should have the following objectives:

(1) Develop a user-friendly spectral signature and exemplar spectra database architecture that will allow users to access the data through the Internet
(2) Develop web site links to relevant spectral information sites
(3) Survey and evaluate expert systems and models that aid in the analysis of spectral data
(4) Improve spectral signature data visualization
(5) Account for atmospheric effects and background clutter
(6) Develop a set of protocols and standards for adding or retrieving data
(7) Identify needed data handing methods and storage capabilities

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(8) Identify spectral data deficiencies and develop coordinated data collection efforts
(9) Develop faster data processing algorithms
(10) Encourage the development of less expensive hyperspectral data processing software

9. The WSLIS Concept is Unique and Innovative

The Web-based Spectral Library Information System (WSLIS) concept is unique because it replaces the current spectral signature database that is fragmented, redundant, inaccessible (hard-to-find), non-standard, and user-unfriendly. It is innovative because it takes advantage of the increasingly successful Internet information superhighway. The digital spectral database could include a survey of software models that exist (worldwide) that work with multispectral and hyperspectral data, document them, and disseminate information upon request. It would answer such questions as, "Where are the models?" "What do they do?" "Who developed them?" "How good are they?" Etc. This would encourage and enable the development of model and spectral signature standards. This saves money. It could be used to generate and coordinate international cooperation and collaboration; gather in one place, links to users (worldwide) working at universities, industry, and government labs; and disseminate unclassified information to the international spectral community.

The military can certainly benefit from this concept. During Operation Desert Storm, the Gulf War of 1990-1991, terrain information was provided by two civilian systems, LANDSAT and SPOT. Images obtained simultaneously in a number of discrete bands (specific sections) of the electromagnetic spectrum were provided by both systems. Due to standard military cartographic procedures and poor policy, actually acquiring the original data created some difficulties. For example, all SPOT data had to be bought commercially and due to royalty issues could not be shared. As a result, the Army was unable to use data purchased by the Air Force because they were not properly funded for this purchase.[5] Protocols developed for this library would allow the military to access the database and acquire the needed information.

10. International Cooperation/Collaboration Issue

Spectral technology (including "hyperspectral" and "ultraspectral") is an emerging, enabling technology that is useful to military, civil, industry, and scientific organizations in many areas. This technology is no longer the sole realm of governments and scientists. It is not limited to a few countries. The tremendous interest in the world for hyperspectral technology capabilities demands more cooperation and more collaboration between countries. Uses of imagery spectroscopy are evolving from traditional mapping applications towards more consumer-oriented applications such as police work, insurance claims adjustment, marketing, precision agriculture, disaster management, real estate and farming. With enhanced computers available, scientists will be able to fully exploit spectral signatures, leading to more and better consumer products. This emerging new technology fully complements the spatial imaging technology that is already being successfully exploited by the Ikonos, SPOT, and Landsat communities, among others. The marriage of imagery with spectroscopy and radiometry provides a unique capability for remote sensing commercial applications. However, all of this requires an accessible, up-to-date, relevant, accurate, and user-friendly spectral library information system.

11. Lessons Learned From Six ISSSR Meetings (1992 to 2001)
(http://www.isssr2001.org/)

Seven topographic information and spectroscopy research requirements to perform the space and airborne remote spectral sensing missions were identified at the first four meetings of the International Symposium for Spectral Sensing Research (ISSSR):

* Global continental topography is poorly and unevenly known at all but the coarsest resolution. Topographic coverage for many parts of the world is limited, inaccurate, or nonexistent. There is a great need for high resolution, global topographic data in a digital, machine-readable format. Such data can best be acquired in a cost-effective manner by spaceborne spectroscopic techniques.

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* The existing topographic database has shortcomings in both accuracy and usability. Three basic problems exist: relative accuracy, absolute accuracy, and currency. Relative accuracy between adjacent or nearby maps is required for comparison purposes in local and regional studies. A high degree of absolute accuracy is a prerequisite if repeat coverage is to be used to monitor change. Currency is required in order to update information with respect to both man-made and natural phenomena. Most current digital databases have been created by the digitization of existing contour maps.

This presents problems in relative accuracy across large areas because of error propagation across map sheet boundaries. This raises serious questions of both data integrity and consistency.

* Aside from efficient collection of raw digital data, rapid processing of this data to usable spectroscopic quantities is needed.

* Development of spectral analysis algorithms to retrieve quantities of interest from spectroscopic data is needed. This involves the creation and maintenance of a spectral signature database.

* Techniques for the rapid application of spectral analysis algorithms to the spectroscopic data to yield the parameter or quantity of interest are needed.

* Development of advanced spaceborne sensors to measure spectroscopic data is needed. In order to take advantage of the more advanced sensors, research is required to assess their feasibility so that when implemented, the anticipated improvement in the accuracy of the results will be cost effective.

* Models to account for atmospheric effects and background clutter are needed. Scene dynamics needs to be simulated and modeled.

(Note) The 1995 ISSSR keynote speaker implied that most needs in his country (India) could be satisfied with 4-meter spatial resolution multispectral data.

Based on these information requirements, as well as specific user need for new suite of sensors capable of detecting chemical and biological agents and the need for better spectral signature matching methods based on an expert system approach that surfaced in the last two ISSSR meetings,[6,7] the need for a digital spectral library accessible through the Internet was reconfirmed.

12. Conclusions

Hyperspectral imagery is a mature technology ready to be exploited for the benefit of mankind. You also should conclude that for some applications multispectral data is good enough. Moreover, current methods of data collection, storage, and usage are inefficient and the large amounts of hyperspectral data continue to be a computer bottleneck in the analysis of the data. Also, crucial data taken by others are hard to find. The available hyperspectral software to analyze and interpret the data is still costly, although getting easier to use. Sensors are becoming more affordable and less complex. Now, if only we could decide which spectral bands, of the hundreds or thousands that are available, will be right for the application in mind and if we could design our sensors to be programmable, we could reduce the amount of data in our system.

Hyperspectral models must be strongly tied to the physics and the phenomenology of the application scenario so that one can use them to determine the minimum number of bands to use for a particular problem in a straightforward manner. We are still wrestling with the definitions, standards, policies, and national security concerns that are associated with any new technology. Finally, there appears to be a strong need to further develop the concept of exemplar spectra to enhance our spectral matching capability.

Hyperspectral technology has proven its worth and is performing civil, military, scientific, and commercial applications well. What is needed now is a Web-based Spectral Library Information System (WSLIS) that will allow the worldwide remote sensing community to better serve the user, improve the technology, find new applications, help educate the workforce, and reduce the cost of doing business.

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