The Laboratory for Applied Remote Sensing and Image Processing

at the University of Puerto Rico in Mayagüez

Sandra Cruz-Pol, Miguel Vélez-Reyes, Shawn Hunt, Hamed Parsiani, José Colom-Ustáriz,
Luis O. Jiménez, and Ramón Vásquez
Electrical and Computer Engineering Department

Fernando Gilbes
Tropical Center for Earth and Space Studies

University of Puerto Rico Mayagüez Campus
P.O. Box 9042, Mayagüez, PR 00681-9042
e-mail: SandraCruzPol@ieee.org, m.velez@ieee.org

http://larsip.uprm.edu/

1. Introduction

The Laboratory for Applied Remote Sensing and Image Processing (LARSIP) at the University of Puerto Rico Mayagüez Campus was established in 1989 thanks to a grant from the US National Science Foundation Minority Research Centers Program. Since then, LARSIP has become one of the most important research groups in signal processing, remote sensing and its applications at UPRM are currently funded by NSF, NASA, NIMA, and DoD. Dr. Luis O. Jiménez heads the laboratory which is currently comprised of 9 professors, 1 researcher, 2 Ph.D. students, 24 MS students, and over 20 undergraduate students.

The objectives of LARSIP are to develop advanced algorithms and technologies for information extraction and management from remote sensing sensors, and to educate and train students in the different technologies associated with remote sensing and signal processing. LARSIP provides a focus for multi-disciplinary research and education by promoting research and education projects that involve electrical and computer engineering researchers and students interacting with researchers and students in application areas such as marine sciences, geology, civil engineering, and chemistry, among others.

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, lead 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 (TCESS) sponsored by NASA University Research Centers Program. More information on these centers can be found at www.censsis.neu.edu and tcess.uprm.edu.

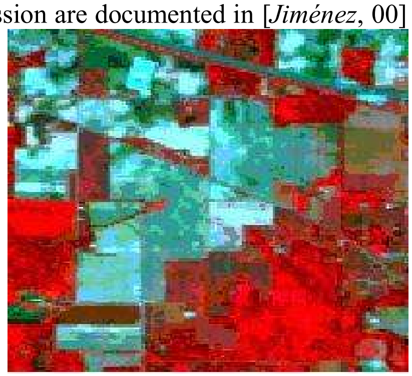
Major research thrusts at LARSIP are in hyperspectral image processing, applied electromagnetics, bio-optics, and signal processing. The research efforts will be described in the following sections.

2. Hyperspectral Image Processing

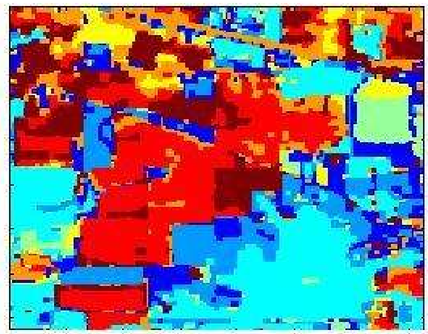
High-spectral resolution (hyperspectral) imaging sensors measure data about the phenomena being studied in hundreds of bands. Imaging sensors such as SEBASS (125 bands), Orbview-4 (200 bands), AVIRIS (224 bands), and HYDICE (210 bands) will give earth scientists and resource managers a powerful tool to help detect and classify features, measure productivity/yield, and identify trends not available with conventional multi-spectral sensors such as LANDSAT 7. To take full advantage of the available information in hyperspectral imagery, information extraction tools that can deal with the huge data volume efficiently are being developed. With sponsorship from NASA, DoD, and NSF, research work al LARSIP in this area has dealt with the development of algorithms for classification and compression of hyperspectral imagery (HSI) that take full advantage of the high spectral resolution information. Research work in this area has focused in three main aspects: dimensionality reduction, classification algorithms, and compression.

