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WEB-BASED SPECTRAL VISUALIZATION AND INTERPRETATION

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ABSTRACT

We discuss a prototype web-based hyperspectral analysis system developed to address concerns about the enormous datasets generated by hyperspectral remote sensing. Our objective is to develop fast and cost-effective techniques to visualize and help interpret the huge hyperspectral data sets involved in the literal and non-literal analysis. We present the need for the prototype system and its implementation. We introduce the I-SPECTRA model as a vehicle to demonstrate the exploitation of this new technology. The paper discusses lessons learned during the prototype development and discusses possible future directions for further development of these web based spectral visualization and interpretation tools.

INTRODUCTION

Utilization of imaging spectrometers to generate hyperspectral data provides significant and unique capabilities to the remote sensing field. With this benefit comes the cost of developing tools and techniques to handle huge amounts of data. With more stringent spectral requirements and capabilities on future orbiting and airborne remote sensing systems, spectral databases are a rapidly growing field. In this paper we focus on the specific challenges of these spectral techniques versus other remote sensing methodologies. The "I-SPECTRA" database demonstration has provided insight into the complexities involved in constructing and accessing the database. I-SPECTRA name specifies a web-based interactive spectral database and analysis system developed by an Aerospace IR&D project. In this paper we describe the I-SPECTRA system and its capabilities.

It is possible using hyperspectral sensors and appropriate data analysis techniques to remotely sense the composition of objects within a scene. The following list provides a few relevant examples of the application of this technology.[1]

- Biological and Chemical Detection
- Disaster Mitigation
- Homeland Security
- Land Mine Detection
- Traffic Flow
- Law Enforcement

Imaging spectrometers collect a very large number of wavelength channels at the same time. Hyperspectral imaging spectrometers collect on the order of hundred of wavelengths per each spatial pixel. For example, the CASI 2 sensor collects 288 bands of data for each pixel imaged. This differs significantly from multispectral systems, which collect on the order of ten bands per pixel. For example, the Landsat Thematic Mapper sensor collected three bands in the visible, one in the near infrared, two in the mid infrared, and one in the thermal infrared only. Please see Figure 1 for a comparison between hyperspectral and multispectral sensors.

Another way to distinguish hyperspectral from multispectral data is the channel size. Hyperspectral sensors have very small wavebands when compared to their multispectral cousins. For example, the Landsat Thematic Mapper channels vary in size from 100 nm in the visible blue channel to 270 nm in the mid infrared channel. This varies considerably from a hyperspectral sensor, such as CASI 2, which has 288 channels with a spectral resolution of 2.2 nm full width at half maximum (FWHM) at 650 nm wavelength. By having so many small wavebands over such a large portion of the electromagnetic spectrum, it is possible with suitable analysis to use hyperspectral data to determine the unique spectral signature of remotely sensed object.

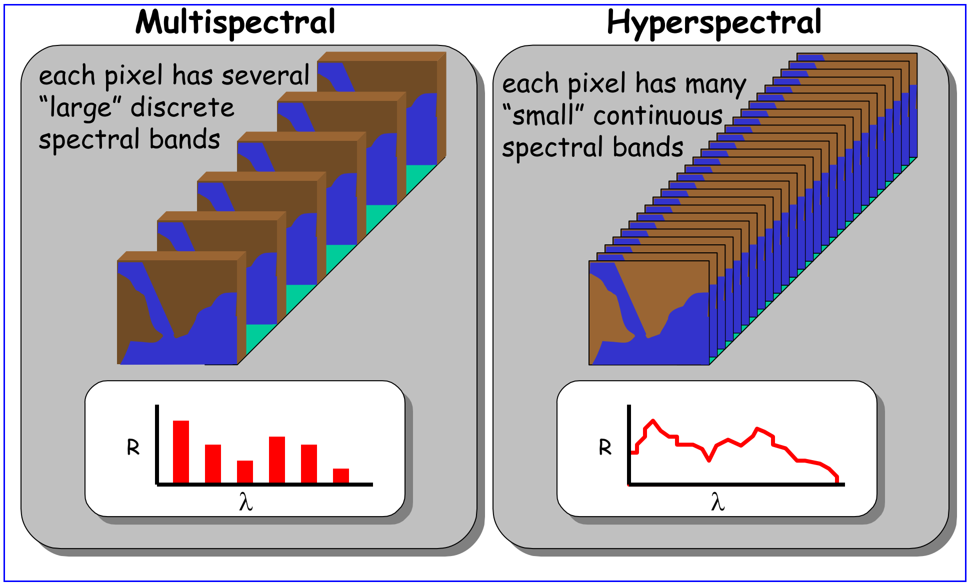

Figure 1, Band characteristics of multispectral and hyperspectral data.

