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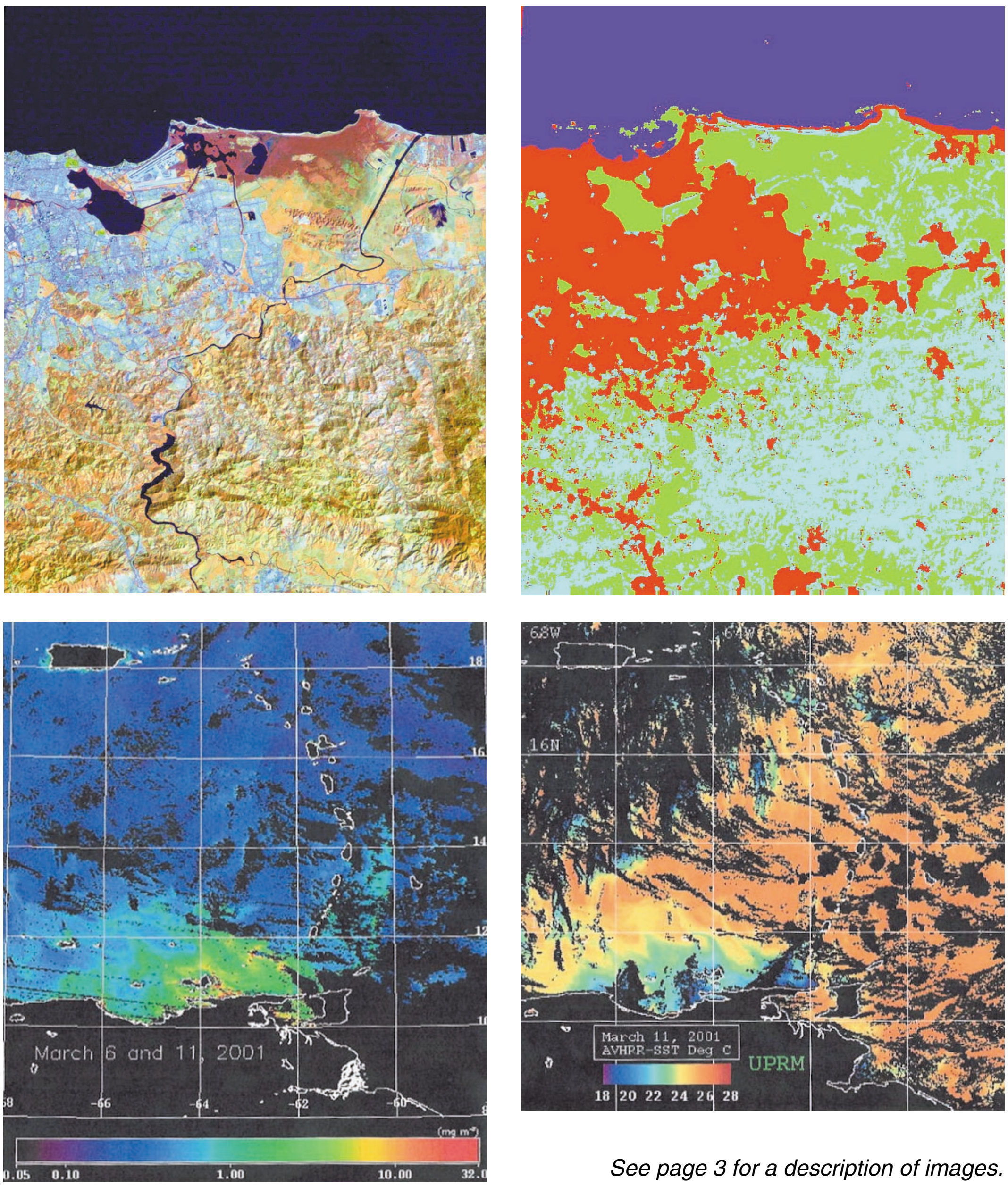

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UNIVERSITY PROFILE

The Laboratory for Applied Remote Sensing and Image Processing at the University of Puerto Rico at Mayagüez

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1. Introduction

The Laboratory for Applied Remote Sensing and Image Processing (LARSIP) at the University of Puerto Rico Mayagüez (UPRM) Campus was established in 1989 through a grant from the US National Science Foundation Minority Research Centers Program. Since then, LARSIP has become an important research group in signal processing, remote sensing and its applications. It is currently funded by grants from NSF, NASA, NIMA, and DoD. The laboratory is currently comprised of nine professors, one researcher, two Ph.D. students, 24 M.S. students, and over 20 undergraduate students.

