Temporal and Spectral Data Mining
for Earth and Space Sciences

Task Leaders

Robert E. Crippen, JPL, Robert.E.Crippen@jpl.nasa.gov, 818-354-2475
Ruth Bergman, JPL, Ruth.Bergman@jpl.nasa.gov, 818-393-9815
Ronald G. Blom, JPL, Ronald.G.Blom@jpl.nasa.gov, 818-354-4681

Product Description

Imaging sensors accumulate vast amounts of data that record the composition, morphology, and dynamic processes of the earth and other planetary surfaces. Here we propose to advance a set computational tools that push beyond the standard limits of image resolution. By detecting subpixel morphologic changes over time, we can identify and quantify active processes on planetary surfaces that might otherwise be missed. By algorithmic removal of veneering materials such as snow, vegetation, and dust, we can unveil the full bedrock character of the terrain. Our end product will be new capabilities in image information extraction that will enhance the utility of image archives and the capabilities of forthcoming image acquisitions. << This is a continuing, "push" task. >>

Current Status: Concepts well demonstrated, but practicality and precision limited by manual inputs.

FY 2000 Targets: Automation and improved accuracy for path radiance correction and spectral unveiling (better results plus analyst time savings of approximately 1-2 hours per scene).

FY 2001 Targets: Completion of "imageodesy" change detection tools (new capability, allowing routine measurement of physical processes not otherwise detected within large databases).

Benefits

Several challenges facing NASA in both the Earth Science and Space Science Enterprises can be addressed by advances in image information extraction. Dynamic natural processes on Earth and elsewhere in the solar system are of particular interest in understanding the evolution of landscapes. Dynamic processes are also significant in that they pose potential hazards to people on Earth and to landers on Mars. Images can reveal these processes and they record much additional information of use to terrestrial and space scientists.

Advances in image information extraction increase the value of image archives and reduce data requirements (and ease data downlink requirements) for future imaging systems. Therefore we propose to advance information extraction capabilities at the limit of image resolution. Specifically, we will address geometric (as opposed to radiometric) change detection by developing methods that we call “imageodesy” (Crippen, 1992). Imageodesy (a concatenation of “image geodesy” and a partial acronym of “image multi-temporal analysis geodesy”) allows the detection of motion (between image acquisitions) down to about 1/10 of a pixel and perhaps even beyond 1/20 of a pixel, depending upon data characteristics and scene content. Imageodesy differs from related work in radar interferometry (e.g. Massonnet et al., 1993) in that it can utilize optical images and is therefore applicable to vast and growing archives of remotely sensed data that already record decades of surficial processes here on Earth and elsewhere in the solar system. Imageodesy also complements ongoing related work in image resolution enhancement (Baldwin et al., 1998).

Imageodesy fully defines motion direction in the geographic (horizontal) plane through analysis of a single image pair, whereas interferometry provides only a one-dimensional scalar measure of change from which direction and calibration of the scalar measure can only be inferred via assumptions regarding the natural process observed. Imageodesy works best in rugged terrain, where image patterns are distinct, while interferometry works best in smooth terrain where layover and other problems do not corrupt the radar phase signal beyond use. The bottom lines are that (1) imageodesy and radar interferometry are differing and highly complementary methods for the detection and measure of dynamic processes, (2) only imageodesy is applicable to the majority of past and forthcoming image data sets, and (3) development and application of imageodesy offers substantial benefit in maximizing information extraction from terrestrial and planetary imaging systems. Figure 1 provides examples of imageodesy results in the measurement of tectonic strain and sand dune motion.

