

# IMPLEMENTATION OF A SINGLE PHOTO SHAPE FROM SHADING METHOD FOR THE AUTOMATIC DTM GENERATION

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**KEY WORDS:** Shape from shading, DTM/DEM, Surface reconstruction, Digital photogrammetry, Radiometric surface model, Image analysis.

## ABSTRACT:

This research work is concerned with the implementation of a shape from shading (SFS) technique for automatically generating a digital terrain model (DTM) using a single digitized aerial photograph of a terrain area with low signal (information) content. The mathematical model for the SFS is established based on the fact that the pixel's gray level variations in image space are proportional to the shading intensity variations of the terrain morphology. The terrain shades in its turn is the function of the illumination intensity and the direction of the incident light with respect to the local surface orientation as well as the incident light direction and the terrain albedo. In this project the Lambertian model is utilized for modeling the terrain reflectivity property. The implemented SFS algorithm is then tested with the simulated and the real data. The simulated data was generated using a predefined bilinear surface and for the real data, an aerial photograph of a smoothed hilly terrain with low information content was chosen. The rmse for the reconstructed surface for the simulated data and the real data were estimated to be equal to  $\pm 3$  cm and  $\pm 4$  m respectively. This means that the gray shade values are also significantly influenced by the other factors such as the non-uniform terrain albedo, atmosphere, etc., which have not been included into our SFS functional model. It should also be mentioned that our implemented SFS model for the real data was accompanied by a preprocessing stage by which the influential noise was significantly reduced.

## INTRODUCTION

Digital image matching is a automatic method for the reconstruction of object surface information from the gray values of digital images. For the automatic derivation of object heights it is usually necessary to estimate the positions of conjugate points in all images. A necessary prerequisite to obtain a reliable solution when performing digital image matching is the presence of sufficient, non-periodic image texture. However, not all images fulfill this demand. Furthermore, if only a single image of the object is available, digital image matching can not be applied. It is necessary to investigate surface reconstruction method which allow for the estimation of object surface parameters from images with poor texture and from single images. Shape from shading(SFS) is one of these methods, that it directly relates image gray values to inclination of the corresponding surface patch relative to the direction of illumination and direction to the imaging sensor. Shape from shading has been investigate in different research area: Computer Vision, Photogrammetry and Astrogeology. In Computer Vision SFS has been developed for surface reconstruction in close range images(e.g. Zhang et al., 1999; Tsai and Shah, 1994; Lee and Kuo 1993)and in Photogrammetry, SFS has been studied for DTM reconstruction or refinement (Heipke et al. 2000 ). In the field of Asterogeology, SFS has been developed for the geometric

reconstruction of planetary surfaces(Davis and Soderblom 1984).

This paper is concerned with the implementation of a SFS technique for automatically generating a digital terrain model(DTM) using a single digitized aerial photograph of a terrain area with low signal(information) content.

## SHAPE FROM SHADING

The mathematical model for the SFS is established based on the fact that the pixel's gray level variation in image space are proportional to the shading intensity variations of the illumination intensity and the direction of the incident light with respect to the local surface orientation as well as the direction of the incident light direction and the terrain albedo. In classical SFS the reconstruction of surface slopes is ambiguous, because there is only one gray value observation per surface element while surface orientation has two degree of freedom. A solution, however, can be obtained by introducing various surface constraints (Zhang et al., 1999). Another possibility to overcome this ambiguity is the introduction of a radiometric and a geometric surface model.

## Radiometric Model

The radiometric model creates the relation between the image gray values and the corresponding surface patches. The image gray values are influenced by the radiance and wavelength of the incident illumination, atmospheric effects, surface reflectance properties and sensor characteristics.

The basic equation of SFS is derived by assuming a constant albedo ( $A$ ) and lambertian reflectance properties for the whole surface. In this case, the gray value  $G(x', y')$  at the position  $x', y'$  in image space only depends on the angle between illumination direction  $\vec{S}$  and the surface normal vector  $\vec{v}$  (fig1):

$$G(x', y') = A \cdot \cos(\vec{N} \cdot \vec{S}) \quad (1)$$

$$= A \cdot \frac{-n_x s_x - n_y s_y + s_z}{\sqrt{n_x^2 + n_y^2 + 1}}$$

Where:  $\vec{S} = [s_x, s_y, s_z]$   
 $\vec{N} = [-n_x, -n_y, 1]$

In the lambertian model the surface looks equally bright from every viewing direction.

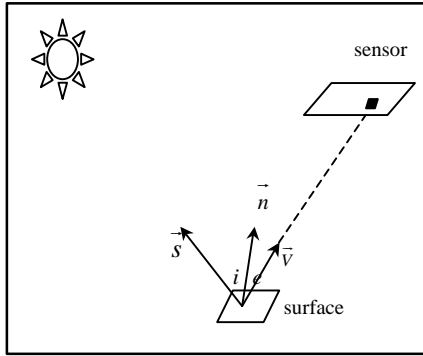


Figure 1: principle of image formation

Another law that is good description of the light scattering behavior of low-albedo surfaces is the lommel-seeliger law. In this model the radiance observed at a sensor comes from light scattered by all particles in the medium lying within the the field of view of the sensor:

$$G(x', y') = A \cdot \frac{\cos i}{\cos i + \cos e} \quad (2)$$

## Geometric Model

In SFS, the geometric model describes a piecewise smooth surface. The geometric model consist of a DTM grid. The grid

nodes is defined by  $X_k, Y_l, Z_{k,l}$ . The mesh size of the grid depends on the roughness of the terrain. A height  $Z_i$  at an arbitrary position  $dX, dY$  is interpolated from the neighbouring grid heights, e.g. by bilinear interpolation :

$$Z_i(X, Y) = Z_1 + (Z_2 - Z_1)dX + (Z_3 - Z_1)dY + (Z_1 - Z_2 - Z_3 + Z_4)dXdY \quad (3)$$

