High-Resolution Interferometric Synthetic Aperture Radar for Discoverer II

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New requirements have recently emerged for high-resolution digital terrain-elevation data. Such data are required for critical applications such as intelligent preparation of the battlefield and precision engagement. The recent development of high-resolution interferometric synthetic aperture radar (IFSAR) has made meeting these requirements a possibility. Because studies have shown that a space-based IFSAR mission is feasible, a high-resolution terrain-mapping mode has been included as an important part of the Discoverer II Technology Demonstration Program. This article presents a survey of the current state of research for space-based high-resolution IFSAR. Research and development have focused on key technical challenges such as phase unwrapping, baseline-tilt estimation, motion contamination, vegetation and urban-area effects, synchronization, and error minimization. The application of high-resolution terrain-elevation data to tactical targeting is also discussed. (Keywords: Interferometric synthetic aperture radar, Mapping, Synthetic aperture radar, Terrain mapping, Topographic mapping.)

INTRODUCTION

Discoverer II is a technology demonstration program jointly sponsored by the Defense Advanced Research Projects Agency (DARPA), the U.S. Air Force, and the National Reconnaissance Office.[1] Its purpose is to develop a system design for satellite surveillance and reconnaissance by producing two prototype satellites for performing ground moving-target indication and synthetic aperture radar (SAR). A constellation of such satellites would be able to meet the needs of next-generation rapid targeting by enabling tasking, collection, exploitation, and dissemination much faster than currently available (minutes instead of hours to days). In addition, the system would allow targets to be geographically located with great accuracy. The consequence would be new capabilities for indication and warning, intelligent preparation of the battlefield, and precision engagement.

The recently developed high-resolution interferometric SAR (IFSAR) is one of the critical enabling technologies for achieving these new battlefield-preparation and precision-engagement capabilities (see the boxed insert for a brief explanation of SAR and

A BRIEF TUTORIAL ON INTERFEROMETRIC SYNTHETIC APERTURE RADAR

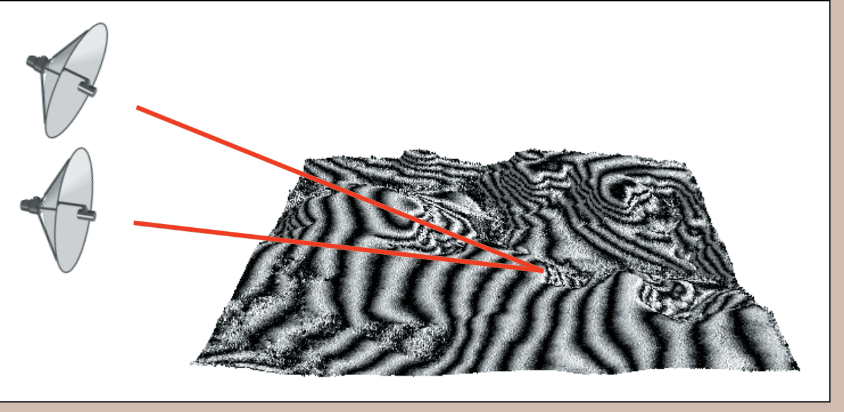
Synthetic aperture radar (SAR) is a technique for performing high-resolution imaging from great distances. SAR works by transmitting coherent broadband microwave radio signals from an airplane or satellite to "illuminate" an area and then receiving the reflected signals. These returns are subsequently stored and processed to simulate signals obtained using a large-aperture antenna. The data are then focused to form a high-resolution image of the area. One major advantage of SAR over optical imaging techniques is that it can operate in virtually any weather.

A fundamental component of SAR imaging is that the signals transmitted and received are coherent. In addition to a precisely measurable time delay, the received signals have a precisely measurable phase relative to the transmitted signal. Coherence provides the means for synthetically creating a very large antenna aperture relative to that which could be provided with a real antenna. This large synthetic antenna size permits imaging at high resolution.