Hyperspectral data is typically shown in a three-dimensional cube. Two dimensions are for the spatial data and the third is for all the spectral band measurements (See Figure 2). Data is captured in frames of pixels, the size of which is set by the sensors altitude and angular aperture.

Next, we will discuss three major challenges associated with hyperspectral analysis. The first challenge is the huge volume of data generated by these types of sensors. The complexity of dataset analysis and distribution is much greater here than in multispectral applications. Richards offers an example comparing the multispectral Landsat Thematic Mapper to the AVIRIS hyperspectral sensor.[2] The multispectral sensor in this example has seven wavebands and eight bits of dynamic range, whereas the hyperspectral sensor has 224 wavebands and 10 bits of dynamic range. Richards shows that, based on these assumptions and ignoring differences in spatial resolution, the hyperspectral sensor generates 40 times as many bits as the multispectral sensor. This isn't so much of a constraint for airborne imaging spectrometers, where data can be hand carried off the platform for later analysis. However, it has considerable effect on spaceborne systems and on real-time performance airborne systems.

The second challenge significant data redundancy within these datasets. Much of the additional data doesn’t add to the inherent information that can be extracted from the hyperspectral dataset. Much of the spectral information from one band can be fully or partly predicted from other bands within the dataset. Generation of correlation matrices based on the data from each band can help identify where the redundancy is lurking. The so-called Hughes effect comes into play here. Hughes states that the number of training pixels must grow to ensure reliable estimates from supervised data classifier algorithms.[3] As the number of features increases, the classifier accuracy will also increase, up to a certain point. Beyond this point, the performance of the classifications actually begins to decrease. Please note that aspects of the Hughes effect may be used to some advantage however. For example, the dimensionality of the data can be reduced for specific applications. Think of this as culling out different multispectral datasets from a single hyperspectral dataset.

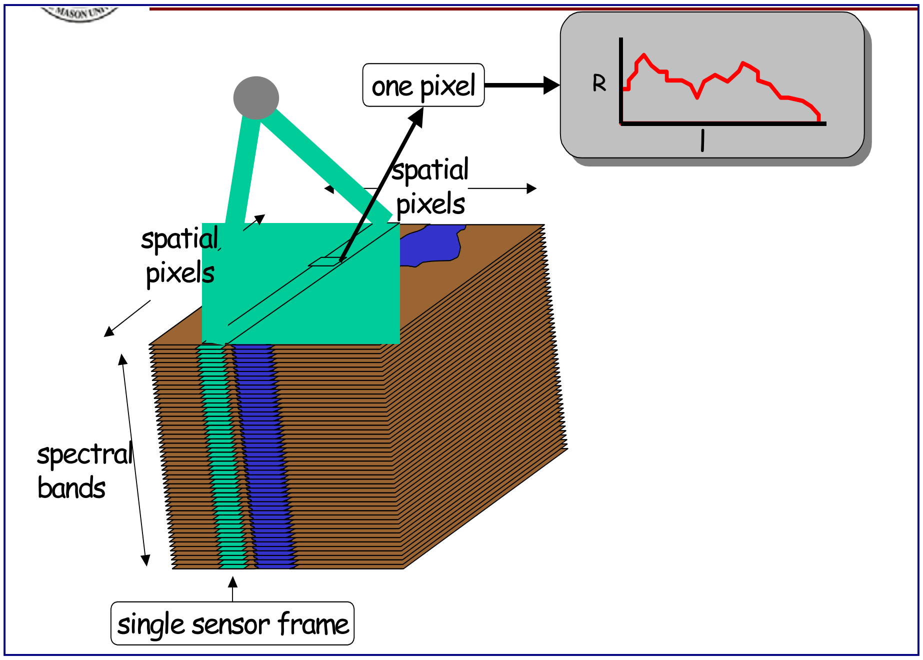

Figure 2, HSI hypercube display.