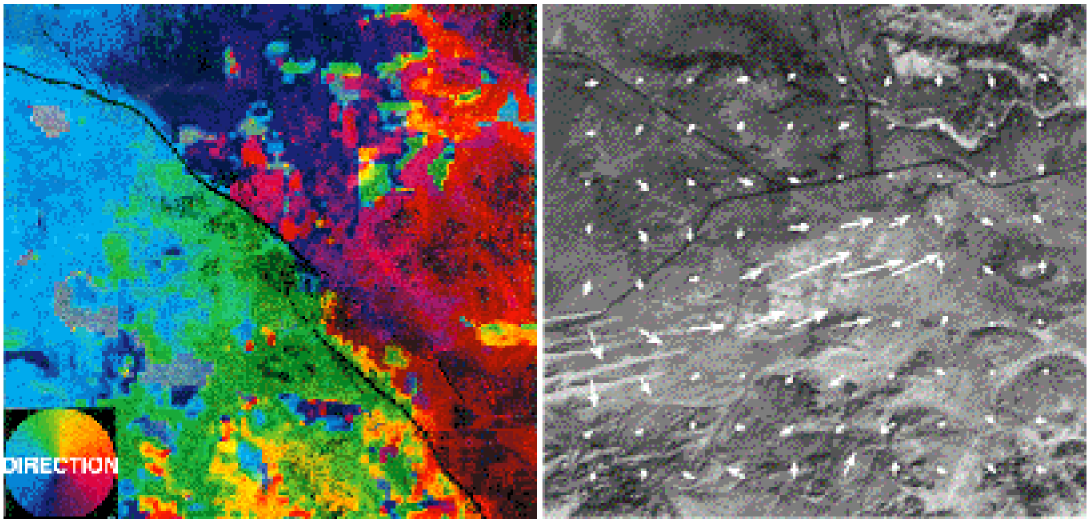

Figure 1 (color). Preliminary imageodesy results using 10 meter SPOT imagery. LEFT: Landers earthquake (Mojave Desert, 28 June 1992) clearly showing the fault break (upper left to lower right) as a discontinuity separating 3-5 meter ground motions of discordant direction. RIGHT: Subpixel sand dune motions of 2-6 meters occurring over 15 months at Superstition Hills, California.

On a parallel front, we have developed an innovative spectral deconvolution procedure that allows software “removal” of subpixel materials that obscure the observation of bedrock. Unlike existing and developing methods of spectral unmixing (e.g. Bierworth, 1990), our approach benefits from the need to characterize only the obscuring material in order to suppress its expression. We have demonstrated and are in the process of publishing (Crippen and Blom, 1999) a method of “de-vegetating” terrestrial scenes (Figure 2) and have preliminary results for an analogous “de-snowing” algorithm (Figure 3). Extension of the method to “de-dusting” and “de-sanding” would help improve lithologic information extraction from Martian and terrestrial scenes.