If a second SAR antenna is nearby, this phase information can also be used to perform interferometry. The classical physics demonstration of interferometry follows the work of Thomas Young in 1801, who first showed how light waves interfere in his double-slit experiment. In that experiment, a coherent beam of light was split in two and allowed to recombine. When displayed on a screen, the resulting pattern showed interference fringes. This pattern is known as the interferogram.

On a flat screen, the interferogram varies in a regular fashion. It can be exactly predicted based on the wavelength of the light and the details of the various optical distances. However, if the screen is not flat, the interferogram varies in a fashion that reflects the shape of the screen. If the interferogram is measured and analyzed, a mathematical model of the shape of the screen can be derived. This is the essence of interferometric SAR (IFSAR). The interferogram from two SARs (see the figure) is measured and analyzed to derive a model of the geometric shape of the area illuminated.

Graham[2] first proposed the use of IFSAR for topographic mapping. Since the mid-1980s, the concept has been subject to significant research and development. Early work at the Jet Propulsion Laboratory in Pasadena, California, focused on demonstrating the concept for SAR satellites with relatively low resolution (e.g., 30 m). The article describes recent work by several researchers examining the potential for IFSAR at high resolution.



Typical IFSAR interference pattern for undulating terrain. (Reprinted from Ref. 3 by permission of Wiley-Liss, Inc., a division of John Wiley & Sons, Inc. © 1998.)

IFSAR). Interferometric processing of two SAR images can generate both high-resolution and high-accuracy digital terrain-elevation data (DTED®). These kinds of terrain-mapping data have extensive utility for visualizing important aspects of the battlefield (e.g., culverts to hide tank columns). In addition, lower-accuracy tactical-reconnaissance sensors can achieve very accurate target geolocation if the lower-accuracy data are registered to a previously generated high-resolution and high-accuracy terrain-elevation data set. Consequently, a terrain-mapping mode is an important component of the Discoverer II Program.

APL has had a lead role in IFSAR technology and systems development for a number of years. The Laboratory led the 1993 Rapid Mapping Project, which evaluated the potential for rapidly producing worldwide DTED at significantly better resolution and accuracy than were currently available. In follow-on targeting studies, APL developed a complete IFSAR simulation. In addition, the Laboratory has led IFSAR systems studies, tests, and development for DARPA, the Army, and the Air Force and has developed numerous innovative concepts and processing methods. As a result, APL was selected to be part of the government team supporting development of the Discoverer II terrain-mapping mode.

This article presents a survey of the current state of technology for high-resolution IFSAR. It is based on DARPA, Army, Air Force, and NASA studies and discusses major trends relevant to space-based concepts for producing high-resolution terrain-elevation data. The technology for generating topographic data is in flux, and no comprehensive review of the state of the art was attempted. Rather, selected current trends and promising new ideas are emphasized. Finally, we do not intended to convey any government agency's preference for any particular architecture or implementation.

*DTED® is a registered trademark of the National Imaging and Mapping Agency.

TOPOGRAPHIC MAPPING FUNDAMENTALS

Terrain-elevation data are used to provide accurate elevation maps and other useful products. Several levels of DTED are defined by post spacing (the distance between samples), vertical accuracy, and horizontal accuracy. Post spacing represents the resolution of the data. Vertical accuracy is measured by the statistical quantity known as the 90% linear error (LE90), which represents the maximum value of vertical error for 90% of the data. Horizontal accuracy is measured by the 90% circular error (CE90), which represents the maximum value of the horizontal-distance post-location error for 90% of the data. The requirements for post spacing and accuracy vary according to a range of functionality. Post spacing can range from 100 to 1 m, relative vertical accuracy from 10 to 0.25 m, and relative horizontal accuracy from 15 to 1 m.

