RADAR REFLECTANCE MODEL FOR THE EXTRACTION OF HEIGHT FROM SHAPE FROM SHADING TECHNIQUE

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Abstract

The shape-from-shading (SFS) technique deals with the recovery of shape of an object through a gradual variation of shading encoded in the image. Most SFS approaches have assumed Lambertian surface to extract DEM from individual images. The quality of the derived DEM from radar SFS in particular, depends on the appropriate radar reflectance model, which relates the radar backscatter to the surface normal.This paper will focus on a new reflectance model for relatingthe radar SAR backscatter coefficient values to surface normal orientation. An iterative minimization SFS algorithm was implemented using this radar reflectance model to derive the height measurements.The most important key of derivation of the surface height using this model is forward and inverse Fast Fourier Transform (FFT). The model performance was evaluated on RADARSAT-1 image using both graphical and statistical analysis. Root mean square error (RMSE) and coefficient of determination (R^2) were used as evaluation criteria for the model performance. The model has shown good performance in reconstructing surface heights from RADARSAT-1 imagery. It gave 17.47m and 97.2% for RMSE and R^2, respectively.

Keywords:*3-D, SFS, Remote Sensing, Radar Remote Sensing, Satellite Images, SAR Imageries.*

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INTRODUCTION

Despite a great deal of information that can be obtained using multiple images, restricted attention to a single image is to avoid difficulties and cost that are inherent with the use of multiple images.Shape from shading (SFS) deals with the process of finding the object's 3D shape from a single image of that object. The recovered surface can be expressed in four types (Durou et al. 2008) :surface height (elevation), normal, slope, and slant and tilt.

Ghayourmanesh and Zahng 2008mentioned that success in SFS depends on two factors. The first one is a suitable imaging reflectance model (also known as "reflectivity function"), and the second is a good numerical algorithm to recover the shape of an object from a given image.The simple model of image formation is the Lambertian model, in which the gray level of a pixel in an image depends only on the light source direction and the surface normal. Several studies investigating Lambertian reflectance model have been carried out on SFS(Wilson and Hancoc 1999, Hongxing 2003, andPrados and Faugeras 2005). The general solution for SFS problem under Lambertian model is given by Equation 1 below.

$$E(x,y) = \hat{n}(x,y).\hat{S}(x,y,z) \tag{1}$$

where E(x,y) is the image irradiance at a point (x,y), $\hat{n}$ represents the three components of surface normal vector (*p, q, -1*) and $\hat{S}$ represents the three components of light source direction (S_x, S_y, S_z).

Unfortunately, Lambertian model is not suitable for representing the relationship between radar backscatter coefficient and the surface orientation or incident angle. This is because the radar backscatter coefficient depends on different physical parameters.Bors et al. 2003have shown that the radar reflectance map can be affected by: 1) physics of radiation-material interaction, 2) the type of terrain, 3) the presence of vegetation or man-made objects, 4) the level of humidity, 5) the radar beam wavelength and polarization, and 6) the process of SAR image acquisition. To obtain a confident results from radar SFS, the radar reflectance model must be determined precisely. Reflectivity model for radar SFS has attracted considerable interest. Wilson and Hancoc 1999have analyzed the reflectance characteristics of sample SAR data to estimated empirical radar reflectance function using the distribution of observed radar intensity with incident angles. In order to avoid the impossibility of classic assumptions of SFS, Hégarat-Mascle et al. 2005 replaced the traditional Lambertian model by a backscattering diagram provided by the integral equation model (IEM).

METHODS

a. Study area

The study area is the Kassala state in the east of Sudan. The area is comprised of water body, mountain, vegetations, and man-made buildings and roads. Therefore, the surface topography and reflectivity materials of the area are relatively complex.

b. Data

The data sets for this study consist of subset of RADARSAT-1 imageryand different sets of Ground Control

Points (GCPs). The subset of RADARSAT-1 imagery, depicted in Figure 1 is Standard 7 (S7) mode. The purpose of choosing this subset was that it contained sufficient features to analyze and evaluate the performance of the algorithm. These features include building, vegetation, water body and mountain as mentioned above. Thus, they provided a complex surface presentation, having a wide range between minimum and maximum surface elevations. It is interesting to note that the highest height values of mountain are located in the center of the figure. The real height values of minimum and maximum are found to equal 400m and 1040m, respectively.