2.1 Band Selection for Dimensionality Reduction

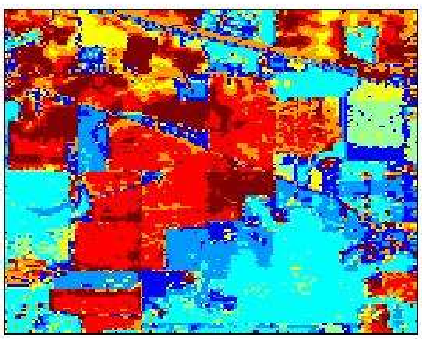
From a statistical modeling perspective, as the number of bands increases, the need for training samples for a classifier can increase exponentially with the number of bands depending on the classifier being used [Jiménez, 98, Jimenez99a]. Therefore, it is of interest to develop methodologies to reduce the dimensionality of the hyperspectral image data but at the same time retain as much as possible their class discriminatory information. Optimal band selection is a combinatorial optimization problem. Here, we have developed band selection algorithms using QR and singular value decomposition matrix factorizations that select bands that approximate the principal components that explain most of the data variability. The advantage of these algorithms is that they run in polynomial time and have been shown that give reasonable good solutions [*Vélez*, 00] and better approximations to principal components [*Vélez*, 01]. Application of this algorithm to classification and data compression are documented in [*Jiménez*, 00] and [*Hunt*, 01].



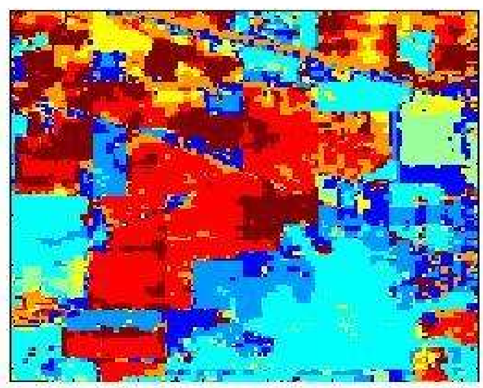
a. AVIRIS NW Indiana's Indian Pine test site



c. Post-Classification Filter based on GMRF



b. Original c-means and covariances clustering 8 Clusters



d. Unsupervised ECHO Classifier.

Figure 1. Original AVIRIS image, clustering algorithm and integration of spatial and spectral information.

2.2 Classification Algorithms

Hyperspectral imagery offers the potential of high discrimination capacity by integrating spatial and spectral information. However, because of high dimensionality this potential benefit is hampered by the difficulty of training classifiers with high dimensional feature vectors and the complexity of models to integrate spatial and spectral information. One of the approaches to deal with high dimensionality problems in classifier training is to reduce dimensionality using the band selection methods described previously. 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 [*Jiménez*, 99e] has been developed with very good performance compared to other approaches based on markov random fields [*McLachlan*, 92] and post processing filtering [*Richards*, 93]. Figure 1 illustrates some results of this work using the AVIRIS image of the Indian Pine Test Site.

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. Using contiguous spectral bands has been tried for the prediction phase of compression algorithms, but this causes both compression and decompression to be sequential. For example, if the last band compressed need to be decompressed, all previous bands must be decompressed. In order to get around this, an algorithm that uses a subset of bands to predict all the rest has been developed. The advantage is that decompression of any band needs only the decompression of this subset. Compression results equivalent to contiguous bands was achieved for AVIRIS images using only six of the 224 original bands. The results with these six bands were also nearly identical to using the firs 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	lin. pred. entropy		number of PC used	lin. pred. 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