Sets of DTED are defined as levels 1 through 5 data, from lowest to highest resolution. The emerging requirements are as follows:

- A level 1 data set must be nearly global. It is defined as having 100-m post spacing, 15-m relative horizontal accuracy, and 10-m relative vertical accuracy. Its projected use is for worldwide general mission planning.
- Level 2 is a higher-resolution near-global data set having 30-m post spacing, 10-m relative horizontal accuracy, and 7-m relative vertical accuracy. Projected use is as tactical terrain data for mission planning.
- Level 3 is defined as a regional data set having 10-m post spacing, 3-m relative horizontal accuracy, and 2-m relative vertical accuracy. Projected use is for flight-training simulators and midcourse weapons guidance.
- Level 4 is also considered a regional data set, with 3-m post spacing, 2-m relative horizontal accuracy, and 0.8-m relative vertical accuracy. Projected use is as tactical terrain data for mission planning and weapon terminal guidance.
- Level 5 contains the highest-resolution data. A level 5 data set is defined as having 1-m post spacing, 0.5-m relative horizontal accuracy, and 0.33-m relative vertical accuracy. Projected uses include battlefield visualization and Special Forces planning.

An incomplete global data set presently exists at even the lowest-resolution DTED product (level 1). DTED at approximately 30-m resolution (level 2) exist for a very small portion of the world (although 30-m DTED of variable quality are available from the U.S. Geological Survey for most of the continental United States). Furthermore, the capability of producing needed regional high-resolution data sets of 1- to 10-m post spacing on demand is not available.

To improve the global coverage of digital elevation data, NASA and the National Imagery and Mapping Agency (NIMA) are sponsoring a special 11-day Space Shuttle mission that will be launched in September 1999. The Shuttle Radar Topography Mission[4] (SRTM) will collect 30-m post-spacing data between 60°N and 57°S. The mission will employ IFSAR using the Shuttle Imaging Radar-version C and a receive-only antenna deployed at the end of a 60-m boom. Performance is projected to be a relative LE90 of 8 m, an absolute LE90 of 13–16 m, and an absolute CE90 of 20 m. The joint NASA/NIMA SRTM Program plans to produce near-global DTED at level 2.

METHODOLOGY

Topographic maps are produced using various techniques, including stereophotogrammetry, human survey, and airborne IFSAR and lidar. Stereophotogrammetry is constrained by weather, has a labor-intensive production process, and cannot meet emerging requirements for timeliness. Human surveys are time-consuming, and access can be denied to surveyors during both crisis and peace times. Airborne IFSAR has demonstrated the capability for generating level 5 data (Fig. 1). In addition, airborne lidar systems have become available that can provide digital elevation models for regional areas of interest with even higher resolution and accuracy. However, access for airborne systems can also be denied in crisis and in peace times.

Consequently, an all-weather and all-access mapping capability requires the use of space-based SAR. IFSAR processing can be performed on SAR images collected from space if a second image of the same target area can be obtained. If the two images are taken so that phase-to-target information is preserved, then the images are called coherent. Otherwise, the images are incoherent. In general, coherence can rapidly degrade with increasing time between the collection of the two images.[5,6] However, if two SAR satellites can be deployed near one another (e.g., within 5 km) so that coherence can be preserved, then interferometric processing can be performed (Fig. 2). IFSAR can estimate the phase differences to a target location between the two SAR images. These phase differences can be used, in turn, to generate elevation maps with quality up to that corresponding to level 5. However, such accuracy and precision requires accurate knowledge of the two antenna phase centers.

The geometrical line segment connecting the phase centers of two IFSAR antennas is called the baseline. Accurate knowledge of this baseline is critical for the production of a high-resolution digital elevation model (DEM). In particular, a knowledge error in the baseline tilt contributes to an elevation error that corresponds to a tilted DEM. The baseline-tilt error can be reduced