The third challenge of hyperspectral remote sensing is the need to remove atmospheric effects from the dataset. This high spectral resolution of hyperspectral data causes fine atmospheric absorption features to be detected and displayed along with data from the target.[4] Many approaches exist to remove undesired atmospheric effects. While effective, so-called atmospheric correction results in additional processing overhead. This problem is not as evident with multispectral datasets, since the few bands available can be tuned to minimize these undesired absorption features.

SPECTRAL LIBRARY INTRODUCTION

Since hyperspectral remote sensing can produce a practically complete target spectrum, it is usually possible to determine the composition of the surface material. Absorption features, or localized characteristic features within the target’s spectra, can be exploited to determine the surface characteristics. Typically, their location bands, relative depths, and widths characterize the absorption features.[5] A spectral library provides the reference upon which remotely sensed hyperspectral data are compared. The spectral library contains a set of spectra of relevant materials that are created either in the lab or by remotely sensing known targets in the field. We will discuss several algorithms that are used to efficiently search the spectral library and determine likely spectral matches.

Typically, any given pixel in remotely sensed data would contain more than one type of object. This will vary, as expected, with the spatial resolution of the hyperspectral sensor. Higher spatial resolution translates to a smaller surface area falling into the sensor's instantaneous field of view (IFOV) and would have higher likely of being a "pure" pixel.

Pure pixels can be found by plotting all the points in N-dimensional space, where N matches the number of sensor wavebands. Pixels on the extremes in each dimension are the end-members. End-members can be found by computing the N-dimensional convex hull for a given dataset. The convex hull of a set of points is the smallest closed set that includes all the points.[6] The points that make up the vertices of the convex hull are also the dataset's end-members.

Techniques exist to perform pixel "unmixing", operations that attempt to identify all the spectral components within a non-pure remotely sensed pixel. The most common technique is to compute a linear mixing model (LMM) for the remotely sensed dataset. This technique assumes that all the materials within a given scene have end-member pure pixels available. From this complete set representing all the types of materials within the scene, an observed pixel value in any spectral band is modeled by the linear combination of the spectral response of component within that pixel.[7]

Tseng defines this linear mixture model as a linear vector-matrix equation:

$$DNi = \sum_{j=1}^{n} (Rij * Fj) + Ej$$

Where "i" is the number of wavebands, "j" is the number of end-members, DN is the spectral reflectance in a spectral band, R is the known reflectance of the end-member, F is the fraction coefficient of the component within that pixel, and E is an error term designed to account for the un-modeled reflectance and represent the unknown noise of observations.[8]

SPECTRAL LIBRARY FUNCTIONAL REQUIREMENTS

In order to be effective, a spectral library must have several common characteristics. First, it must contain a fairly large set of spectral signatures, including appropriate meta-data. Metadata or the "data about the data." is supporting information that describes some particular aspect of the target data. Examples of appropriate metadata within a spectral library include sensor characteristics and environment conditions used to collect a specific sample. The individual spectral signatures are relatively small from a database perspective consisting of up to a few thousand pairs of bands and measurements.

Second, the spectral library must have the individual data elements arranged into well-organized logical categories so that users can effectively explore the library. These categories must be structured so that the user can effectively reduce the size of the relevant signatures returned through each navigation step. For example, the library could be divided between man-made and natural materials at the first step. There may be several hierarchical arrangements for the navigation tree implemented, depending on the mission and audience of the library.

A spectral library must have a robust search capability to ensure users can efficiently locate required information through a variety of means. The search capability must enable the user to locate spectra by searching the meta-data and/or data itself. To be truly successful, a spectral library must combine text searches of descriptive information, such as sensor name or a spatial coverage, with searches within spectral characteristics itself. An area for future research is in tools that allow the user to visually describe spectral characteristics for searching purposes.

Finally, the spectral library should provide diverse output formats. This will enable the user to extract the required information from the library in a format they can readily use. Various formats of export should be supported, including text files, Excel spreadsheets, and XML representation.

WEB-BASED SPECTRAL LIBRARY

Now that we've seen the functional requirements for a generic spectral library, the next step is to discuss how this can be delivered from a web server.

