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MEASUREMENT OF SURFACE MICROTOPOGRAPHY USING HELICOPTER-MOUNTED STEREO FILM CAMERAS AND TWO STEREO MATCHING TECHNIQUES

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Abstract

A common problem in acquiring ground truth data for use in microwave interaction modelling is the capture of surface roughness data that are both sampled at distances comparable to a fraction of the microwave wavelength and extensive enough to represent the surface statistics in at least one resolution cell of the microwave remote sensor employed. This leads to a requirement for height measurements with sub-centimeter accuracy and tedious data reduction. Existing techniques such as electronic transits are usually inadequate for this purpose. Contact devices such as profilometers (templates) are by nature one-dimensional and cannot span the required distances. Aerial photogrammetry and interferometric methods suffer from a lack of the necessary resolution.

A technique has been developed for acquiring the necessary photogrammetric data using twin 70-mm film cameras mounted on a helicopter boom. The apparatus will be described and an estimate of the accuracy with which ground surface roughness can be characterized using this device will be given.

In order to facilitate the tedious data reduction process, either standard stereogrammetric techniques must be employed or new techniques developed. For this study both standard and crosscorrelation methods were used. Stereogrammetry will be compared with a completely automated image matching technique. Dense disparity images were generated from the helicopter stereo pairs. Using interior orientation parameters supplied by the camera manufacturers, and assuming that exterior orientation parameters remained constant between control target and test field photography, an extremely dense DEM for a test field has been derived. Results will be compared and accuracy estimates will be presented.

Introduction

In recent years, there has been an evolution in remote sensing investigations from largely qualitative, descriptive studies to more quantitative analyses involving transformation of the received data into geophysically meaningful quantities such as mineralogic composition, particle size distribution and surface roughness. Accordingly, recent successes in remote sensing using synthetic-aperture radar (SAR) such as Seasat and SIR, and the increasing number of planned SAR instruments (e.g., Magellan, Eos, and ERS-1), have led to efforts to understand the relationship between radar backscatter and the corresponding parameters which describe the characteristics of the surface causing the return. Radar backscatter from a surface is dependent on the roughness of the surface, the local incidence angle, the complex dielectric constant of the surface, and the wavelength and other characteristics of the incident radiation (Ulaby et al., 1982). For surfaces with moderate relief and whose electromagnetic properties are similar, the first effect dominates and the radar backscatter can be regarded as a measure of the surface roughness at or near the scale of the radar wavelength.

Many attempts have been made to quantify the relationship between surface roughness and radar backscatter (e.g., Farr and Engheta, 1983). These attempts have been hampered by lack of a practical means of characterizing the roughness of natural surfaces with sufficient accuracy and extent to match both typical resolutions and wavelengths of feasible SAR sensors. The surface under study must be sampled at intervals comparable to a fraction of the radar wavelength. It must also be measured over a large enough area to fully represent the surface height statistics in at least one resolution cell (preferably more) of the SAR employed. For typical systems this leads to a requirement for sampling surface height at sub-centimeter intervals in two dimensions for distances of several tens of meters. Electronic transits are inadequate for this purpose. Contact devices such as profilometers (templates) are by nature one-dimensional and cannot accurately span the required distances. On the other hand, fixed-wing aerial stereophotogrammetry suffers from lack of the required resolution and a costly data reduction process. Interferometric methods are either economically impractical or require platform location knowledge beyond the current state of the art.

A technique for acquiring the necessary data using airborne film cameras has been developed. Two co-boresighted 70-mm metric cameras with 100-mm geometrically calibrated lenses are attached to either end of a 6.2 m boom mounted longitudinally under a small helicopter. The cameras are remotely triggered from the passenger seat. Using Kodak Aerochrome 2448 film, and with a contrast ratio of 1.6, the resulting ground resolution is 7.5 mm when the helicopter flies at 30 m above local terrain. Field of view for the cameras is 20 m. The apparatus, originally built for the Canadian government, has been used in the Mojave Desert in California to photograph control targets and natural sites used in the Mojave Field Experiment to provide input for electromagnetic interaction models being developed at JPL. These models will provide the connection between radar backscatter, roughness, and dielectric constant.

Manual Data Reduction Technique

At this writing, images from one field site have been used to compare two data reduction methods. The first used a manual stereo measurement technique to derive height information. Positive transparencies from the cameras were mounted on a Kern Instruments DSR-11 Analytical Plotter. The optical axes of the cameras were assumed to be parallel and orthogonal to the stereo base, and scale was derived from stereo base altitude, which was determined from measurement of the image overlap. The plotter moved automatically to a predefined x-y point and the operator removed parallax, thereby measuring height. One-dimensional linear profiles were taken in each direction across the films at 5-cm spacing, digitizing one height measurement every 5 cm. The profiles were then combined into a DEM. Profiles were also successfully generated every meter at 1-cm spacing but were not used in this study.