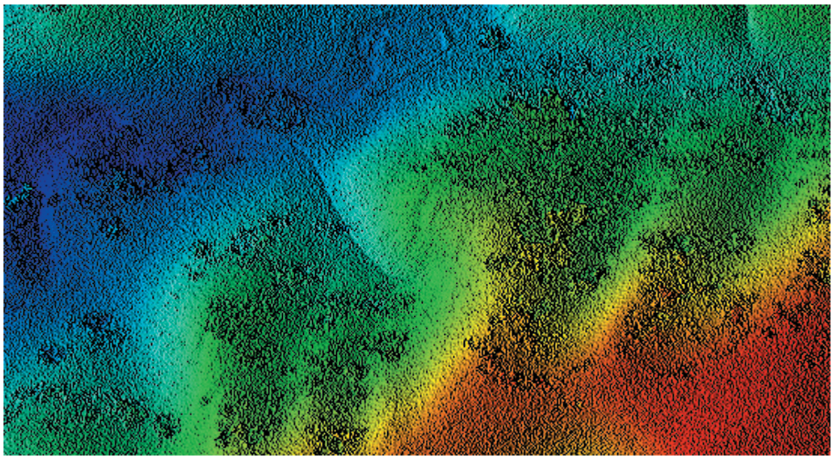


Figure 1. Sun-shaded and elevation color-coded representation of a high-resolution digital elevation model. The model was derived from APL processing of airplane-based IFSAR data collected over Camp Roberts, CA. The collection system, known as the Global Topographic Mapping Digital Collection System (GTM DCS), was developed by ERIM International, Inc., Ann Arbor, MI. SAR image-formation processing was performed by Sandia National Laboratories. Post spacing is 1.0 m. Red, green, and blue represent 185.0, 142.5, and 100.0 m (World Geodetic System [WGS]-84), respectively, with other colors and elevations correspondingly interpolated. The image area, 450 × 300 m, appears three-dimensional when viewed with ChromaDepth glasses.

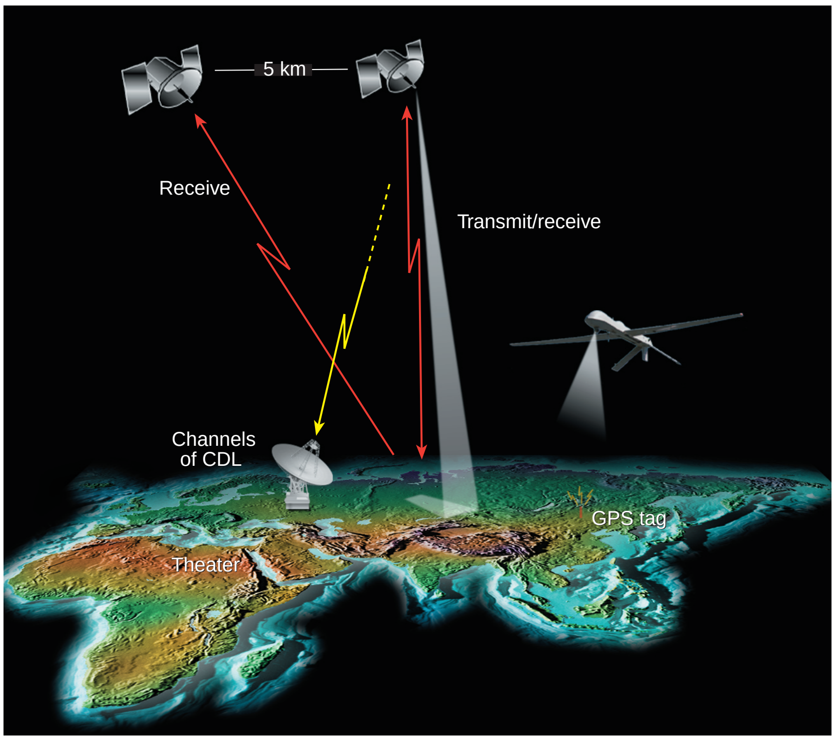


Figure 2. Collection and exploitation scenario for Discoverer II IFSAR. Shown is the bistatic mode, in which one satellite transmits and receives and the other (about 5 km away) only receives. A high level of geolocation accuracy can be achieved for the IFSAR data products, either by differential Global Positioning System (GPS) processing or by the use of control points such as GPS tags, as shown. Data can be downlinked to the theater using channels of the Common Data Link (CDL). The geolocation accuracy of data from unmanned air vehicle sensors (as shown) can be greatly improved by registration to the collected IFSAR data (adapted from Hughes[1]).

by two methods: (1) precision navigation using techniques such as differential Global Positioning System (GPS) processing[7, 8] or (2) use of a different topographic data set to supply tie points to estimate the baseline tilt. In the second method, differences are computed between selected points in a candidate high-resolution DEM and the tie points. These differences can be used to estimate the baseline tilt for the candidate DEM, which can then be corrected for baseline-tilt errors.