The objectives of LARSIP are to develop advanced algorithms and technologies for extraction and management of information from remote sensing sensors, and to educate and train students in the various technologies associated with remote sensing and signal processing. LARSIP provides an environment for multi-disciplinary interaction of electrical and computer engineering researchers and students with their counterparts in application areas such as marine sciences, geology, civil engineering, and chemistry.

LARSIP is associated with the Center for Subsurface Sensing and Imaging Systems (CenSSIS), a National Science Foundation Engineering Research Center, which is an industry/university consortium led by Northeastern University, in partnership with Boston University, RPI and UPRM. It is also associated with the UPRM Tropical Center for Earth and Space Studies sponsored by the NASA University Research Centers Program. More information on these centers can be found at http://www.censsis.neu.edu and http://tcess.uprm.edu, respectively.

The major research thrusts at LARSIP are hyperspectral image processing, applied electromagnetics, bio-optics, and signal processing. Research efforts in these areas will be described in the following sections.

2. Hyperspectral Image Processing

High-spectral resolution (hyperspectral) imaging sensors measure data in hundreds of wavelength bands. Imaging sensors such as SEBASS (125 bands), Orbview-4 (200 bands), AVIRIS (224 bands), and HYDICE (210 bands) will give earth scientists and resource managers a powerful tool to detect and classify features, measure productivity/yield, and identify trends in data not available from conventional multi-spectral sensors such as LANDSAT 7. To take full advantage of the available information in hyperspectral imagery, information extraction tools are being developed to handle this large volume of data efficiently. Sponsored by NASA, DoD, and NSF, LARSIP has performed research in the development of classification and compression algorithms that take full advantage of the high spectral resolution information in hyperspectral imagery (HSI). Research work in this area has focused on dimensionality reduction, classification and compression algorithms, and analysis for subsurface object identification.

2.1 Band Selection for Dimensionality Reduction

From a statistical modeling perspective, as the number of bands increases, the number of samples needed to train a classifier can increase exponentially, depending on the classifier being used [1,2]. Therefore, it is of interest to develop methodologies to reduce the dimensionality of the hyperspectral image data while retaining their class discriminatory information as much as possible. Optimal band selection is a combinatorial optimization problem. Band selection algorithms have been developed to use QR and singular value decomposition matrix factorizations to select bands that approximate the principal components that explain most of the data variability. The advantages of these algorithms are that they run in polynomial time and that they have been shown to yield reasonably good solutions [3] and better approximations to the principal components [4]. Application of these algorithms to classification and data compression have been reported in the literature [5,6].

2.2 Classification Algorithms

Hyperspectral imagery offers the potential for high discrimination by integrating spatial and spectral information. However, due to the high dimensionality of the data, this potential benefit is hampered by the difficulty of training classifiers with high dimensional feature vectors and the complexity of models that integrate spatial and spectral information. One of the approaches to deal with high dimensionality problems in classi-

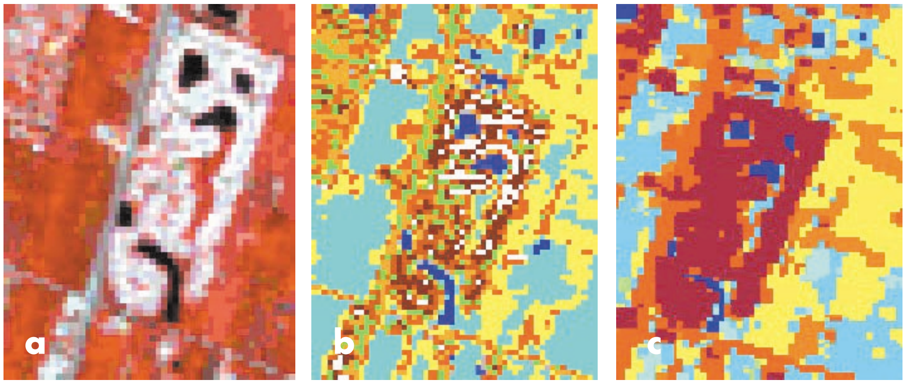

Figure 1. Use of Unsupervised Classifier ECHO algorithms. (a) Segment of original AVIRIS image of NASA Kennedy Space Center exhibiting urban spatial structure. (b) Classical C-means clustering classification on a pixel-by-pixel basis (c) Unsupervised ECHO classification using spatial information to improve the detection of urban spatial structure.

fier training is to reduce dimensionality using the band selection methods previously described. Another approach being studied at LARSIP is the use of regularization methods to stabilize the classifier parameter estimates. Another important research thrust in hyperspectral classifiers is the incorporation of spatial information. At LARSIP an unsupervised version of the ECHO classifier [7] has been developed. It was shown to have very good performance compared to other approaches based on Markov random fields [8] and post-processing filtering [9]. Figure 1 illustrates the application of the unsupervised classifier ECHO algorithm to an AVIRIS image of NASA Kennedy Space Flight Center.

