CURRENT APPROACHES TO THE PROBLEM OF SIDE-LOOKING RADAR MAPPING

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ABSTRACT

A camera measures angles and a photograph is a central projection. Radar measures distances and radar images are therefore range projections. Therefore, stereo model geometries are quite different between radar imagery and aerial photography. Contour compilation from radar can be made practical using similar techniques and orientation procedures that are used for conventional photogrammetry. The measuring principal is completely different. This paper discusses geometric corrections of side-looking radar images emphasizing the correction of radar layover geometry. Implementation is made on an AS-11AM analytical plotter with modification made to plotter software that is used for map compilation using panoramic photography.

I. INTRODUCTION

After World War II, side-looking radar (SLR) has been made available for the observation and interpretation of terrestrial and other planetary surfaces. It has a great potential for being developed as an all-weather mapping tool. Numerous photogrammetrists and mapping scientists such as La Prade (1963), Rosenfield (1968), Leberl (1976a) and others have made various developments and performed tests using SLR for mapping. No practical procedures have yet been established due to the limited mapping accuracies of radar (Leberl, 1977) which are mainly influenced by the unique radar geometry. This paper discusses geometric corrections of radar images. In order to make corrections to radar images, the first step is to understand radar imaging geometry.

II. RADAR IMAGING GEOMETRY

Radar is a ranging device which measures distances whereas a camera measures angles. In other words, a camera produces photographs based on a central perspective projection whereas a radar produces images in a range projection. All points on the ground which are at the same distance from the radar antenna will project into the same point. A mountain top and points at the base of the mountain will have a common image point if they are at the same distance. This phenomenon is generally called radar layover. Fiore (1967) defined it as equal-slant-range blur. High relief areas with high depression angles often result in layover geometry because the tops of high objects are closer to the antenna and will therefore be recorded before the bases of the objects. Radar layover is always displaced directly toward the antenna.

Layover geometry is one of the obstacles in the accomplishment of stereo models on photogrammetric stereo plotters which use the concept of central projection. However, since radar images are in range representation, layover geometry can be solved by trilateration, meaning that the position of ground objects can be determined by the intersection of the ranges (fixed-distance relationship) from two radar stations. The stereo geometry of an overlapped SLR model is therefore, based on the intersection of two ranges.
The SLR range measurement generates a sphere with origin at the radar station and radius equal to the slant range. Each radar view can be defined as a conical surface with a specific squint angle from the flight path. Side-looking radar usually scans in a perpendicular direction with a 90°

squint angle, the radar view then becomes a circular plane perpendicular to the flight path. The objects imaged lie on a circle with radius equal to the slant range. Two such range circles with origins at two antenna stations must intersect if each contains the same ground point. This is the basic geometric condition of stereo radar images. Therefore, the mathematics and geometry of radar stereo models is quite different from conventional photographic stereo models, although the stero plotting procedures can be similar.

III. CURRENT APPROACHES

Stereo radar compilation has been previously attempted. Norvelle (1972) had developed techniques and programs for proper mathematical modeling on an AS-11A analytical plotter through interior-, relative-, and absolute-orientation as in conventional photogrammetric procedure. Map manuscripts had actually been compiled using terrestrial radar imagery, but no anlaysis was performed on the mapping precision. Using Apollo Sounder and SEASAT images, Leberl (1976b, 1982) has experimented with compilation on an AP/C and a Kern stereo plotter. Leberl has also made both theoretical and empirical error analyses on stereo radar mapping (1979) but still no sound techniques as to modeling and compilation procedures have been established. For the Venus Radar Mapper (VRM) mission, the Photogrammetry Section of the Branch of Astrogeology, U. S. Geological Survey, at Flagstaff, AZ, has been continuing to conduct research and development in mapping, using side-looking radar images. Various approaches have been attemped (Wu, 1979, Wu et.al. 1980). The studies of stereo radar-mapping problems have advanced to a point where the radar layover problem can be mathematically solved (Wu, 1983).

The solution involves two equations, each of which represents a sphere (or a circle with a 90° squint angle) and relates the radar station and radar range to a ground point in each of a pair of overlapped radar images supplemented by a specific projection and rotation (Wu, 1983).