Estimation of the interferometric phase is directly available only from the complex SAR imagery in the "wrapped" form (i.e., bounded by zero and 2π). Consequently, the phase must be "unwrapped"; that is, multiples of 2π must be added to the wrapped phase to derive the interferometric phase and subsequently the elevation estimate. For relatively smooth terrain, it is adequate to use a simple unwrapping algorithm in which multiples of 2π are added whenever absolute wrapped-phase differences between adjacent samples are more than π. This simple procedure is exact as long as the absolute unwrapped phased difference is less than π. However, for noisy data and rough terrain, simple unwrapping fails, and more complex algorithms are required.

The major problem with phase unwrapping is aliasing (undersampling) within the interferogram. Such aliasing is caused by noise, layover (i.e., superposition of signals within the same range bin), and too-large baselines. Several techniques have been proposed to deal with phase-unwrapping problems (e.g., Roth[9]); Ghiglia and Pritt[3] have recently compared them with one another. Another aspect of the phase-unwrapping process is the need for tie points. A region that has been unwrapped can have the various relative factors of 2π correct but still have an overall absolute 2π ambiguity for a local region. Consequently, a tie point is required to fix the absolute value of 2π, and special IFSAR processing has been proposed (e.g., Imel[10]). However, for high-resolution IFSAR, the effective local region may be disjoint (divided by boundaries of aliasing) and small (Fig. 3).

One possible way to deal with this problem of disjoint and small regions for phase unwrapping is to introduce a short second baseline. This second baseline can be designed to produce an interferogram that does not exceed the range of 2π over the swath of interest.[11] This allows computation of a coarse height map without use of any form of phase unwrapping. The cycle number ambiguities in the phase data derived from the large baseline can then be resolved by reference to the heights computed from the small-baseline data. For airborne IFSAR systems, adding another antenna at a short baseline is feasible. This approach is used for the DHC-7 aircraft IFSAR system that is being developed at Sandia National Laboratories under the sponsorship of the Army Rapid Terrain Visualization Program.

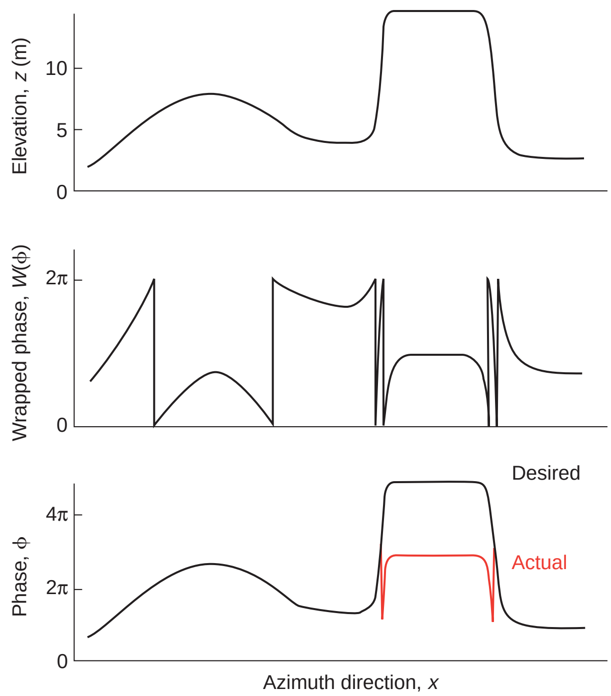


Figure 3. Phase-unwrapping challenge for terrain jumps. Top: Conceptual elevation z profile in azimuth direction x. Because about 5 km of baseline is needed to get the elevation accuracy for space-based IFSAR, the phase ϕ goes through a cycle for approximately every 6 m of elevation change. Center: Corresponding wrapped phase $W(\phi)$ that would be derived from processing two complex SAR images. Bottom: Phase-unwrapping results. Conventional phase-unwrapping algorithms (labeled as actual) work well if there are no isolated terrain jumps. However, jumps can cause such algorithms to fail and give errors corresponding to the wrong multiple of 2π. The solution is to merge these data with another digital elevation model (DEM) that may be noisier but lacks this ambiguity problem. Such a DEM can be acquired by processing data from a third antenna at a short baseline or by performing SAR stereoprocessing on two-antenna data.