2.3 Lossless Compression of Hyperspectral Imagery

Another application of the band selection method is for lossless compression of hyperspectral images. Because of the nature of hyperspectral images, different spectral bands can be very similar, and this similarity can be exploited for compression. Use of contiguous spectral bands has been attempted in the prediction phase of compression algorithms, but this causes both compression and decompression to be sequential. For example, if the last band compressed needs to be decompressed, all previous bands must be decompressed. In order to avoid this, an algorithm has been developed to use a subset of bands to predict the rest. The advantage is that decompression of any band requires only the decompression of this subset. Compression results equivalent to contiguous bands were achieved for AVIRIS images using only six of the 224 original bands. The results using these six bands were also nearly identical to using the first six principal components, the optimal linear predictors. Some results are shown in Table 1.

Table 1. Entropy results of prediction using principal components and a subset of bands.

Bands	Linear predictor entropy		Number of PCs used	Linear predictor entropy
29	7.830790		1	7.989636
29-42	7.262668		2	7.109786
29-42-89	6.776586		3	6.476988
14-29-42-64	6.620856		4	6.300056
9-29-36-42-66	6.543167		5	6.157913
1-29-37-42-70-123	6.046576		6	5.919479

2.4 Hyperspectral Image analysis for Subsurface Object Identification

A fundamental challenge to imaging and pattern recognition systems is the detection of objects embedded in a diffusive and dispersive medium with discrete sources of clutter. Particular examples of complex media are the atmosphere and the ocean. Most of the previous work focuses on statistical detection and estimation of parameters. Physics-based modeling has been used to understand the relation between the objects of interest, the sensors and the environment [10, 11]. Current research at LARSIP includes the integration of physics-based signal processing with the spectral and spatial information in hyperspectral data for subsurface sensing. Algorithms are being developed to solve ill-posed problems in inversion methods applied to hyperspectral image analysis [12, 13]. The applications mainly focus on remote sensing to detect objects under the atmosphere or the ocean surface (e.g. coral reefs). The sensor mainly used is a high-resolution imaging spectrometer (hyperspectral) sensor.

3. Applied Electromagnetics

The applied electromagnetics group applies computational models to a variety of remote sensing applications, such as microwave absorption spectra near 22 GHz and active remote sensing of clouds [14-16]. They examine the effects of the atmospheric stability over the ocean on algorithms for radio path delay and wind speed retrieval from space. The applied electromagnetics group also examines the effect of the air pressure in water vapor retrieval algorithms at tropospheric heights. For these studies, a variety of data sources are used, including data from the altimeter and water vapor radiometer of the NASA Topex/Poseidon Satellite and from the National Weather Service radiosondes.

A preliminary study examined the effects of the atmospheric stability of the ocean in the estimation of radio path delay used in current spaceborne radiometric instruments [14]. This effect was studied using a NASA Topex/Poseidon data set, which included low wind speeds, as well as ocean and atmosphere ancillary data from the National Oceanographic Data Center (NODC) and the National Weather Service (NWS). The effect of the atmospheric stability on the wind speed was examined and corrected [16]. The correlation between the path delay derived from the