As shown in Fig. 1a, S_1 and S_2 are radar stations in, respectively, radar paths P_1 and P_2; R_1 and R_2 are ranges of ground point G measured normal to the radar paths, respectively, from S_1 and S_2. Equations (1) and (2) represent two spheres but equations (4) and (5) represent only 2 circles when H_G, the elevation of ground point G, is determined in terms of flight heights, ranges and depression angles as in equations (3), (6), and (7).

$$(X_G - X_1)^2 + (Y_G - Y_1)^2 + (H_G - H_1)^2 = R_1{}^2 \tag{1}$$

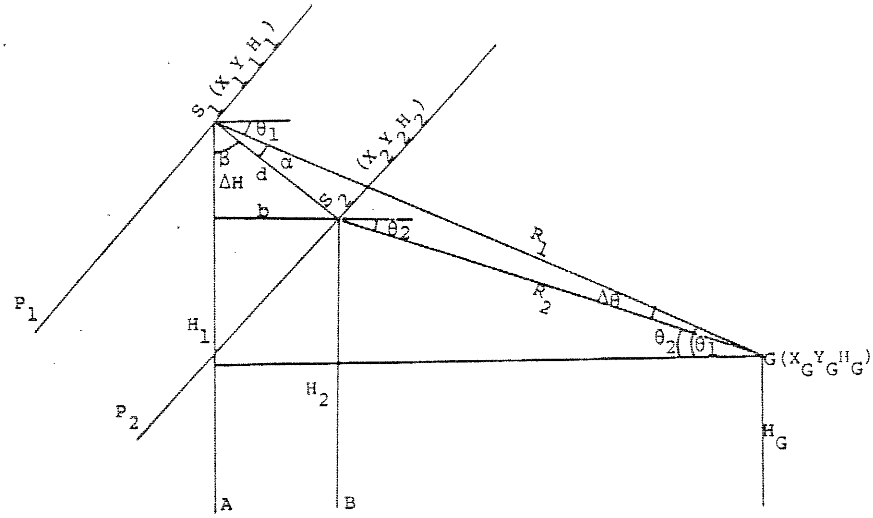
$$(X_G - X_2)^2 + (Y_G - Y_2)^2 + (H_G - H_2)^2 = R_2{}^2 \tag{2}$$

$$H_G - H_1 = R_1 \sin \Theta_1, \quad H_G - H_2 = R_2 \sin \Theta_2 \tag{3}$$

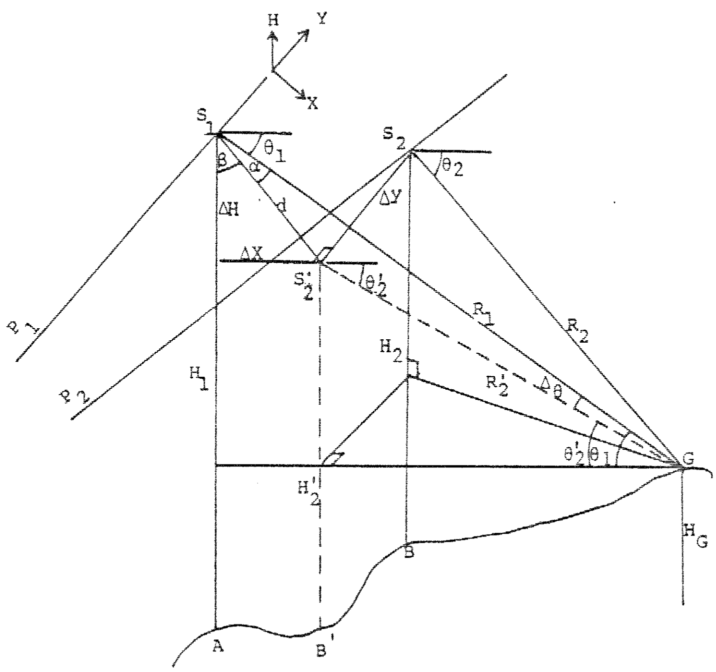
$$(X_G - X_1)^2 + (Y_G - Y_1)^2 = R_1{}^2 - R_1{}^2 \sin^2 \Theta_1 = (R_1 \cos \Theta_1)^2 \tag{4}$$

$$(X_G - S_2)^2 + (Y_G - Y_2)^2 = R_2{}^2 - R_2{}^2 \sin^2 \Theta_2 = (R_2 \cos \Theta_2)^2 \tag{5}$$

Where, $\Theta_1 = 90° - (\alpha + \beta)$,



(a) Special case: Vertical planes of both radar looks are coincident.