For space systems, however, adding an antenna can have considerable cost impact. Fortunately, a coarse height map can be computed by SAR stereoprocessing. In fact, such stereoprocessing (i.e., microregistration) is required for high-resolution IFSAR to have acceptable coherence because of a height-induced misregistration effect. Consequently, for a judicious design, the cycle number ambiguities for small regions can be resolved by reference to the heights from the stereo-DEMs. This alternative does not require a third antenna, and the author has been shown that it works in configurations of interest to space-based systems.

PHENOMENOLOGY: THE EFFECTS OF ENVIRONMENTAL AND SCENE VARIATIONS

As with all techniques, topographic mapping using SAR has limitations that must be recognized. For example, just as optical stereoprocessing cannot be performed in regions of obscuration and deep shadow, SAR-based topographic maps will have data voids in regions of radar layover, shadow, and low cross section. Because radar penetration of foliage (at X band) is limited, SAR-based topographic maps generally correspond to the tops of trees rather than to the ground. Urban areas are problematic because of multipath effects. All of these phenomena occur because SAR-based techniques measure the elevation of the radar-reflective surface.

Estimating elevation in vegetation with IFSAR is a substantial technical challenge. As recently shown in an analysis of high-resolution IFSAR aircraft data (M. W. Roth, unpublished data, 1997), the major effect in vegetated areas is the existence of significant amounts of layover and shadow due to the extreme roughness of the reflective surface. In regions of shadow, elevation cannot be estimated, but in layover regions there is significant decorrelation. The layover decorrelation results from the mixing of radar scattering elements having large differences in elevation within the same range cell. Such decorrelation causes large errors in elevation estimates. Because decorrelation is smaller for small (versus large) IFSAR baselines, one possible approach is to estimate elevation in vegetation using a small baseline.

Even for a small baseline, however, large elevation errors always occur in layover regions because the error is fundamental to the physics of radar scattering. Mixing returns from scatterers at different elevations within the same range bin always produces an elevation estimate that is a mixture of the elevations (i.e., the radar centroid). In layover, the elevation differences can be large, and the resulting elevation mixture can be very different from the elevations of any of the scattering surfaces. The smaller decorrelation of small-baseline systems does not help. In fact, the smaller decorrelation of small-baseline systems can be misleading—the large decorrelation of large-baseline systems clearly identifies regions of layover, whereas the decorrelation of small-baseline systems is so small that it does not separate layover from other sources of decorrelation, such as noise or misregistration.

One method for reducing holes and improving errors from bad data regions is to re-collect data for the same area from a different aspect angle and merge the data. In this way, shadowed regions from one aspect need not be shadowed from a different aspect, and elevation data can be selected from the nonshadowed region. This method can work if shadowed regions can be clearly identified, and identification is possible if the various system and processing noises are low enough. Such a scheme can also work for layover regions if the layover regions can be clearly identified. In this regard, the greater decorrelation of large-baseline systems makes identifying layover regions easier than use of the smaller decorrelation of small-baseline systems.

In addition to the usual effects, such as range walk and azimuth shift, IFSAR has motion-induced effects that can occur and that influence SAR images. When two SAR phase centers are separated in the along-track direction, target motion along the line of sight causes a differential phase shift between the corresponding complex-SAR-image pixels. Although this effect can be used to measure phenomena such as ocean currents,[12] it can also induce errors in IFSAR topographic mapping if the target area has wind-generated motion. Random motion from vegetation can also contribute to loss of coherence, particularly for two-satellite IFSAR designs with significant time periods of along-track separation. In many cases, judicious selection of satellite separations can mitigate motion-induced IFSAR errors.

