

Shape Reconstruction of Fracture Surface for HSLA Materials using Photometric-Stereo Images

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ABSTRACT

Shape from photometric stereo images is a method of constructing 3D shape of a 2D image of any scene using its multiple images. It recovers shape from multiple images of the same scene generated using a fixed viewing direction and the different light source direction. In this work we have considered only two images- left image and right image of fracture surface of High Speed Low Alloy (HSLA) material. The images used in this paper are captured using Scanning Electron Microscopes (SEMs). We have presented a very simple approach to recover the shape from photometric stereo-images -using features matching algorithm.

Keywords

Shape-from-shading (SFS), Stereo-image, gradients, laplacian, tilt angle, depth.

1. INTRODUCTION

The goal of the shape recovery is to derive a 3-D scene description from one or more 2-D images [1]. The two main technique involved are Shape-from-shading (SFS) and Shape-from-photometric-stereo. SFS deals with the recovery of shape from a gradual variation of shading in the image. Shape-from-photometric-stereo recovers shape from multiple images of the same scene generated using a fixed viewing direction and the different light source direction.

In this paper we are presenting the work where we have recovered 3D shape of the fracture surface using Stereo images. We have assumed that the object has uniform reflecting properties, the light sources and the viewer are very distant and the surfaces are considered to be pure Lambertian.

Stereo images of the fracture surface are initially preprocessed using median filters to remove the salt and pepper noise. Then the left and right images are aligned along X-axis and Y-axis. For each of the pixel in an image various features are calculated and the features of the pixel in left image are matched with the features of the corresponding pixel and its neighboring pixels in right image. The minimum distance between the two similar pixel values that belongs to left image and right image are then calculated and mapped to determine the z-value (depth) of the stereo images. The entire process of recovering shape is given below in figure 1.

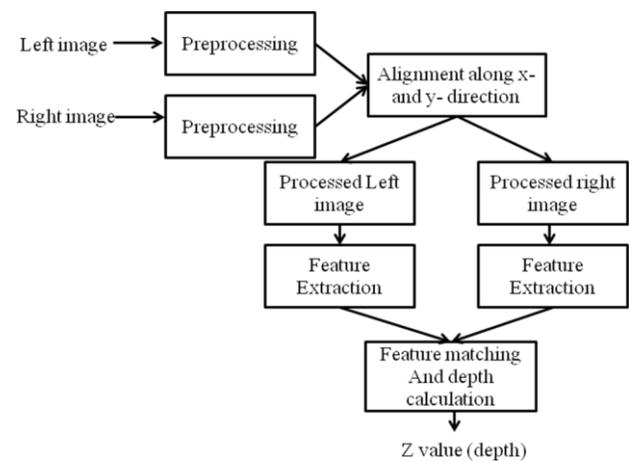


Figure 1: Process of recovering shape from photo metric stereo images of fracture surfaces.

2. RELATED WORKS

Many works have been done to process the given the 2D image using many techniques. The Shape from Shading (SFS) Technique was first developed by B K P Horn in early 1970s, and since then many approaches have been emerged. SFS techniques can be divided into four groups: minimization approach, propagation approach, local approach and linear approach. Minimization Approaches find the solution by minimizing an energy function. One of the earlier minimization approaches, which recovered the surface gradients, was by Ikeuchi and Horn [2]. Brooks and Horn [3] minimized the same energy function, in terms of the surface normal. Frankot and Chellappa [4] enforced integrability in Brooks and Horn's algorithm in order to recover integrable surfaces (surfaces for which $zxy = zyx$). Propagation Approaches propagate the shape information from a set of surface points (e.g. singular points) to the whole image. Horn's characteristic strip method [5], [6] is essentially a propagation method. A characteristic strip is a line in the image along which the surface depth and orientation can

be computed if these quantities are known at the starting point of the line. Bichsel and Pentland [7] proposed a minimum downhill approach for SFS which converged in less than ten iterations. Local Approaches derive shape based on the assumption of the surface type. Pentland's local approach [8] recovered shape information from the intensity, and its first and second derivatives. He used the assumption that the surface is locally spherical at each point. Under the same spherical assumption, Lee and Rosenfeld [9] computed the slant and tilt of the surface in the light source coordinate system using the first derivative of the intensity. Linear Approaches compute the solution based on the linearization of the reflectance map. Pentland [10] used the linear approximation of the reflectance function in terms of the surface gradient, and applied a Fourier transform to the linear function to get a closed form solution for the depth at each point. Tsai and Shah [11] applied the discrete approximation of the gradient first, then employed the linear approximation of the reflectance function in terms of the depth directly. Their algorithm recovered the depth at each point using a Jacobi iterative scheme. Chen [12] has present an improvement on the integration of gradient data obtained by the photometric stereo method, which is achieved using a zero padding approach for interpolation in the frequency domain. Lee et al. [13] have proposed an iterative algorithms for shape reconstruction based on multiple images taken under different lighting conditions. They have determined the surface height by minimizing a quadratic cost functional, which is defined to be the square of the brightness error obtained from each individual image in a parallel or cascade manner. Hertzmann et al. [14] have proposed technique for computing the geometry of objects with general reflectance properties from images.