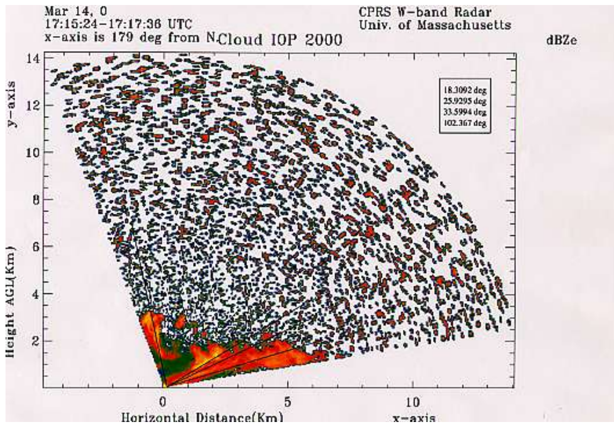
3. Applied Electromagnetics

The group works with computational models for different remote sensing applications, such as microwave absorption spectra near 22 GHz, and active remote sensing of clouds [*Cruz-Pol*, 98, 99, 00, 01b]. The group examines the effects of the atmospheric stability conditions over the ocean on algorithms for radio path delay and wind speed retrieval from space. This 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. Collaborative work is being performed with the University of Massachusetts at Amherst in the area of cloud studies. Specifically, we are looking into 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, the lab used data from the UMASS Cloud Profiling Radar System (CPRS) and from NOAA S-band profiles. 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 (33GHZ and 95 GHz). This research is conducted in collaboration with Dr. Stephen Sekelsky. Other collaborations with UMass include; ground penetrating radar for lake-sediments profiling and front-end design for UHF wind profiler radar using surface mount components.

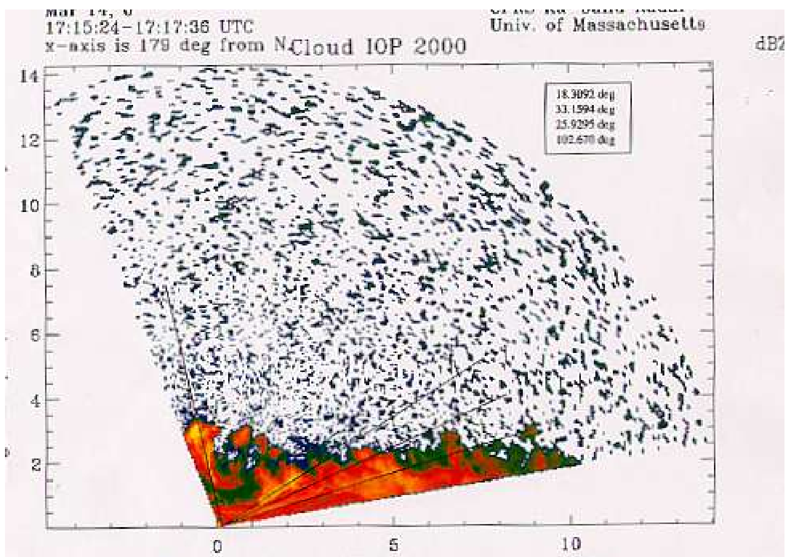
A preliminary study examined the effects of the atmospheric stability conditions of the ocean in the radio path delay estimation used in current radiometric instruments on board of satellite missions [*Cruz-Pol*, 98]. This effect was studied using a data set which included low wind speeds from NASA Topex/Poseidon and ocean and atmosphere ancillary data from the National Oceanographic Data Center (NODC) and the National Weather Service (NWS). The effect that the atmospheric stability has on the wind speed was examined and corrected by *Cruz-Pol*, 00 and *Cruz-Pol*, 01. The correlation between path delay [cm] derived from Topex/Poseidon radiometer and derived from the radiosonde balloons profiles was examined for very low wind for two cases.

This first case was when the atmospheric conditions are assumed to be neutral. Most current wind speed and path-delay algorithms are developed under this assumption, e.g. T/P algorithm was derived under this assumption. In this case, sea surface temperature is assumed to be equal to the air just above the ocean. The correlation is repeated for the case when the wind speed is corrected to take into account the actual atmospheric conditions of the ocean. The data to derive this state was derived from ancillary data sets from the National Oceanographic Data Center (NODC) and from the National Weather Service (NWS) atmospheric profiles around the globe collocated in space and time with the T/P data. The air temperature was measured by the radiosonde lowest reading on the atmospheric profile. The sea surface temperature was measured by the ocean buoys from the NODC data set.[*León* et al., 99]

It was found that degradation occurs in the TMR-RaOb path delay correlation 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 it is indicative of a need for a modification to improve the TMR-RaOb path-delay one-to-one correspondence. The need for 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 co-located radiosonde data, which will include all wind conditions under clear skies (2 years of T/P data over 30 instead of 15 radiosonde stations).