SAR images of cultural areas are complicated by urban effects such as layover, shadows, multipath effects, motions, corner reflectors, and varying reflectivity. Such effects could contribute to significant elevation error for IFSAR. Modeling of urban effects has shown that characteristic signatures could potentially be used to minimize errors in IFSAR elevation estimation. For example, multiple heights can occur at a pixel location for tall buildings. This information can potentially be used to detect the front edge of large urban structures.

There would be significant advantages if challenging regions (layover, shadow, low radar cross section) could be identified automatically. Automatic identification could enable special processing to be directed to such areas for minimizing errors. In addition, IFSAR can generate high-resolution error maps that can provide a precise estimate of the error at each DEM post. Consequently, because of the great utility of such information, automatic identification would be useful for estimating post-by-post error, as well as for identifying the challenging regions and forwarding the information to users as part of the overall DTED product.

Examination of DEMs generated by a level 3 IFSAR aircraft system[13] and comparison with optical DEMs have shown that there can be other kinds of artifacts of unknown origin. For this system, the radar data represented individual trees at 1/4 of their actual heights, closed canopies at 1/2. Individual trees in the radar DEMs were displaced toward the flight path by 10 to 20 m. As many as 10% of the hilltops contained large errors (>7 m) in spite of high correlation values. Ravines in the radar data were shifted toward the flight path by an average of 10 m, giving rise to the perception that the ravines in the radar data were too shallow. Radar elevation and slope errors varied systematically with the true grazing angle. The better radar elevation data occurred at a grazing angle of approximately 53° and on a positive terrain slope between 0 and 10°. Most likely, these artifacts are the consequence of the specific signal processing applied and could be essentially removed by improved processing.

SYSTEMS ISSUES

DTED timeliness requirements are derived from the Army's need to rapidly deploy forces into any theater upon command.[14] A global data set at a 30-m resolution needs to be collected only once. However, regional collection at a 1-m resolution requires a timely collection capability. Such topographic data sets are required to meet crisis-response and Force projection requirements. These timeliness requirements were specified as 20 × 20 km in 18 h, 90 × 90 km in 72 h, and 300 × 300 km in 12 days. For example, consider the utility of these sizes by examining Bosnia. A 20 × 20 km area would cover the local region around Tuzla, a 90 × 90 km area would cover the region around and between Sarajevo and Tuzla, and a 300 × 300 km area would cover all of Bosnia. These regional timeliness requirements are challenging for any mapping technology.

For high-resolution IFSAR system concepts, the most significant sources of elevation error are

- Vertical errors due to interferometric phase noise
- Baseline calibration errors
- Phase unwrapping errors
- Ephemeris errors

Ephemeris errors can be minimized with precise tracking techniques (e.g., Bertiger et al.[15]). Less significant sources of error include propagation errors, horizontal errors due to SAR image fidelity, mosaic boundary errors, and long-term receiver phase balance. Interferometric phase noise can come from a number of sources. These include SAR image noises, either thermal or multiplicative. Decorrelation significantly increases phase noise and can occur from baseline separation, volume scatter, or temporal instability. Image-pair misregistration can cause decorrelation. Finally, interferometric phase noise can come from differential channel phase errors. Several models of interferometric phase noise and its influence on elevation accuracy exist (e.g., Rodriguez and Martin[16]; Carrara et al.[17]).

In addition, for a bistatic IFSAR operation, some means must be provided to ensure that signals are received at the proper time and frequency. Timing synchronization is required to synchronize the collection interval for the transmit/receive radar and the receive-only radar so that both radars collect the same swath. This is critical for appropriate positioning of the data window. Techniques for pulse-timing synchronization include GPS time transfer and direct reception of the transmitted pulses. Frequency synchronization is required to position the receive-only signal within the azimuth prefilter bandwidth. This need implies that the relative velocity between the satellites must be measured.