3. STEREO IMAGES USED

The stereo images used in this work are of a fracture surface of HSLA materials with a magnification (M) of 250 and tilt angle (θ) of 8 degrees using SEMs. The images were taken in National Metallurgical Laboratory, Jamshedpur, India. The stereo images are given below in figure 2.

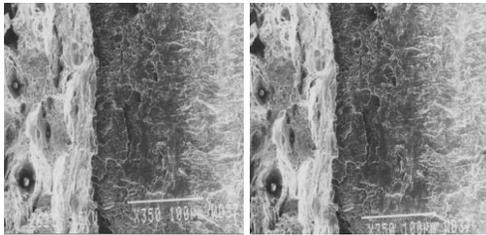


Figure 2: Left and right images of fracture surface.

4. ALIGNMENT ALONG X-AXIS AND Y-AXIS

The 3D Shape recovery from a stereo image highly depends on proper alignment technique. In our work, we have chosen the

simplest alignment technique where the processed images were first binarized by selecting a threshold value appropriate for the particular image. A binarized image $g(x, y)$ is defined as

$$\begin{aligned} g(x, y) &= 1, \forall f(x, y) > T \\ g(x, y) &= 0, \forall f(x, y) \leq T \end{aligned} \quad (1)$$

A global thresholding technique was applied for selecting the value of T. Density of the black pixels in each row and column of the 2-D image were plotted to form a histogram along X-axis and Y-axis.

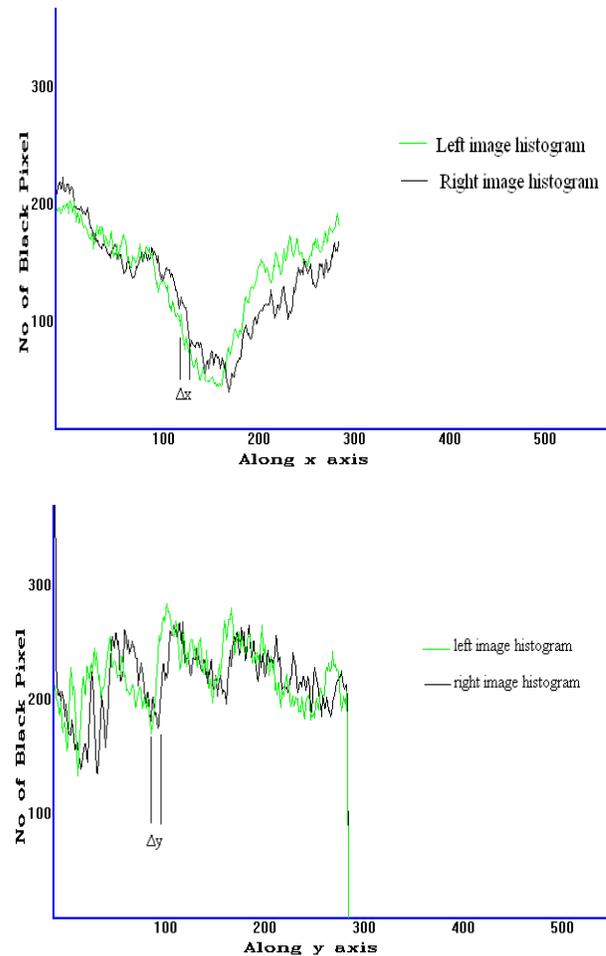


Figure 3: Histogram of stereo images along X-axis and Y-axis.

The deviation Δx and Δy is computed along X-axis and Y-axis. The original stereo images is then aligned keeping left image fixed and transforming the right image along x-axis and y-axis.