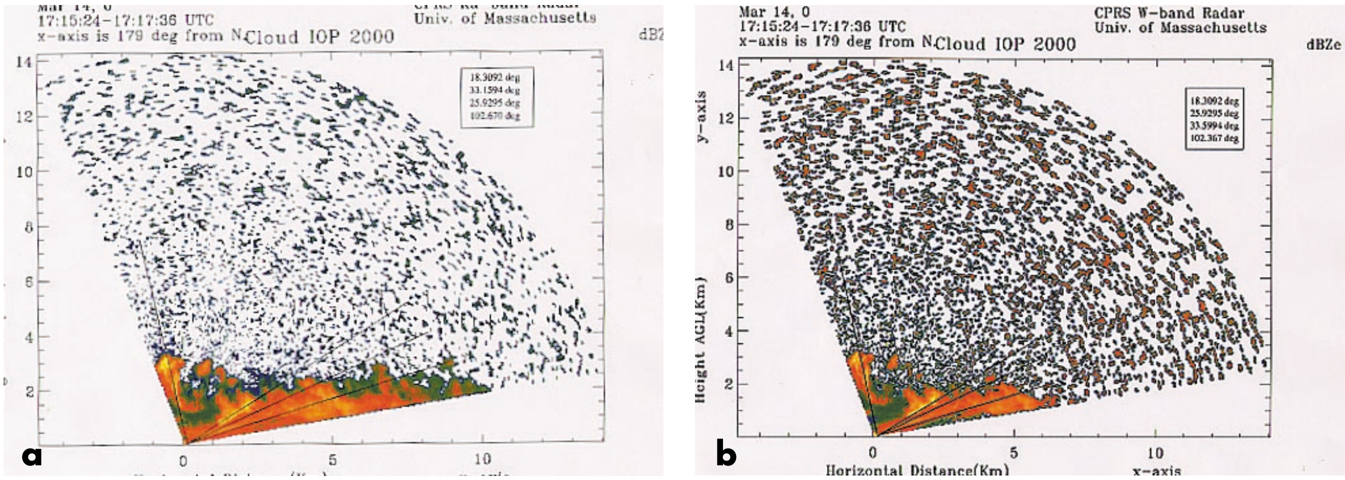

Figure 2. UMass-CPRS radar reflectivity scans of a stratus cloud at (a) Ka-band (33 GHz) and at (b) W-band (95 GHz), both processed at UPRM. The microphysical structure of the liquid water content inside the cloud can be retrieved from the difference in extinction rates at these two frequency bands. The total cloud liquid water content can then be computed by integrating over the antenna scattering volume.

Topex/Poseidon radiometer and that derived from the radiosonde balloon profiles was examined for two very low wind cases.

The first case was when neutral stability at the air-sea interface was assumed. Most current wind speed and path-delay algorithms assume this, including the Topex/Poseidon algorithm. In this case, it is assumed that the sea surface temperature is equal to the air temperature just above the surface. The correlation is computed again for the case when the wind speed is corrected to take into account the actual air-sea interface conditions. This state was derived from atmospheric profiles around the globe collocated in space and time with the Topex/Poseidon data. These ancillary data were obtained from the National Oceanographic Data Center (NODC) and the National Weather Service (NWS). The air temperature at the surface was assumed to be the sample nearest to the ground of the radiosonde's atmospheric profile. The sea surface temperature was measured using ocean buoys from the NODC data set [17].

It was found that degradation in the atmospheric path delay correction occurs, using the phase difference between the Topex microwave radiometer and radiosonde observation, when the atmospheric stability state of the ocean is taken into account. This is to be expected since the algorithm used to calculate path delay did not take into account this condition, and the need for a radio path-delay algorithm that takes into account air-sea atmospheric state is therefore evident. Current work is underway to compare a larger data set of Topex/Poseidon and coincident radiosonde data, which will include clear-sky conditions at all wind speeds, over two years of Topex/Poseidon data over 30 instead of 15 radiosonde stations.

Collaborative work with the University of Massachusetts at Amherst is being performed in the area of cloud studies. The specific areas of interest are the microphysical structure of stratus clouds, the development of better algorithms to retrieve rain rate and raindrop size distribution from precipitating clouds and the modeling of ice crystals in high cirrus clouds. For these studies, this group used data from the UMass Cloud Profiling Radar System (CPRS) and from NOAA S-band profilers. The UMass CPRS is a dual-frequency Doppler radar operating at Ka- and W-bands. The use of two frequencies allows one to retrieve information about the hydrometeor content. Figure 2 depicts the CPRS data processed by UPRM students, showing the radar reflectivity from the cloud at both frequencies (33 GHz and 95 GHz). This research is conducted in collaboration with Dr. Stephen Sekelsky. Other collaborations with UMass include ground penetrating radar for profiling of lake sediments and front-end design for a UHF wind profiler radar using surface mount components.