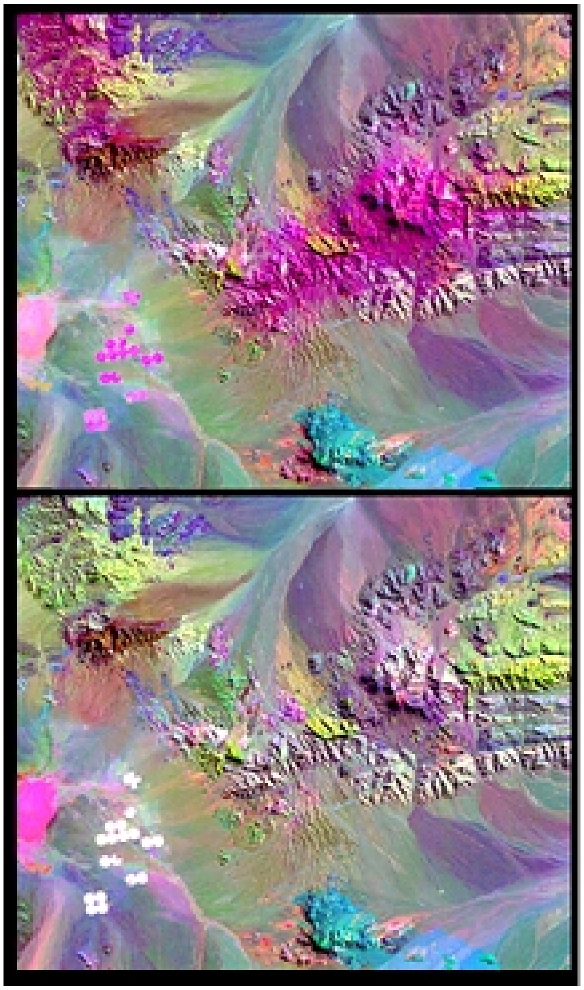

Figure 2

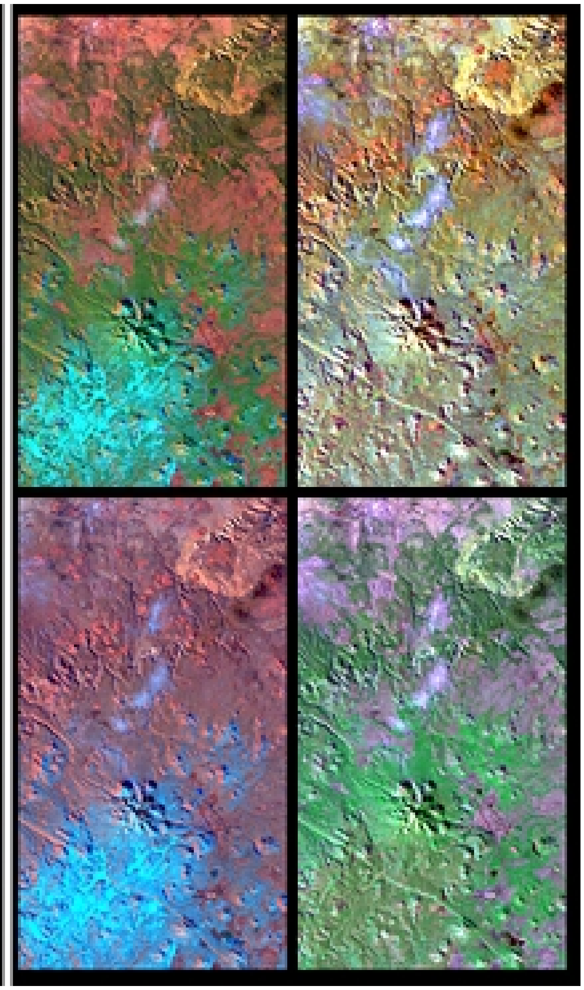

Figure 3

Figure 2 (color). De-vegetation of a Landsat image of Rachel, Nevada. In the "before" image (top), mountain top vegetation appears reddish-magenta and obscures the underlying lithology. In the "after" image (bottom), vegetation is suppressed and the revealed lithologic patterns are contiguous with adjacent naturally exposed terrain.

Figure 3 (color). De-snowing and de-vegetation of a Landsat image of Williams, Arizona. Snow appears cyan and vegetation appears green in the unprocessed image (upper left). Selective suppression of vegetation (lower left) and snow (lower right) is demonstrated. Suppression of both reveals spectral contrasts of volcanic features and other geologic materials (upper right).

Our algorithm for spectral deconvolution relies upon accurate path radiance (additive atmospheric radiance) corrections. We have previously conceived and published a statistically-based method of extracting path radiance values directly from multispectral data (Crippen, 1987). We call it the "regression intersection method" (RIM). Advantageously, RIM eliminates limiting assumptions required by alternative methods. Because of the great importance of path radiance measurement to our developing spectral deconvolution work, as well as to remote sensing image calibration in general, we now seek to develop automated procedures for implementing RIM that utilize computational resources that have become available since our initial work. Substantial improvements in accuracy and reduction or elimination of manual work on path radiance determinations will be achievable for many scenes using RIM.

In summary, this research will:

* Produce software tools that increase the value of forthcoming (and existing) remote sensing data sets by enhancing information extraction potentials.
* Be directly applicable to terrestrial and planetary change detection research.
* Reduce the need for increased data volumes to detect fine scale terrain characteristics.
* Complement existing and other developing measurement techniques.
* Improve and automate a fundamental remote sensing data calibration procedure.

Technical Approach

In each of our tasks we seek information that is “hidden” in the image. The challenge is to create innovative methods to deconvolve and extract that information.

Subpixel ground displacements alter a scene by changing radiance, pixel-by-pixel, in areas of image contrast. In very simplified concept, individual pixels represent squares of areally averaged radiance. Pixel radiance changes from the “before” image to the “after” image when adjacent darker or lighter terrain encroaches into the pixel square. Consistent changes across several pixels constitute subtle shifts in pattern that can be matched statistically at subpixel scales. Matching groups of pixels at each point on a grid results in a vector field that defines the ground displacements.

Refining the image to isolate the ground shift signal requires recognition of and compensation for (1) satellite attitude differences between the images, (2) illumination and view angle differences, if any, (3) data quality factors, and (4) possible ground reflectance changes. Our work seeks to define and quantify these factors and to develop algorithmic solutions to their effects. For example, satellite attitude differences will commonly produce mis-matches in the image pair that are substantially greater than those attributable to ground displacements. Compensation for attitude variations relies upon recognition of their spatial pattern, which is predictable, and scale, which should be much broader than the ground displacement features. Illumination and view angle differences may be avoided by matching “after” image acquisition parameters to those of the “before” image. However, compensation for unavoidable differences might be possible by modeling irradiance distribution and parallax as it relates to topography. For Earth scenes, this should soon benefit from the advent of high resolution elevation models derived from the Shuttle Radar Topography Mission (SRTM). For other planets, elevation modeling might be derivable from the images themselves or from additional images of the scene. Simulation is essential in quantifying the impact of various factors and the precision of our results. In real applications we can usually recognize reasonable results, but only in simulations do we know exactly what the answer should be so that precision can be quantified.