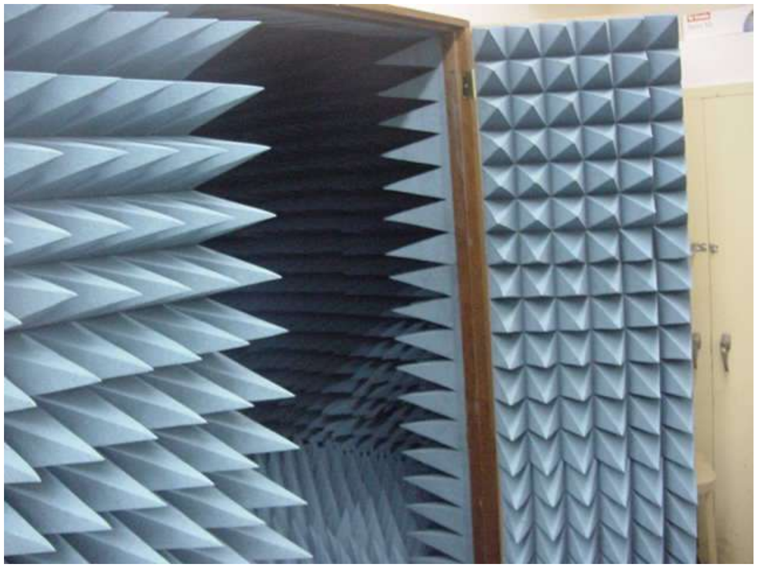
(a) Radar Scan data showing the radar reflectivity at Ka-Band (33 GHz)



(b) Radar Scan data showing the radar reflectivity at W-Band (95GHz)

Figure 2. UMass-CPRS radar reflectivity data from a stratus cloud for the Ka and the W bands processed at UPRM. The microphysical structure of the liquid water content inside the cloud can be retrieved from the difference in extinction rates at this two frequency bands. Total cloud liquid water content can then be integrated over the antenna scattering volume.

Other research activities by the applied electromagnetics group includes, the development of a laboratory for simulation, fabrication, and testing for different types of microwave antennas and circuits [*Colom*, 01]. During the last two years, students have been working in different 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, etc. The group works in the simulation of new microwave structures including microstrip passive structures and printed antennas. The group also performs research on the simulation of different kinds of microwave tunable components fabricated with ferroelectric materials. The simulations are performed using various numerical methods techniques for electromagnetics such as Method of Moments and Finite Difference Time Domain.



(a) Anechoic Chamber.

(b) Network Analyzer 8350 and other microwave equipment.

Figure 3. Some of the recently acquired equipment with the support of the NSF (Major Instrumentation Research) MIR grant for the UPRM Radiation Lab.

3.1 Radiation Lab FACILITIES

The Radiation lab is equipped with state of the art equipment acquired with a NSF MRI grant. The most important 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), a milling machine for prototype fabrication, an HP J Class Workstation and one IBM RISC 6000 Workstation. The laboratory also has available different electromagnetic simulators such as Momentum, XFDTD, and HFSS.

4. Space Information Laboratory and the Bio-optics Laboratory

4.1 Satellite Receiving Capabilities

The Space Information Laboratory (SIL) of the NASA-funded Tropical Center for Earth and Space Studies 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 in digital tapes since the installation of the HRPT antenna in December of 1996. We have distributed satellite data to people with different interests in and outside of Puerto Rico. In addition, we recently installed an X-Band antenna that allows us to receive data from RADARSAT and LANDSAT-7. In the near future, the station will have the capabilities to receive data from Terra and Aqua 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 actually used by the Bio-Optical Oceanography Laboratory (BIOL) in different ways. NOAA-AVHRR data provide information of the Sea Surface Temperature and allow to track hurricanes in the region. Orbview-SeaWiFS data are used to study the phytoplankton dynamics.