Accuracy of the measurement depends on stereo acuity and the base-to-height ratio. Parallax measurement accuracy was about 6 micrometers on the film. Stereo disparity may be measured to within 0.5 pixel. Estimated error in the height measurements for these data is 3 mm at a camera height of 30 m when conditions were optimum. Under adverse conditions (which included lack of focus, platform motion, poor lighting and lack of surface texture), errors are estimated to be as high as 9 mm. Operator time for each point was less than 0.6 seconds, but operator fatigue prevented sustaining this rate for long periods. Stereo models such as those used here may be generated in 3 to 10 workdays. The speed of this technique can be greatly increased by measuring in a dynamic mode where the machine profiles the surface continuously, and the operator keeps the measuring mark on the surface. Loss of accuracy is estimated at 5 to 8 times in this mode, however a surface may be measured in 2.5 hours.

Automated Data Reduction

The second method employed to reduce the stereo data is a completely automated image-matching technique originally developed for generating very accurate and dense automated DEMs from SPOT satellite imagery (Muller, 1989; Muller et al., 1988a). Positive transparencies were digitized with a fixed pixel size of 16 micrometers using a stereo pair of RS170 CCD cameras mounted in a Kern DSR-11 Analytical Plotter. The Analog-to-Digital Converter (ADC) on an Imaging Technology framegrabber interfaced to a VaxstationII/GPX workstation used 8-bit quantization. These 512 x 480 pixel frames (equivalent to 8.192 x 7.68 mm on the film) were then radiometrically corrected for severe vignetting (Tadrowski, 1988) and mosaicked into an 8 x 7 abutted image.

The Otto-Chau stereo-matcher (Otto and Chau, 1988), based on a region-growing version of the adaptive least-squares correlation algorithm originally described by Gruen and Baltsavias (1988) is currently running on either a single Sun-3 workstation or using Remote Procedure

Calls (RPCs) on an ETHERNET of Sun-3 workstations using a task parallelism "farming" technique described in Muller et al. (1988a). The algorithm involves more than 10**5 floating-point operations per pixel per iteration of the least-squares adjustment process (loc. cit.) but usually converges within one or two iterations. This results in a single Sun-3 CPU execution time of approximately 0.2 seconds per patch of 15 x 15 pixels (the patch size chosen after extensive testing). The RPC-distributed version of the Otto-Chau algorithm reduced the execution time of around 32 days to about 7.5 days on five workstations on which there were three other stereo-matching jobs running. A user-selectable grid of 5 pixels was chosen to jump-step the patch in the region-growing process. Experiments currently in process using an array of transputers (Muller, 1989; Muller et al., 1988a) should reduce this computation time to a few hours on the 32 T800-4MB PARSYS (TM) Supernode installed at UCL. The speed-up could be increased by up to a factor of 32 if a Supernode of 1024 transputers were used.

For the stereo matching described here, tiepoints were generated manually using a digital stereo measurement system developed on a Sun workstation (Muller, 1988). Ten manually-determined tiepoints were determined to approximately 0.3 pixel and were then further refined (with several being rejected) by the Otto-Chau matcher. From 10 tiepoints, the stereo matcher generated 231664 matches out of a maximum possible 240000 points.

Using interior orientation parameters supplied by the camera manufacturers and assuming that exterior orientation parameters remained constant between a control target stereo-pair and this test site photography (as insufficient control targets were available within the field of view of the test site), image co-ordinates were transformed into ground co-ordinates. The extensive quality assessment performed for the Otto-Chau stereo matcher on SPOT-DEMs indicates accuracies to better than 0.3 pixel RMS (Day and Muller, 1988) which is equivalent to 1.5 mm in this photography.

Comparison of the Techniques

Topographic data from each technique were linear least-squares fit to remove mean values and trends due to unknown helicopter attitude and local terrain tilt. RMS roughnesses (i.e., standard deviation of the data from the best-fit plane) were then calculated for each. Results for the manual matching method show an RMS roughness of 6.53 cm. Comparison with a result of 7.55 cm for the automated method yields a relative difference of 16%.

The discrepancy includes the inherent errors in the two processes but is certainly dominated by the fact that the height field is mapped differently by the two techniques, as follows. The test site used for this study, an area of pahoehoe lava mantled by aeolian deposits drawn from nearby alluvium, was characterized as a part of the experiment. It is composed of solid material (quartz and basalt sand 61%, gravels 23%, cobbles 8% and bedrock or boulders 3%) and non-solid vegetation (creosote, low scrub and grasses with heights < 1 m 6%) (S. Bougan, personal communication). The automated technique will either extract heights over the canopy or will produce gaps in the matching process if the surface violates the implicit assumption of contiguity. By comparison, photogrammetric operators tend to use visual interpolation to extract the height of the underlying surface, except where the vegetation is dense enough to prevent observation of the surface. Thus it is expected that the automated technique will produce a higher estimate of the surface roughness than the manual technique, as observed here. At platform elevations typical of aerial photography this difference is insignificant, but as applied here it is not.

Implications for Radar Studies

The question remains, what roughness is sensed by the radar? At shorter wavelengths (e.g., X or C-band), the vegetation may present an opaque canopy, and at longer wavelengths (e.g., L or P-band) drier vegetation is probably penetrated and scattering by the underlying surface will dominate. Volume scattering by the individual components of the vegetation will also occur, except at the longest wavelengths. Its magnitude will depend on leaf and woody material size and moisture content, biomass, radar polarization, and other effects. Where volume scattering is significant, neither estimate of the roughness, nor indeed any surface scattering model, will account properly for the radar return. A more complete description of the scattering surface and volume will be required in order to properly model the interaction.

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