Other research activities by the applied electromagnetics group include the development of a laboratory for simulation, fabrication, and testing of different types of microwave antennas and circuits [18]. During the last two years, students have been working on a variety of projects such as the design of GPS receivers, design of a broadband amplifier and antenna for GPR applications, modeling of MMIC passive structures, and design of RF remote sensing radars. The group works in the simulation of new microwave structures including microstrip passive structures and printed antennas. This group also performs research on the simulation of a variety of microwave tunable components fabricated with ferroelectric materials. The simulations are performed using various numerical methods for electromagnetics such as the Method of Moments and the Finite Difference Time Domain method.

3.1 Radiation Lab Facilities

The applied electromagnetics group of LARSIP has available Radiation Lab facilities, equipped with state-of-the-art equipment acquired from an NSF MRI grant. The principal instruments housed in the lab are two vector network analyzers (13 and 50 GHz), one spectrum analyzer (50 GHz), a near field scanner and an anechoic chamber for antenna measurements (2-40 GHz, see Figure 3), a milling machine for prototype fabrication, an HP J-Class Workstation and one IBM RISC 6000 Workstation. The laboratory also has available a variety of electromagnetic simulation tools, such as Momentum, XFDTD, and HFSS.

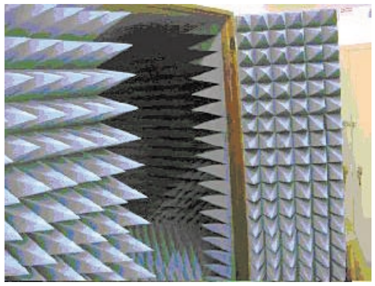

Figure 3. The anechoic chamber in the UPRM Radiation Lab, part of the recently acquired facilities and equipment supported by an NSF Major Instrumentation Research grant.

4. Space Information Laboratory and Bio-Optical Oceanography Laboratory

4.1 Satellite Receiving Capabilities

The Space Information Laboratory (SIL) of the NASA-funded Tropical Center for Earth and Space Studies (TCESS) aims to provide data from several orbiting satellites to the scientific community. Its facilities currently house a TeraScan HRPT reception system from SeaSpace, which schedules, acquires, and processes data from NOAA and NASA satellites. More than 700 GB of data from over 10,000 passes have been received and stored on digital tapes since the installation of the HRPT antenna (Figure 4a) in December of 1996. We have distributed satellite data to users with a variety of interests, both inside and outside of Puerto Rico. In addition, we recently installed an X-Band antenna (Figure 4b) that allows us to receive data from the RADARSAT, LANDSAT-7 and Terra satellites. The location of these antennas makes possible the acquisition of data from the Mid-Atlantic Ocean to the Gulf of Mexico and from Brazil to the Northern United States. Satellite data collected at SIL is used by the Bio-Optical Oceanography Laboratory (BIOL) in a variety of ways. The NOAA-AVHRR data provide information on sea surface temperature (SST) and also allow tracking of hurricanes in the region. Orbview-SeaWiFS data are used to study the dynamics of phytoplankton populations.

4.2 Validation of Satellite Data

During the past several years, an important part of our research has been focused on the acquisition of field data for validation of bio-optical algorithms used in ocean color sensors, like SeaWiFS and MODIS. Field measurements were performed in oceanic and coastal waters using a bio-optical rosette. This optical rosette is used to measure the bio-optical properties down to 200 meters. Multi-year time series recorded at the Caribbean Time Series (CaTS) station show seasonal variations in the optical properties of near-surface waters that are associated with seasonal events, like the intrusion of the Orinoco River during fall. Such variability is the cause of low accuracy in the estimation of phytoplankton Chlorophyll-a using the current bio-optical algorithms. We are now focusing on studying other seasonal events, like coastal upwelling in Venezuela during spring (see lower panel of cover image), to determine their importance in determining the bio-optical properties of the region. Near real-time images of AVHRR and SeaWiFS are provided by SIL and used by the organizers of field campaigns (see cover image, lower panel). That was the case during our last research cruise in March 2001, in which the images helped to sample the very strong coastal upwelling more completely.

5. Signal Processing

5.1 Multisensor Fusion Algorithm for Feature Recognition using Subsurface Sensing

The goal of this research is the creation of an algorithm (or algorithms) to perform Automatic Object Recognition (AOR) using the archeological multisensor data as the testbed.

This research is conducted in collaboration with Dr. Marco Giardino, a research scientist at the NASA Earth System Science Office at Stennis Space Center. The multisensor data are obtained from a Ground Penetrating Radar (GPR), a magnetometer, a conductivity sensor, a 15-band ATLAS plane, and a CCD array sensor. All are obtained at a geographically referenced site, along with actual excavation data. Example data are shown in Figure 5. Accurate interpretation of the data is achieved using object recognition algorithms, combined with signal verification and validation obtained through detailed excavations.