5. FEATURES EXTRACTION AND MATCHING ALGORITHM

For each pixel in left and right images Feature Set (FS) comprising of six various features listed below are obtained. The Feature Set (FS) is defined as

$$FS = (F_1, F_2, F_3, F_4, F_5, F_6) \quad (2)$$

where F1 is an intensity, F2 is X-gradient, F3 is Y-gradient, F4 is gradient magnitude, F5 is gradient orientation and F6 is Laplacian value respectively.

5.1 F₁ (Intensity):

It is an amount of received light energy in individual pixel as the result of interaction among the various materials and the light source.

$$F_1(x, y) = f(x, y) \quad (3)$$

where f(x, y) is an intensity value.

5.2 F₂ (X-gradient) and F₃ (Y-gradient):

The gradient of an image intensity function is at each image point a 2D vector with the components given by the derivatives in the horizontal and vertical directions. At each image point, the gradient vector points in the direction of largest possible intensity increase, and the length of the gradient vector corresponds to the rate of change in that direction. The gradient of image intensity function is defined by n expression

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (4)$$

The Sobel operator represents an approximation of the image gradient where the difference between the third row and the first row approximates the derivative in the x-direction, and the difference between the third column and the first column approximates the derivative in the y-direction.

Sobel Operator to calculate X-gradient is defined by

$$F_2(x, y) = \sum M \times f(x, y) \quad (5)$$

where M is defined by 3 x 3 mask shown below

-1	-2	-1
0	0	0
1	2	1

Sobel Operator to calculate Y-gradient is defined by

$$F_3(x, y) = \sum M \times f(x, y) \quad (6)$$

where M is defined by 3 x 3 mask shown below

-1	0	1
-2	0	2
-1	0	1

5.3 F₄ (Gradient Magnitude):

A gradient magnitude operator detects the amplitude edges at which pixels change their gray-level suddenly. It is defined by

$$\text{mag}(\nabla f) = \left[G_x^2 + G_y^2 \right] = \left[\left(\frac{\partial f}{\partial x} \right)^2 + \left(\frac{\partial f}{\partial y} \right)^2 \right]^{\frac{1}{2}}$$

i.e.

$$F_4(x, y) = \sqrt{F_1(x, y)^2 + F_2(x, y)^2} \quad (7)$$

5.4 F₅ (Gradient Orientation):

If F₂(x, y) and F₃(x, y) are the outputs of x and y derivative operators, then the gradient orientation or direction is calculated by

$$F_5(x, y) = \arctan \left(\frac{F_2(x, y)}{F_3(x, y)} \right) \quad (8)$$

5.5 F₆ (Laplacian Value):

It uses a second order derivative which can be expressed as follows

$$\nabla^2 f \cong \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \quad (9)$$

Simplifying the above equation and incorporating the diagonals directions in the above equation yields the following expression.

$$F_6(x, y) = \sum M \times f(x, y) \quad (10)$$

where M is defined by by 3 x 3 mask shown below

0	-1	0
-1	4	-1
0	-1	0

In Stereo images, the pixel value in right image is deviated by a minute distance corresponding to the pixel in left image. The above six features for each pixel in left and right image are calculated. Then, a window of size n x n is navigated in right image to match the feature $F_i(x, y)$ of a pixel $f(x, y)$ in left image with every feature $F'_i(x, y)$ in the navigated window. The navigation window is chosen keeping in view the pixel value $f(x, y)$ of the left image can be located at nearby pixel of neighboring area in right image. The navigation window and the deviated pixel value $f'(x, y)$ for corresponding pixel $f(x, y)$ of left image is shown below in figure 4 in right image.

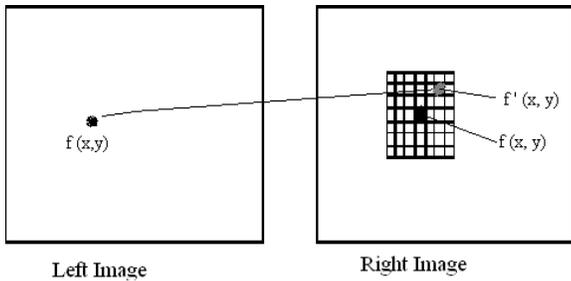


Figure 4: Navigation window in right image of a pixel $f(x,y)$ in left Image

Since the pixel value deviated will have similar feature in left image and right image, the Euclidean distance between feature set of left and right image is calculated. The minimum Euclidean distance between the features set of left and right image will give approximation of the deviated pixel in right images.