Fig. 4. The Space Information Laboratory L-Band and X-Band Antennas

4.2 Validation of Satellite Data

During the past several years, an important part of our research have been focused in the acquisition of field data for validation of bio-optical algorithms used in ocean color sensors, like SeaWiFS and MODIS. Fieldwork is carried out in oceanic and coastal waters using for the first time a bio-optical rosette (see photo). 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 depicts seasonal variations in the optical properties of near-surface waters that are associated to seasonal events, like the intrusion of the Orinoco River during fall. Such variability is responsible for low accuracy in the estimation of phytoplankton Chlorophyll-a using the current bio-optical algorithms. Other seasonal events, like coastal upwelling in Venezuela during spring, are now the focus of our studies to determine their importance in the bio-optical properties of the region. Near real-time images of AVHRR and SeaWiFS are provided by SIL and used to delineate the field campaigns. That was the case during our last research cruise in March 2001. The images helped to better sample the very strong coastal upwelling during that time. Examples of these images are shown below.

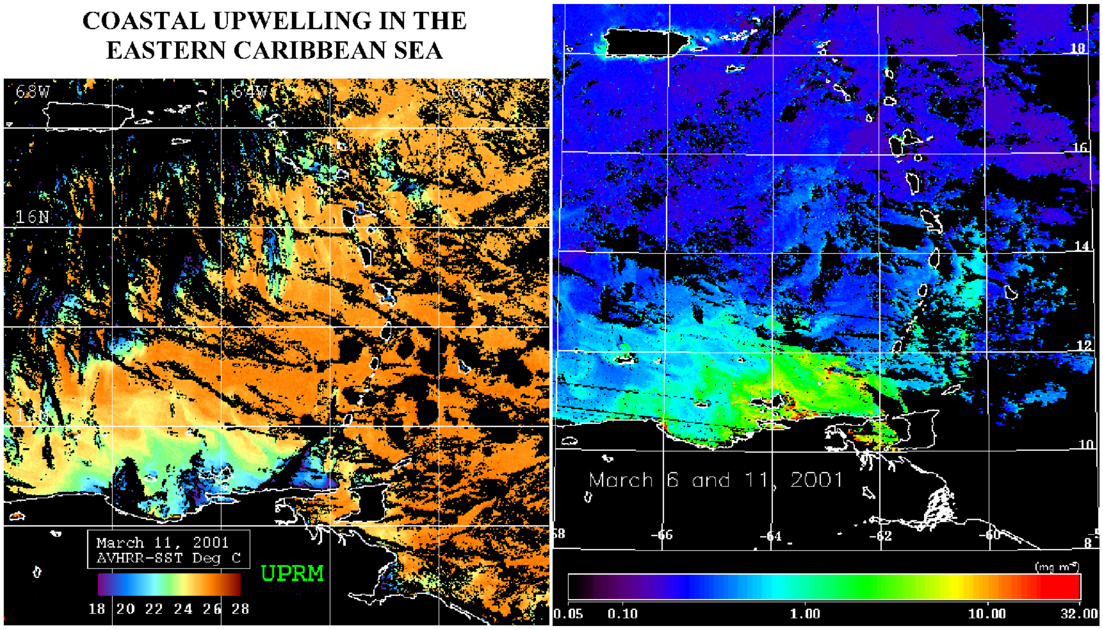


Figure 5. Coastal Upwelling in the Eastern Caribbean Sea

5. Signal Processing

5.1 Multisensor Fusion Algorithm for Feature Recognition, using subsurface image data

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

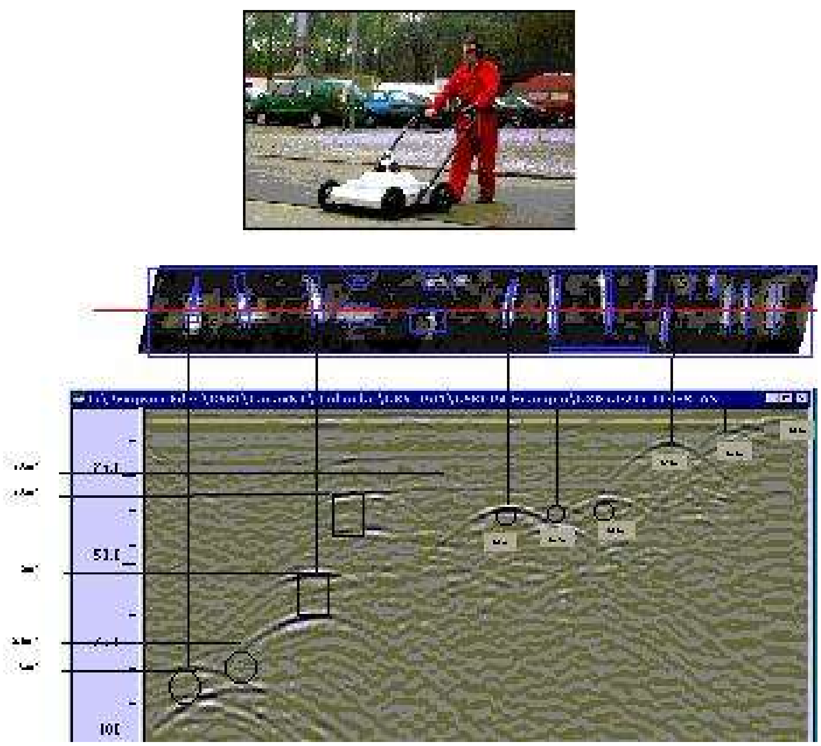
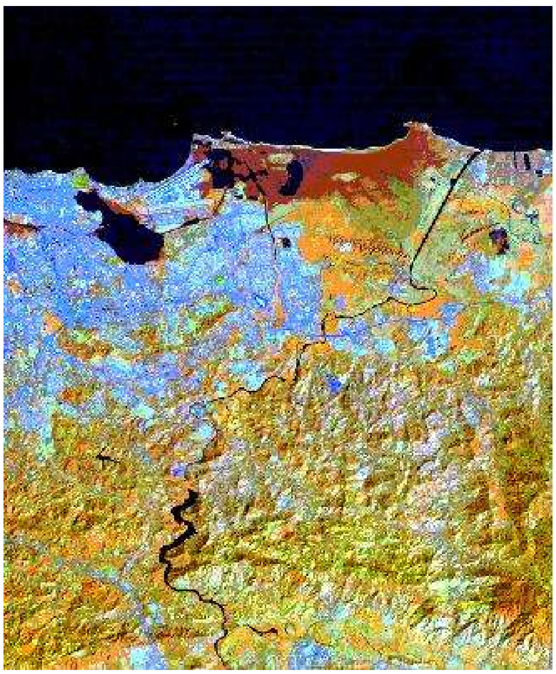


Figure 6. GPR device and survey data of a native american burial site provided by NASA Stennis Space Center.

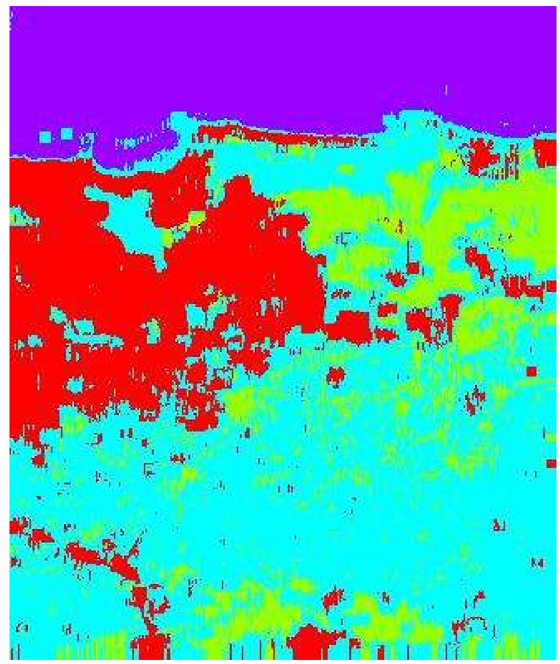
This research is conducted in collaboration with Dr. Marco Giardino, a NASA research scientist of Earth System Science Office, at Stennis Space Center. The multisensors data which is being made available are obtained from a Ground Penetrating Radar (GPR), magnetometer, conductivity, 15 band ATLAS plane, and CCD array sensors. All are obtained from a geographically referenced site, along with actual excavation data. Object recognition algorithms combined with signal verification and validation obtained through detailed excavations allows accurate interpretation of the data.