Finally, independent master oscillators on the two satellites, as well as a bistatic configuration, means that common-mode monostatic cancellation of low-frequency stable-local-oscillator noise is not appropriate. The result is an increase in the integrated sidelobe ratio and the consequently multiplicative noise ratio (MNR). Reduction in the relative phase noise between the two oscillators is required to improve the MNR of the SAR map formed by the receive-only radar. Techniques for ensuring phase coherence include using atomic clocks, phase-locking the two separate receive local oscillators, and employing auto-focus to correct low-frequency phase errors. Several techniques have been used in interferometric radio astronomy to ensure local-oscillator phase coherence between spatially separated receivers. Most of these techniques involve transmitting signals derived from the separate local oscillators to opposite receiving sites or to a central site and measuring phase differences. For closed-loop systems, phase correction is transmitted by a narrowband link to phase-lock the remote oscillators. Alternatively, the measured phase differences could be used to correct the data during processing.

APPLICATION EXAMPLE

Tactical reconnaissance ("recce") data typically contain a target object within either an infrared/optical or a SAR image. Precision targeting can be achieved if an accurate geolocation for the target object can be obtained. However, recce data typically do not have adequate geolocation accuracy to meet targeting requirements. To get improved geolocation accuracy, recce data are registered to some data set with better geolocation accuracy, and the geolocation of the target is then inferred from the registered recce data. However, previous databases are sparse, require labor-intensive production, and do not meet the needs for very precise targeting. Consequently, new data are needed that can meet precise targeting needs.

High-resolution IFSAR data can meet the needs for an accurately geolocated database for registration and precise targeting of recce data. For example, because IFSAR DEMs can be accurately geolocated (to less than 1 m with proper system engineering), and because the SAR images that were used to form the DEM are exactly registered to the DEM, these SAR images are accurately geolocated to the same degree as the IFSAR DEMs. These SAR images, in turn, can be compared with recce data to accurately geolocate the recce data.

The methodology for accurately registering recce data to SAR images can sometimes be problematic, however. For example, accurately registering two different SAR images is difficult if collection geometries differ significantly. In addition, accurately registering infrared/optical data with SAR data can also be problematic. Registration also is frequently a manual process in which an operator selects features for common objects in the two images to be registered. Typically, cultural features are selected. If the images do not contain enough cultural features or if manual operations are too slow, then the methodology cannot meet precise targeting requirements.

In 1995, APL demonstrated the potential for IFSAR technology to produce an improved registration methodology that overcame the problems just listed. An APL IFSAR simulation showed that the IFSAR-derived DEMs could generate synthetic optical images that could be accurately registered to simulated recce optical images. The principle was established by comparing synthetic images directly derived from a source DEM with synthetic images derived from the corresponding IFSAR-simulated DEM over a wide range of topographic conditions. The registration technique was completely automated. The IFSAR system simulated was the conceptual system for the Topographic Satellite (TOPSAT), designed to generate level 2 DTED.[18]

The Discoverer II Program has asked APL to further demonstrate this methodology, both by using real flight-test data and by extending the methodology to SAR images. In particular, a DEM derived from one set of flight-test data will be used to simulate SAR images for a different collection geometry corresponding to another set of flight-test data. The SAR image from the second set of flight-test data will be registered to the simulated SAR data, and the accuracy will be demonstrated.

CONCLUSIONS

A space-based system for high-resolution topographic mapping would have to measure elevation on the order of tens of centimeters at a resolution of 1 m. In addition, collection would have to be at a range on the order of 1000 km for a contiguous area of the order of 100,000 km^2 within less than 2 weeks. The creation of such a capability would represent a significant technical achievement in the history of science and engineering. The impact of the capability would be revolutionary for both intelligent preparation of the battlefield and precision engagement.

The emergence of technology for high-resolution IFSAR has created the potential for such a capability to exist. The technical challenges, while not insurmountable, are significant. The Discoverer II Program has embraced these challenges with risk-reduction efforts. The success of these efforts will lead to the technology maturation needed for a space-based demonstration.

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