Our work in spectral unveiling and the requisite atmospheric corrections utilizes only the image data themselves and again reaches into the data to extract information that is not readily apparent. In the RIM method of determining path radiance, spectrally uniform but topographically variable sites are identified and their pixels are plotted in n-dimensional space. Each site should form a linear trend, and extrapolations of all linear trends will ideally pass through (intersect at) a common point corresponding to zero ground radiance since that is the only point at which differing materials appear the same. The sensor measured radiance for zero ground radiance corresponds to the desired measure of additive atmospheric path radiance (plus sensor calibration offset). This is a simple concept, but the tricks are in the details. Algorithms are needed to determine the spectral similarity of materials having variable irradiance. Some differing materials will have trends that differ only slightly such that minor errors result in parallel trends that "intersect" at infinity. Thus the method can be sensitive to noise and mis-identification of spectral uniformity. Our previous results, using substantial manual input, show that these sensitivities can be overcome. But automation will require algorithms that can fully replace the user. We are optimistic that we can design sufficient algorithms because the method is tolerant of random errors given a sufficient statistical sampling, and automation facilitates greatly increased sampling. The net result should be not only a practical tool, but more precise measurements of path radiance, which is an important issue in relating imaged radiance to ground reflectance across numerous applications.

Our approach to spectral unveiling focuses on the direct removal of an obscuring veneer. To date we have demonstrated suppression of vegetation and snow in Landsat imagery. The method relies upon a spectral index for only the substance to be removed. The procedure utilizes the concept that all features in a scene are detectable only if they create image contrast. The method maps the variability of the substance using the spectral index and then suppresses image contrast in each band that can reasonably be attributed to the substance as indicated by statistical relationships. We should be able to generalize the method to the removal of other materials, including perhaps dust, thin clouds, or CO_2 ice on Mars. The key is to derive a good spectral index image. To the first order, this is fairly easy for vegetation and snow in Landsat imagery because they have distinct and large spectral contrasts with all rock types and with each other even in broadband imagery. For other materials, incorporation of hyperspectral data should allow the derivation of additional spectral index images. Hyperion (EO-1) orbital data will become available during the course of this research and JPL has a large collection of AVIRIS airborne data on hand.

The algorithms we are developing are computationally demanding. Imageodesy has been implemented previously on the CRAY T3D and has required hours of computation. We now plan to implement the algorithms on a beowulf-class supercomputer. The beowulf is a high-performance massively parallel computer built primarily out of commodity hardware components, interconnected by a private high-speed network. It consists of a cluster of workstations that are dedicated to running high-performance computing tasks. Beowulf-class machines can provide supercomputer performance for a third to a tenth of the price of a traditional supercomputer.

The processing required for these algorithms includes computation of correlation functions over local areas of an image. By assigning different portions of an image to different processor nodes, each node can perform the bulk of the computation assigned to it independently of other nodes. Computational speed is particularly necessary during algorithm development when many iterations of the entire process are required during a series of experiments.

Status and Milestones

FY 1999 Status:

* Imageodesy algorithm development and preliminary application to a time series of SPOT images for tectonic and eolian process detection and measurement.

* Conceived and implemented vegetation and snow suppression algorithms that are directly applicable to broadband imaging sensors. Currently completing a manuscript that includes application to a specific geologic mapping task (Crippen and Blom, 1999).

* Developed strategy for generalizing and automating the RIM atmospheric correction procedure.

FY 2000 Milestones:

* Create, demonstrate, and publish the automated RIM atmospheric correction algorithm.

* Determine spectral data requirements for extending our feature suppression algorithm to dust and sand for image enhancement of terrestrial deserts and Martian landscapes.

* Complete algorithm development adequate for a time series analysis of terrestrial subpixel sand dune motion.

* Determine and quantify via modeling the impact of factors that may limit precision in imageodesy, such as radiometric quantization and natural scene variance.

FY 2001 Milestones:

* Produce enhanced, user-friendly computational tools for imageodesy and demonstrate them in the context of tectonic ground displacements and sand dune motion.