5.2 TexARS (Texture Analysis for Remote Sensing)

This project is in the area of image analysis with emphasis on textural cues. Texture can be defined as the property of a visual scene characterizing the placement of simple elements called texels following specific rules. Texture has been widely used for image segmentation, medical imaging and in computer vision systems. Integrating texture with edge information, contrast,

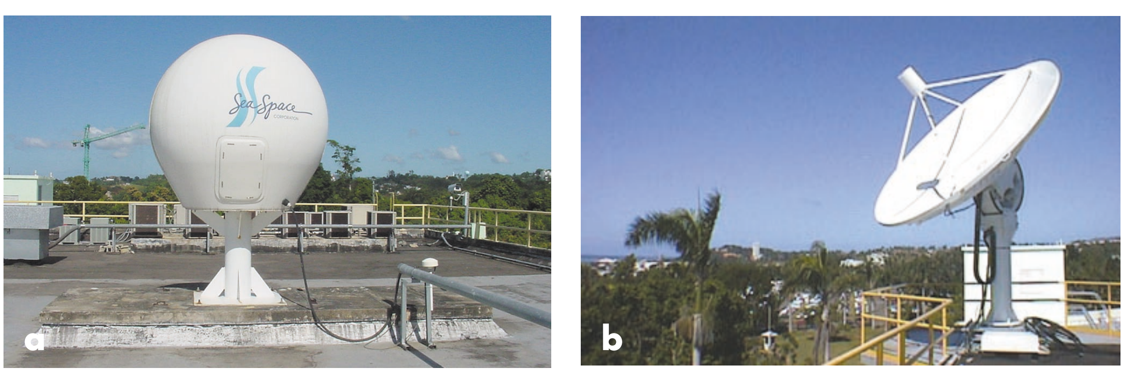

Fig. 4. Antennas at the Space Information Laboratory for receiving remote sensing satellite data. (a) L-Band and (b) X-Band.

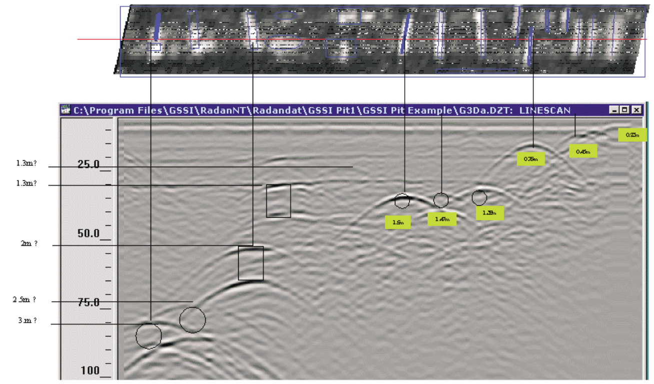

Figure 5. Ground-penetrating radar (GPR) survey data of a Native American burial site. Data provided by NASA Stennis Space Center.

color, and shading, complex vision systems can be developed to perform automated recognition of objects in a scene. These objects can be distinct as well as obscured, and can vary with respect to rotation, scaling and lighting conditions.

A texture has several properties such as homogeneity, periodicity, coarseness, fineness, etc. These properties can be extracted by applying certain algorithms to the images, which can be broadly classified as statistical, structural, multifrequency and multiscale methods. Recently, the texture analysis group of LARSIP has concentrated on developing new algorithms for texture analysis that are computationally efficient and give good classification performance for a wide variety of images [19]. New multi-resolution algorithms have been developed and used for invariant texture classification [20]. Many of the algorithms have been applied for classification of remote sensing images [21] from sensors such as Landsat and SAR. The upper panel of the cover image shows a Landsat image of San Juan, Puerto Rico (left) and its classification using a wavelet transform method (right).

Research efforts are now focused on parameter extraction from radar images for characterization of soil moisture and ocean currents. New techniques are being investigated for optimal texture feature selection using evolutionary computation methods [22]. Algorithms are being developed that yield reliable results, since related multidisciplinary projects, such as climate modeling, demand accurate estimates of parameters from remote sensing images for use in their models. The focus of this research is to develop texture-based algorithms that cater to the needs of a wide variety of applications and to implement these procedures efficiently.

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