The relative distance along x-axis, ∂x is then obtained as difference between X value of left and right images where minimum Euclidean distance, Ed is achieved.

$$Ed(j, k) = \left(\sqrt{\sum (F'_i(x + j, y + k)^2 - F_i(x, y)^2)} \right)$$

$$\partial x = x_{\text{right}} - x_{\text{left}} \text{ for } \min(Ed(j, k)) \quad (10)$$

where $0 \leq (j, k) < n$

6. DEPTH CALCULATION

In order to calculate the depth value of every pixel value $f(x, y)$, ∂z , of a stereo images we have used the geometry shown in figure 5, in which the points X, Y appear at X', Y' and X'', Y'' in stereo pictures taken at tilt angle $\pm \theta$. The lengths $X'Y'$ and $X''Y''$ can be measured either from the two photos separately or from stereo images directly. The difference $X'Y' - X''Y''$ is called the parallax ∂x .

According to the geometry shown in figure 5:

$$\partial z = \left[\frac{1}{2M \sin \theta / 2} \right] \partial x \quad (11)$$

where ∂x is the relative distance measured, M is Magnification factor and θ is the tilt angle i.e. the inclination angle between the two images.

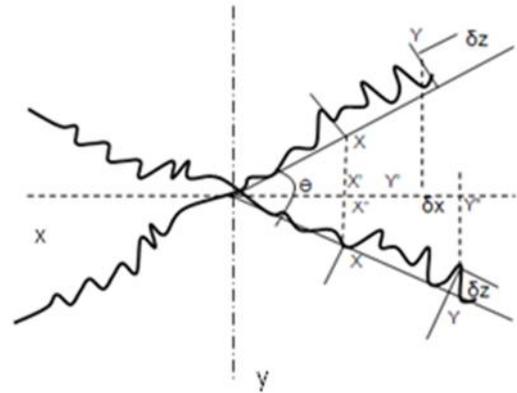


Figure 5: Determination of parallax, δx from stereo imaging

7. RESULTS AND DISCUSSION

For the stereo images used in the work the 3D shape obtained using the above algorithm is shown below in figure 6 with a various navigation window.

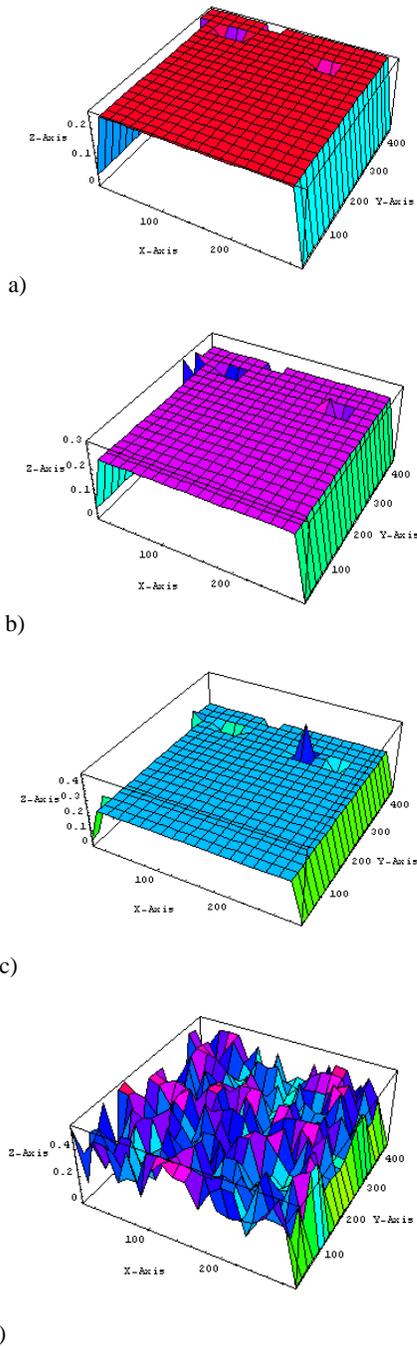


Figure 6a-d: 3D shape recovered from the stereo images using navigation window of a) 7 x 7, b) 11 x 11, c) 13 x 13 and d) 15 x 15

The Shape recovered also depends on the size of navigation window; navigation window with a size greater than 21 does not yield satisfactory results. This work can also be improved using multiple pair of stereo images of the same object and region based alignment techniques.

8. CONCLUSION

This paper describes simple approach to reconstruct shape using photometric stereo images. The method can be improvised incorporating more features participating in recovering shape and also by considering multiple images of the same scene with different tilt angle. The input images taken into consideration for validating the proposed algorithm is an image of fracture surface of High Speed Low Alloy (HSLA) material. The proposed algorithm can be validated for other application requiring depth information using stereo-images.

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