* Test imageodesy at sand dune sites in repeat-coverage high-resolution Mars Global Surveyor images in order to detect and measure geologic processes and surface/atmosphere interactions that might otherwise be below the threshold of detection (pending data availability).

* Integrate imageodesy results with terrestrial radar interferometric results to synergistically achieve a first-ever, spatially complete, high-resolution, three-dimensional mapping of tectonic strain.

Customer Relevance

This work is of direct relevance to the Space Science and Earth Science Enterprises of NASA. Imagery is a primary data product for most NASA observational systems. Methods that maximize information extraction increase the value of that data. New methods that push the limits of resolution also push the limits of detection, which particularly in the case of a space probe might facilitate discoveries that would otherwise be missed.

NASA strategic plans emphasize exploration of Mars in the coming decade and beyond. A stated objective for Mars missions is "systematic examination of local areas at extremely high spatial resolution in order to quantify surface/atmosphere interactions and geological processes." Sand dunes are an observable record of such interactions and processes on Mars, and our imageodesy method is designed to precisely quantify changes over time. Meanwhile, dust is widely distributed across Mars and ice obscures polar regions. Our spectral deconvolution algorithms, applied to future imagery having higher spectral dimension than currently available, could help facilitate the mapping of bedrock geology. Mars is the first planet targeted for human exploration. Optimizing knowledge of geologic exploration targets and the hazards of active surface processes is essential.

The Europa Orbiter Mission (reaching orbit in 2008-2009) should also benefit from imageodesy. The primary questions to be answered at Jupiter's fourth largest moon concern the existence and dynamics of a liquid ocean beneath the fractured icy surface. The Europa Orbiter will image the surface at 100m resolution, but for only one month, after which the sensor will succumb to radiation damage. Detection of surface dynamics during that short time span will require a yet unknown level of precision, but improved algorithm sensitivity could allow detection of processes that would otherwise be missed (Blom et al. 1997).

One of the objectives of the Earth Science Enterprise (ESE) strategic plan is to "improve our ability to understand local tectonics and to relate these to seismic hazard vulnerability through advanced geodetic techniques." Our preliminary results for the Landers earthquake indicate the potential of imageodesy in meeting that objective. Additional objectives include the development of remote sensing techniques, contributions to natural resource management, and the calibration of measurements. Our de-vegetation routine has already drawn considerable interest in academia and industry, and the automated RIM procedure will facilitate data calibrations that improve spectral deconvolution and many other remote sensing methodologies. Terrabytes of image data downlinked from future missions will benefit from, and indeed require, automated methods.

Technical References

Baldwin, D.G., W.J. Emery, and P.B. Cheeseman, 1998, Higher resolution earth surface features from repeat moderate resolution satellite imagery: IEEE Trans Geosci Remote Sensing, v. 36, p. 244-255.

Bierwirth, P.N., 1990, Mineral mapping and vegetation removal via data-calibrated pixel unmixing, using multispectral images. *International Journal of Remote Sensing,* v. 11, no. 11, p. 1999-2017.

Blom, R., R. Crippen, R. Granat, J. Roden, and P. Stolorz, 1997, Searches for sub-pixel surface motions on Earth and Europa. *Workshop on Remote Sensing of Planetary Ices: Earth and Other Solid Bodies,* held at Flagstaff, Arizona, 11-13 June 1997, W. Calvin, H. Keiffer, F. Carsey., and A. Nolin, conveners.

Crippen, R.E., 1987, The regression intersection method of adjusting image data for band ratioing: *International Journal of Remote Sensing,* v. 8, no. 2, p. 137-155.

Crippen, R. E. 1992, Measurement of subresolution terrain displacements using SPOT panchromatic imagery: *Episodes,* v. 15, no. 1, p. 56-61.

Crippen, R.E., and R.G. Blom, 1999, Unveiling the lithology of vegetated terrains in remotely sensed imagery. *Photogrammetric Engineering and Remote Sensing,* submitted July 1999.

Massonnet, D., et al., 1993, The displacement field of the Landers earthquake mapped by radar interferometry: Nature, v. 364, no. 6433, p. 138-142.

Investigators

Robert Crippen (Ph.D.'89, UCSB) and Ronald Blom (Ph.D.'87, UCSB) specialize in innovative uses of remotely sensed data. Crippen invented, and Blom helped develop, the basic imageodesy, atmospheric correction, and spectral unmixing approaches that we propose to extend and automate. Ruth Bergman (Ph.D.'95, MIT), is a sensor information scientist specializing in artificial intelligence and machine learning.