Figure 3 below shows a generic web-based system architecture. This architecture supports a combination of both dynamic and static information exchanges. All activity is initiated on the client's system via the web browser. Requests are sent over the network as HTTP requests to the web server software that resides on the back-end box.

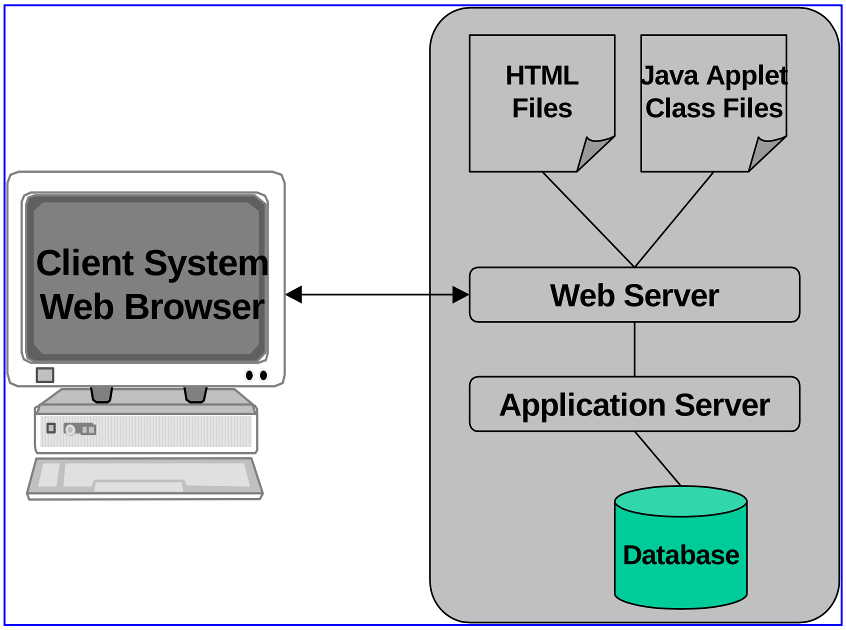

Figure 3, Generic web architecture.

The web server handles all requests for static content by itself. It retrieves the appropriate files and transmits them back to the requesting client system. Examples of static files include HTML pages, Java Applet class files, and images.

When the user requests dynamic content from the web server, the request is handed off to an Application Server. The function of this software is to interface with the back-end systems (typically databases or collections of flat files), process the results, and return them to the requesting user. It is important to note that the user is not aware of which content is static and which is dynamically generated. Nothing displayed or any special operation that the user must explicitly perform is required to interact with the dynamic aspects of the system.

There are many diverse technologies that can be utilized as the application server of a web-based system. These technologies are divided into two major areas: server-side and client-side processing. Client-side processing is typically limited to "light-weight" tasks, such as user input validation or dynamic HTML display. This is usually implemented in a scripting language, such as JavaScript and VBScript. It is very challenging to develop for the client-side environment, since it is necessary to support diverse web browsers, each with different versions of the scripting language.

More robust client-side processing can be performed via Sun's Java Applets. These are small compiled Java programs that run as a thread from within the client's web-browser. Java Applets provide more robust graphical user interface (GUI) components than basic HTLM forms and can directly reach back to the web server via TCP/IP networking or directly to that server's database via the JDBC application program interface (API).[9]

There are several limitations to using Java Applets however. Every browser implements security policies to keep applets from compromising system security.[10] For security reasons, Java Applets cannot interact directly with the user's files or operating system. Java Applets were intended to run uniformly on any operating system and web browser, but in practice, inconsistent implementation between different browsers and even different versions of the same browser make this problematic.[11]

CASE STUDY: THE AEROSPACE CORPORATION'S I-SPECTRA SYSTEM

The Aerospace Corporation's **I-SPECTRA** IR&D project, initiated in FY1999, was completed during FY2002. There is an enormous amount of digital spectral data distributed over several different agencies and commercial spectral libraries in many different formats. Some data are commercial, others are government (and thus free). The consolidation of these spectral data into a single database, which can be easily accessed, searched, and interactively manipulated, will greatly enhance the usefulness of this information. This *interactive capability* is what is unique about I-SPECTRA that other spectral libraries do not have. I-SPECTRA database development and demonstration has provided insight into the complexities involved in constructing and accessing such a complicated website database. The development of the I-SPECTRA system is a very timely exploitation of opportunities in this rapidly growing field.