(b) General Case: Vertical planes of both radar looks are not coincident.

Figure 1 - Solution of radar-layover problem. (S_1 and S_2 are two stations along radar paths P_1 and P_2, from which ground point G is measured and recorded. Θ_1, Θ_2, and R_1, R_2 are depression angles and ranges, respectively, of radar stations S_1 and S_2.)

$$\alpha = \cos^{-1}\left[\frac{R_1^2 + d^2 - R_2^2}{2R_1 d}\right]$$

$$\beta = \cos^{-1}\frac{\Delta H}{d} = \sin^{-1}\frac{b}{d}$$

$$d = (\Delta H^2 + b^2)^{1/2}$$

$$\Delta H = H_1 - H_2$$

$$b = [(X_1 - X_2)^2 + (Y_1 - Y_2)^2]^{1/2}$$

$$\Theta_2 = \Theta_1 - \Delta\Theta \qquad (7)$$

$$\Delta\Theta = \cos^{-1}\left[\frac{R_1^2 + R_2^2 - d^2}{2R_1 R_2}\right]$$

By solving simultaneous equations (4) and (5), i.e., by determining ground coordinates X_G and Y_G of a ground point, and combining with the elevation H_G, which is obtained by taking the average of the two equations in (3), the plotter computer will command the stage plates to displace radar images as though the images were taken by conventional aerial photography so that the stereo model can be retained for photogrammetric measurements.

In the general case, the two vertical planes of the two radar look directions do not coincide, as shown in fig. 1b. Then the solution to the radar-layover problem is, first, to project the plane S_2BG normally onto plane S_1AG, so that the vertical plane S_2BG is in the vertical plane S_1AG, becoming plane $S_1AB'GS_2'$.

$$R_2' = (R_2^2 - \Delta Y^2)^{1/2} \qquad (8)$$

If the model coordinate system is rotated to the P_1S_1 system, then $Y_2' = Y_2 - \Delta Y$, $H_2' = H_2$, and $b = \Delta X = X_2 - X_1$. The rest of the parameters are determined by using the same procedures as are used in the special case (coplanearity of S_1, S_2 and G).

Based on this solution of the radar geometry, algorithms are implemented with the modification of plotter software on the upgraded AS-11AM analytical plotter.

Modification is made to existing software used for map compilation from panoramic photography on the analytical plotter which also has a type of line scan geometry. Stereo radar compilation will then be performed using practically the same procedures, i.e., interior orientation, relative orientation and absolute orientation, that are used in conventional photogrammetry. Since stereo radar is to derive terrain topography from the radar time (along-track) and range (cross-track) coordinates, the interior orientation is to convert radar image x and y coordinates to time, t, and range, r, by interpolation from polynomials formed by time marks along the track and range marks across the track. This in turn will determine position and the range of the two radar antenna stations. Layover correction will then be made so that stereo model will be retained after relative orientation is established. With ground control points, the absolute orientation relates radar image x and y coordinates to ground X, Y and Z coordinates of terrain object points.

As the origin of the image coordinate system, the principal point can be put anywhere on the radar image, but is usually chosen to be at the near-range-side edge with the Y-axis representing the flight direction to form a right-hand coordinate system. Other corrections such as curvature and model deformation already exist in the plotting software.

Since software modification is still in progress, there are no results yet to be reported. Once software modification on the AS-11AM analytical plotter is completed, and if good results are obtained, the next step is to apply the modified software to the AS-11B1 analytical plotter. Combined with the capability of image correlation on the AS-11B1 plotter, stereo models of side-looking radar images should be retained very well.

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