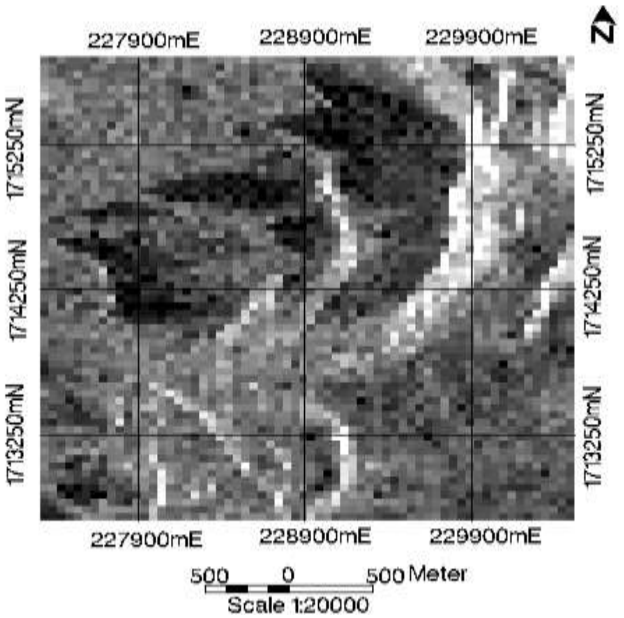

Figure 1: Subset of RADARSAT-1 S7 Mode Image

c. Methodology

The properties of a surface determine the variations of radar backscatter values on an image. Characterization of these properties and the relationship between the image and surface orientation can be provided by the reflectance map. In this study, a new model represented by Equation 2 was developed for radar reflectivityinstead of Lambert's model. Accordingly, an iterative minimization radar SFS algorithm was applied to SAR image for the extraction of the height. It is interesting to note that thisalgorithm is a further development of Hongxing 2003SFS algorithm, which has been applied to optical remote sensing using Lambert's reflectance model.

$$R = \frac{\dfrac{p.s_x + q.s_y + s_z}{\sqrt{1+p^2+q^2}\sqrt{{s_x}^2+{s_y}^2+{s_z}^2}}}{\left[1-\left(\dfrac{p.s_x + q.s_y + s_z}{\sqrt{1+p^2+q^2}\sqrt{{s_x}^2+{s_y}^2+{s_z}^2}}\right)^2\right]^{\frac{3}{2}}} \qquad (2)$$

A program for an iterative minimization radar SFS model was developed in MATLAB version R2008b. The input for the program was the RADARSAT-1 and the output was a two-dimensional array of heights for individual pixels. The output was available in many formats and could be manipulated using most Geographic Information Systems (GIS) and image processing software packages.

RESULTS AND DISCUSSIONS

The iterative minimization SFS algorithm was applied to RADARSAT-1 subset image (Figure 1) corresponding to Kassala area in the east of Sudan. Lambert's reflectance model and the proposed radar reflectance model represented by Equations 1 and 2, respectively were involved in SFS algorithm. The range of the real absolute surface heights of this subset lies between approximately 400m to 1040m. Also, the highest values of elevations are located in the center of this subset.For all results, the evaluation of the accuracy was carried out qualitatively and quantitatively by comparing the heights reconstructed from the previous and the proposed models with the real heights. Some 123 ground control points (GCPs) were used for this purpose.

Figure 2 shows the absolute height reconstructed using the new reflectance model (Equation 2). The average range of overall absolute surface heights of this figure lies between approximately 393m and 1009m. Compared to that of the ground truth, there is a significant positive correlation between them. Another finding is that the average elevation of the points in the middle of the figure is approximately 1009m. This finding supports previous information reported for Figure 1, that the highest values are located in the centre of the figure. In contrast, the range of the absolute heights reconstructed by Lambert's model (Figure 3) was between approximately 420m and 900m. Also, the average absolute height value of the middle area is approximately 700m.

Finally, Figure 4 shows a significant improvement of surface height reconstructions resulted from applying the new radar reflectance model represented by equation 2. The graph shows that there is a strong relationship between the developed reflectivity (red), and that of the real (black). The range of the Lambert curve (green) is narrower than those of the real and new radar model. The respective peak points of the curves, representing the highest frequency values, are approximately 640m, 730m, and 730m for Lambert, real and new model. Their corresponding frequencies are about 33, 17, and 18 for Lambert, real, and the new model, respectively. Compared to the Lambert's reflectivity, the results of the new reflectance model is more accurate significantly.

In order to assess the accuracy of the recovered height numerically, RMSE and R^2 values were calculated for both reflectance models. As shown in

Table 1they are: 56m and 0.44, and 17.47m and 0.972 for Lambert and the proposed models, respectively. As indicated by *RMSE* and R^2 values, the surface topography reconstructed by the new reflectance model is numerically more stable and robust rather than that from Lambert's model.