A laptop computer based demonstration for I-SPECTRA was developed in FY2001 that could be taken directly to potential users, trade shows and technical conferences to demonstrate the I-SPECTRA capabilities. This very early version of I-SPECTRA was demonstrated at the International Symposium on Spectral Sensing Research (ISSSR) in June 2001 in Quebec City, Canada.

The purpose of the I-SPECTRA website is to provide a comprehensive *interactive* spectral information database and links to other libraries and spectral application websites around the world. University researchers, spectral application developers, and vendors of spectral analysis tools in the fields of astronomy, botany, chemistry, geology, and marine science are potential users of this capability. An external I-SPECTRA website could also facilitate setting standards and common formats in the cataloging and presentation of spectral data and advancing spectral library technology and capabilities.

Potential commercial user applications include mineral exploration, precision farming, forest management, land use and urban planning, law enforcement, agricultural commodities, astronomical, and space sensor calibration/validation. I-SPECTRA database is a "dynamic spectral library" which will be routinely updated. The database allows users to choose a particular surface from a graphical interface, and then determine the spectrum in engineering units. The database also allows for the import of new spectral modules as they become available. The proposed service concept is a web-based interactive spectral database and analysis system containing thousands of spectra of various terrestrial, atmospheric, astronomical and laboratory spectra. Computed spectra of atmospheric transmission are also included. The spectra can be quickly located through meta-data that permits the user to conduct a custom search by type of spectra, date of acquisition, sensor, etc. Users of the I-SPECTRA database can download any data product from raw signature to observed spectrum.

The development work for an operational I-SPECTRA website has been completed. The pilot website can be accessed internally within Aerospace. The Aerospace Corporation is currently considering how the I-SPECTRA website could be hosted for external use. The site has a variety of about 2000 spectra in the database. I-SPECTRA project acquired the ASTER Spectral Library Version 1.2 which includes spectral data from JPL, USGS and John Hopkins University and additional publicly available data was also imported into the I-SPECTRA database.

I-SPECTRA users can choose the specific spectra type from the list, determine the x and y units to be used, and then have the plot displayed. The x and y axis can be either linear or log plot. Additional information regarding the spectra such as the source of the data (BASS, NIRIS, CVF, laboratory, etc.), type (earth surface, comet, nova, star, optical constants, etc.), wavelength range, position, etc. are also displayed.

Research Systems, Inc. (RSI) was contracted to assist with developing I-SPECTRA. The "I-SPECTRA" database contains 17 different fields including object names and wavelength ranges. I-SPECTRA system allows the user to choose any or all of the fields to be displayed in the object selection table as well as sort the table by any of the user-defined fields. The user also has full control of the line style (dotted, dashes, solid, etc) and line color for the plots. Validation of user inputs and download capability of the ASCII data files and plot image files are also supported.

The website also provides information such as "About I-SPECTRA" which explains the I-SPECTRA database system and a "How-to-Use" instruction section. It also has a section titled "Links to Other Databases", which provides direct links to other spectral databases. Finally, it has a "Feedback" page, which is used to register and receive comments on I-SPECTRA from the website users.

In summary, the development of The Aerospace Corporation's I-SPECTRA system was successful in accomplishing the IR&D goal of an *interactive* spectral database and analysis system. Additional spectral data will be imported into the database in the future and the interactive manipulation and analysis capabilities will be expanded as the I-SPECTRA system evolves.

CONCLUSIONS

Robust and available spectral libraries are required to properly exploit hyperspectral remote sensing. This paper has described in some detail the architecture and several high-level requirements for the design and implementation of web-based spectral libraries. We've shown how a variety of diverse technologies are utilized to implement web-delivered database driven spectral library and discussed some of the tradeoffs associated with each of these approaches. Upon this foundation, we presented a case study of the I-SPECTRA system developed by The Aerospace Corporation. We are considering several areas for further research. First, we're investigating advanced user interfaces. These would allow the user to describe spectra via an image or a rough sketch. Second, we're going to look into the use of web services as an alternative interface to the library. Web Services rely on a variety of standards to directly connect applications via a network, allowing them to share business logic, data and processes through a programmatic interface.[12]

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