MEASUREMENT OF DYNAMIC GEOLOGIC PROCESSES AT SUBPIXEL SCALES

Robert E. Crippen
Ronald G. Blom
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109 USA

Commission VII, Working Group 4

KEY WORDS: Dynamic, Geology, Remote Sensing, Subpixel Measurement, SPOT, Image Matching

ABSTRACT

Methods have recently been developed for the utilization of remotely sensed image data in the measurement of terrain displacements resulting from geologic processes. In optical imagery, measurements precise to a fraction of a pixel are achieved by statistical image matching. In radar imagery, measurements precise to a fraction of a wavelength are achieved by interferometry. Each method has distinct advantages. Radar interferometry is currently more high developed, but the advent of globally available, one-meter optical satellite images will greatly increase the utility of optical methods.

INTRODUCTION

Terrain displacements related to earthquakes, sand dune migration, volcanic activity, glacial motion, and gravitational sliding can be measured with precisions finer than image resolution by optical remote sensing methods as well as by radar interferometry. Applications to date have shown both methods to be uniquely valuable in the detection, mapping, and measurement of geologic and environment processes. The two methods also have differing strengths and are thus complementary.

METHODS

Optical methods involve image cross correlation of multitemporal images (Crippen, 1992). A 'before' image is used as a reference base upon which a grid is delineated. At each node, a neighborhood of pixels (e.g. 100 x 100) is sampled and compared to pixels at the corresponding location in an 'after' image. The peak subpixel correlation point is determined by interpolating the 'after' image repeatedly, following the path of increasing correlation. This point defines a vector relative to the node in the 'before' image reference base. By calculating a vector at each node, an evenly spaced array of vectors is generated for the entire image. Typically, the dominant pattern shown in the vector array corresponds to satellite attitude differences between the two scenes. However, this pattern can be modeled, estimated, and removed because it is consistent across the scene, differing greatly in spatial frequency from the terrain displacement patterns we seek to reveal.

Radar interferometry has been extensively demonstrated and well documented in recent years (e.g. Massonnet et al., 1993; Peltzer and Rosen, 1995). Measurements require a multitemporal pair of images plus an elevation data base (which may also be derived by radar interferometric means if an appropriate third radar image is available). The measurement is derived from the radar phase information, which is independent of the radar backscatter measurements usually displayed in a radar image.

COMPARATIVE ADVANTAGES

Optical methods are two-dimensional, potentially providing a complete mapping of both horizontal dimensions (assuming the scenes are nadir looking). However, they provide no sensitivity to vertical displacements . Radar interferometry is one-dimensional but can detect vertical displacements and some horizontal displacements because measurements are along the oblique 'slant' path of the radar beam. Optical methods are most reliable in rugged terrain where image patterns are strong. Radar interferometry is most reliable in low relief areas, where problems such as layover cannot occur. Both methods suffer from temporal decorrelation, which results from environmental changes in the scene (e.g., vegetation growth). Optical methods require a cloud-free atmosphere and consistent sun angles, which are irrelevant factors for radar interferometry. Because radar interferometric measurements are made relative to signal phase, they do not provide absolute measurements. Absolute measurements can be made only by observing spatial gradients from a known (or presumed) value at a geographic reference point. Confusion can occur where spatial gradients are too steep. In contrast, optical methods provide direct measurements.

Currently, radar interferometry provides measurement precisions on the order of a few centimeters (i.e., on the order of a tenth of the signal wavelength). Optical methods using spaceborne imagery can measure only meter-scale displacements at best (e.g., a tenth of a pixel using SPOT panchromatic data). Optical methods are limited not only by the spatial resolution of the data but by the radiometric resolution as well. If the radiometric quantization steps (DNs) do not differ substantially from the local image variance, relatively precise interpolations are not possible. This is why optical methods work best in rugged (shaded) terrain, where the image patterns are strong (and local variance is high).

With the coming of one-meter optical data from spaceborne sensors in the next few years, optical imagery will approach the precision of radar interferometry. Optical data also provide the capability to actually see the displacements. Subresolution misregistrations in images are readily apparent in video displays that flicker multitemporal images (Crippen and Blom, 1992). This has previously been used to visualize actual displacements along strike-slip faults.

BENEFITS OF REMOTE SENSING IN GEODESY

Using remote sensing for precise measurement of dynamic processes in the environment has several advantages. Firstly, it is spatially comprehensive. Millions of measurements can be made across a satellite image that covers a region where even a dense GPS array would have only a few dozen stations. Secondly, it requires no anticipation. Potential 'before' and 'after' images are being acquired everyday by numerous satellites. No baseline geodetic field measurements need be made in anticipation of an earthquake (or other event) that might never occur in the researcher's lifetime. Thirdly, it is cheap and easy. The growing available (and improving) data sets cost the user nothing until and unless needed; the expense of travel and field logistics can be avoided; and researchers can perform their studies at their desk when convenient.

We have coined the term 'imageodesy' to refer to the use of remote sensing for the precise measurement of dynamic processes across an image. The term is a concatenation of the words "image geodesy" and also a partial acronym for "Image Multitemporal Analysis geodesy". We see great potential for imageodesy as terrestrial remote sensing moves beyond the questions "What's there?" and "How has it changed?", to the question "Where is it going?".

REFERENCES

Crippen, Robert E., 1992, Measurement of subresolution terrain displacements using SPOT panchromatic imagery. *Episodes,* 15(1), pp. 56-61.

Crippen, R.E., and R.G. Blom, 1992, The first visual observation of fault movements from space: The 1992 Landers earthquake. *EOS, Transactions of the American Geophysical Union,* 73 (43), pp. 364.

Massonnet, D., M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl, and T. Rabaute, 1993, The displacement field of the Landers earthquake mapped by radar interferometry. *Nature,* 364, pp. 138-142.

Peltzer, Gilles, and Paul Rosen, 1995, Surface displacement of the 17 May 1993 Eureka Valley, California, earthquake observed by SAR interferometry. *Science,* 268, 1333-1336.