5.2 TexARS (Texture Analysis for Remote Sensing)

This project encompasses the area of image analysis with emphasis on texture cues. Texture is the property of a visual scene that characterizes 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, color and shading, complex vision systems can be developed to perform recognition of objects in a scene. These objects can be distinct as well as obscured, varying with respect to rotation, scaling and lighting conditions.



(a)



(b)

Figure7. (a) SAR image of San Juan, Puerto Rico (b) Classified image using wavelet transform method.

A texture has several properties such as homogeneity, periodicity, coarseness, fineness, etc. These properties can be extracted by application of certain algorithms on the images, which can be broadly classified as statistical, structural, multifrequency and multiscale methods. The *texture analysis group* of *LARSIP* has in the recent past concentrated on developing new algorithms for texture analysis that are computationally efficient and give good classification performance over a wide variety of images [*Manian*, 00a]. New multiresolution algorithms have been developed and used for invariant texture classification [*Manian*, 98]. Many of the algorithms have been applied for classification of remote sensing images [*Manian*, 00b] from sensors such as Landsat and SAR. Figs. 6 and 7 show a Landsat image of San Juan, Puerto Rico and the classification using a wavelet transform method.

Research efforts are being directed towards parameter extraction from radar images for soil moisture and ocean currents characterization. New techniques are investigated for optimal texture feature selection using evolutionary computation methods [*Manian*, 01]. Algorithms that give reliable results are being developed, as other multidisciplinary projects such as climate modeling demand accurate estimates of parameters from remote sensing images for use in their models. The focus is to develop texture based algorithms that cater to the need of wide variety of applications and also to implement them efficiently.

6. References:

Colom, José, "*Anaylis and Design of a Tunable Multilayer Lange Coupler*", Journal of Integrated Ferroelectrics, in press.

Cruz Pol, S. L., and C. S. Ruf, "*A Modified Model for the Sea Surface Emissivity at Microwave Frequencies*, "IEEE Trans. on Geosciense and Remote Sensing, Vol.38, no. 2, March 2000.

Cruz Pol, S. L., C. S. Ruf and S. J. Keihm, "*Modified Model for the Microwave Sea Surface Emissivity*", IGARSS '99 Symposium, Germany, 1999. •

Cruz Pol, S. L., C. S. Ruf and S. J. Keihm, "*Improved 20-32 GHz Atmospheric Absorption Model*," Radio Science, Vol. 33, No. 5, pp. 1319-1333, September-October 1998.

Cruz Pol, S. L., N. Colón-Díaz and S. M. *Sekelsky "Multidimensional Cloud Images Retrieval From Dual- Frequency Millimeter-Wave Radar* ", IGARSS 2001 Symposium, Sydney, Australia, 2001a.

Cruz-Pol, S. L.,"*Microwave Remote Sensing: Estimation of Ocean Parameters*", NASA/TCESS Report, March 2001b.

Jiménez, L. O., and Medina, J., "*On the Integration of Spatial and Spectral Information in Unsupervised Classification for Multispectral and Hyperspectral Data*." SPIE Conference, Florence, Italy, September 1999.

Jiménez, L. O., Vélez-Reyes, M., Chaar, Y., Fontan, F., and Santiago, C., "*Partially Supervised Detection Using Band Subset Selection in Hyperspectral Data.*" SPIE Conference, Orlando Florida, 1999,

Jiménez, L.O., Landgrebe, D.A., *"Hyperspectral Data Analysis and Supervised Feature Reduction Via Projection Pursuit*," IEEE Transactions of Geoscience and Remote Sensing, to be published in 1999.