Where:

$Z_1, Z_2, Z_3, Z_4$  : heights of the neighbouring grid

Then,

$$n_x(Z_i) = \frac{\partial Z(X, Y)}{\partial X} = (Z_2 - Z_1) + (Z_1 - Z_2 - Z_3 + Z_4)dY \quad (4)$$

$$n_y(Z_i) = \frac{\partial Z(X, Y)}{\partial Y} = (Z_3 - Z_1) + (Z_1 - Z_2 - Z_3 + Z_4)dX \quad (5)$$

The observed gray value(eq. (1),(2))become a function of the mesh height  $Z_{k,l}$  and the albedo .

## Observation Equation

If the light source direction, the interior and exterior orientation are assumed to be known quantities, the  $Z_{k,l}$  and  $A$  are treated as unknowns. Subsequently, each object surface element is projected in to image space using the collinearity equations of photogrammetry and initial values of grid nodes height  $Z_{k,l}$ .

Next, the observed grey value  $g(Z_{k,l})$  is resample for resulting position. The corresponding observation equation read:

$$V_j = G(Z_{k,l}, A) - g(Z_{k,l}) \quad (6)$$

One such equation can be formulated for every object surface element projected into every available image. The unknowns are then computed in an iterative least squares adjustment.

## IMPLEMENTATION

The implementation SFS algorithm is tested with the simulated and the real data. In this research work, the lambertian model is utilized for modeling the terrain reflectivity property. It is very difficult to choose good test image for SFS algorithms. A good test image must match the assumptions of the algorithms, e.g. lambertian reflectance model, constant albedo value. It is not difficult to satisfy these assumptions for synthetic image. In

real image, there will be errors to the extent that these assumptions are not matched.

In this research, simulate data was generated using a predefined bilinear surface and for real data an aerial photograph of a smooth hilly terrain with low information content was chosen.

### Surface Reconstruction Using Synthetic Image

Synthetic image in scale of 1:40000 was generated by a ray-tracing algorithm, using the synthetic DTM, together with a constant value for the surface albedo.

The exterior orientation of the image and light source position were considered as known values. The unknown mesh heights were reconstructed in a least squares adjustment according to eq.(6). The RMSE for the reconstructed surface was estimated to be equal to 3cm.

### Surface Reconstruction Using Real Image

One black and white aerial image with an image scale of approximately 1:40000 of poorly texture area in Iran was used(fig.2). The image was digitized using photogrammetric scanner with a pixel size of 14 $\mu$ m, resulting in a ground sample resolution of about 0.56m. The interior and exterior orientation were determined using digital stereo plotter. The illumination direction was calculated from known time of the image acquisition and geographical coordinates of surface area. The maximum height difference within the chosen test area is about 50m.



Figure 2: Digitized aerial image

For this area a DTM with a mesh size of 3m was measured analytically(fig.3). Then average albedo value was estimate from the digital image by considering the measured DTM.

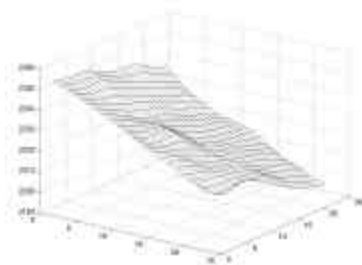


Figure 3: Perspective view of the reference DTM

The RMSE for the reconstructed surface for this image was estimated to be equal to 4m.

It should also be mentioned that our implemented SFS model for the real data was accompanied by a preprocessing stage by which the influential noise was significantly reduced.

The results show the gray shade values are also significantly influenced by the other factors such as the non-uniform terrain albedo, atmosphere, etc. which have not been included into our SFS functional model.

## CONCLUSION

Shape from shading has been investigated using two different data: synthetic and real data. DTM heights were determined from aerial images of poor texture. The RMSE for the reconstructed surface for the simulated data and the real data were estimated to be equal to 3cm and 4m respectively.

The result for the real image shows that the lambertian reflection does not sufficiently describe surface reflectance properties. Surfaces with unknown and varying albedo must be considered. This can be formulated within the frame of multi image shape from shading.

There are several possible directions for future research:

- Reflectance models used in SFS method are too simplistic. Recently, more sophisticated model has been proposed(e.g.Clark, 1992). This not only includes more accurate model for lambertian but also includes replacing the assumption of orthographic projection with perspective projection which is a more realistic model of cameras in the world..
- Another direction to improve the results of SFS is the combination of shading with some other techniques, such as: image matching, shape from shadow and etc. or use the results of SFS to improve the results of other techniques.

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