Table 1: RMSE and R^2 for Lambert and the Proposed Models

Model	RMSE (m)	R^2
Lambert	56.8	0.44
Proposed	17.47	0.972

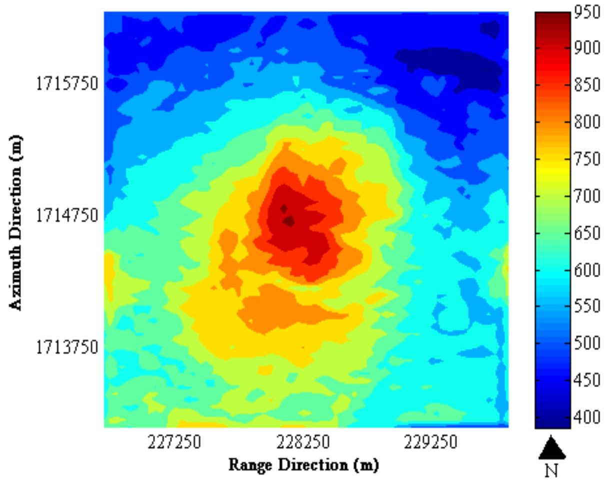

Figure 2: Filled Contour Plot of Absolute Heights from New Model

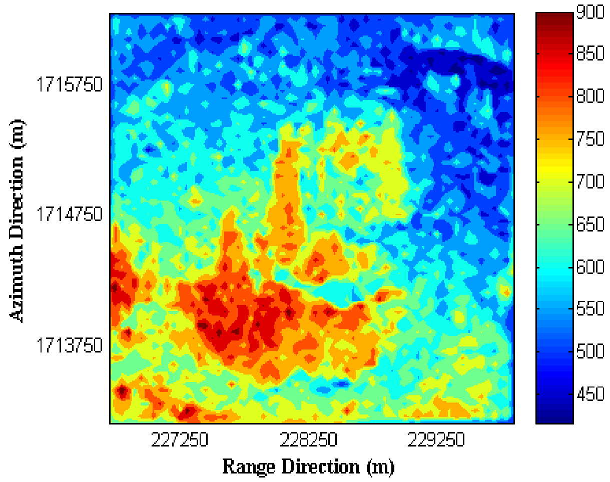

Figure 3: Filled Contour Plot of Absolute Heights from Lambert Model

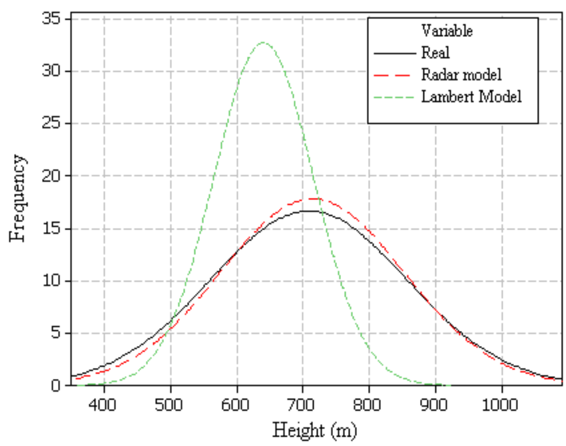

Figure 4: Improvement of Height from Developed Radar Reflectance Model

The impact of the proposed radar reflectance model on the results obtained from the radar SFS algorithm was studied and analyzed. The presented results indicate that the new radar reflectance model has improved the accuracy of the final absolute height measurements. Compared with the findings of the Lambert's model, the new radar reflectivity is much better and significant. These results may be explained by the fact that the nature of the surface under study is heterogeneous, meaning essentially a heterogeneous target. This implies that the radar backscatters are dominated by many parameters such as reflectivity materials, surface roughness and moisture, angle of incident, and other parameters. In such surfaces, SFS algorithms cannot give accurate results using Lambert's reflectance model.

CONCLUSION

The basic assumption underlying SFS techniques is the Lambert reflectance model for image formation. Unfortunately, this assumption is not valid for radar imageries. Thus, considering the incident angle as the most important factor in radar backscatter, a new radar reflectance model was developed for 3D acquisition using SFS technique. The most important finding of this research is that the developed radar reflectance model has a significant effect on the accuracy of the absolute surface height. This is clear from the validation results obtained from the developed radar reflectivity model when compared to that of Lambert. RMSE and R^2 of the absolute heights of 17.47m and 97.2% achieved by the former were much better compared to 56.8m and 43.5% achieved by latter model. At the same time, the quality of height reconstructions using the developed reflectance model also improved through reduction of distortions.Durou et al. 2008

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BIOGRAPHIES

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