Jimenez, L.O., Landgrebe, D.A., "*Supervised Classification in High-Dimensional Space: Geometrical, Statistical, and Asymptotical Properties of Multivariate Data*," IEEE Transactions on Systems, Man, and Cybernetics, Vol. 28, No. 1, pp. 39-54, February 1998.

Jimenez, L.O., Morales, A., Creus, A., "*Classification of Hyperdimensional Data Based On Feature and Decision Fusion Approaches Using Projection Pursuit, Majority Voting, and Neural Networks*," *IEEE Transactions on Geoscience and Remote Sensing*, May 1999.

Jimenez, L.O., Vélez-Reyes, M., Chaar, Y., Fontan, F., and Santiago, C. "Partially Supervised Detection Using Band Subset Selection in Hyperspectral Data." Proceedings of the SPIE Conference, Orlando Florida, 1999.

L.O. Jiménez-Rodríguez, M. Vélez-Reyes, J. Rivera-Medina, and H. Velásquez, *"Unsupervised Decision Fusion for Hyperspectral Data*." In Image and Signal Processing for Remote Sensing VII, Proceedings of SPIE, Vol. 4541, September 2001.

León, L., Vega, M and Cruz-Pol, S. L., "*Study of the Effects of the Air/Sea Atmospheric Stability on the Satellite Radiometric Path Delay Retrieval*", JTM, 1999.

Manian, V., A. Vega and R. Vásquez, "*Comparison of feature selection algorithms for texture image classification*," Proceedings of SPIE AeroSense'01, April 2001.

Manian, V., and R. Vásquez, "*Scaled and rotated texture classification using a class of basis functions*," Pattern Recognition, Vol. 31, No. 12, pp. 1937-1948, 1998.

Manian, V., R. Hernández and R. Vasquez, "*Classifier performance for SAR image classification*," Proceedings IGARSS'00, July 2000b.

Manian, V., R. Vásquez and P. Katiyar, "*Texture classificaiton using logical operators*," IEEE Trans. IP, Vol. 9, pp. 1693-1703, Oct. 2000a.

S. D. Hunt and M. Vélez-Reyes, *"Band selection for lossless image compression.*" In S.S. Shen and M.R. Descour, editors, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VII, Proceedings of SPIE Vol. 4381, April 2001.

McLachlan, G. J., "*Discriminant Analysis and Statistical Pattern Recognition*," John Wiley & Sons, 1992.

Richards, J. A., "*Remote Sensing Digital Image Analysis, An Introduction*" 2nd ed. New York: Springler-Verlag, 1993.

Vélez-Reyes, M. and D.M. Linares, "*Comparison of Principal-Component-Based Band Selection Methods for Hyperspectral Imagery.*" In Image and Signal Processing for Remote Sensing VII, Proceedings of SPIE, Vol. 4541, September 2001.

Vélez-Reyes, M. and L. O. Jiménez, "Subset Selection Analysis for the Reduction of Hyperspectral Imagery." In Proceedings IEEE International Geosciences and Remote Sensing Symposium, July 6-10, Seattle, WA, 1998.

Vélez-Reyes, M., L. O. Jiménez, D.M. Linares, and H.T. Velázquez. *"Comparison of matrix factorization algorithms for band selection in hyperspectral imagery."* To appear in Proceedings of SPIE Aerosense, Orlando, FL, 2000.

Vélez-Reyes, M., L. O. Jiménez, F. Pagán, and G. Fernández, *"Subset Selection for the Analysis of Hyperspectral Data."* In Proceedings of the 1997 International Symposium on Spectral Sensing. Held in San Diego CA during December 13 to 19, 1997.

7. Acknowledgements

Research work at LARSIP has been supported by grants from National Science Foundation, NASA, Department of Defense, ARMY Topographic Engineering Center, and the Government of Puerto Rico.