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Surface Reconstruction Using Shadow Profilometry

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ABSTRACT

Digital image analysis has rich potential in application to post-disaster forensic investigations. The underlying concept is to reconstruct the exterior surfaces of object fragments that failed under load or were torn apart because of explosive forces. The surface reconstruction technique must be sufficiently accurate to capture detailed characteristics of small samples for identification and classification of the object under examination. This paper presents an inexpensive technique for constructing a digital image of a three dimensional surface of very small objects which preserves the minor details via two dimensional slices produced using shadow profilometry.

Categories and Subject Descriptors

I.3.5 [**Computer Graphics**]: Computational Geometry and Object Modeling – *curve, surface, solid, and object representations.*

General Terms

Algorithms, Experimentation

Keywords

Surface reconstruction, surface modeling, image acquisition techniques, and digital photography.

1. INTRODUCTION

Digital image analysis has rich potential in application to post-disaster forensic investigations. The underlying concept is to reconstruct the exterior surfaces of object fragments that failed under load or were torn apart because of explosive forces. For example, after an explosion, investigators usually desire to reassemble the objects involved because it offers a snapshot of the disaster moment. However, they are often faced with a huge array of small pieces of torn and ripped metal leaving them with a rather difficult puzzle.

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The most prominent technique for object reconstruction is known as *Range Scans* [1]. Unfortunately, this method is dependant upon either casting expensive lasers that break down under magnification, or by using large beams of light that hide the smaller details of a surface. For these reasons this technique was found to be inadequate when constructing objects less than a few centimeters large. The technique presented in this paper does not suffer from this shortcoming when dealing with very small surfaces, and will have the ability to correctly scan much smaller objects.

2. METHODOLOGY

The surface reconstruction methodology to be discussed in this paper involves a number of steps. First, a sharp shadow is cast through a small slit at an angle to the surface to highlight its features along the shadow's edge [2]. A picture of this shadow is taken. The shadow is moved relative to the surface in a regular increment and another picture is taken. This process is repeated until the entire surface has been covered. This produces a set of images, each possessing a shadowed-highlighted section. An edge detection algorithm is used on each image to quantify the cross-sectional slice of the surface identified by the shadow and the edges of the surface are removed. These edges are then stacked together to reconstruct the entire surface.

2.1 Image Acquisition

Since the main use of this method involves very small objects, such as the one shown in Figure 1, the sample is placed under a microscope with a high-definition grayscale digital camera attached. A fiber optic light source is used to create a thin beam of light (Figure 1). The light is cast onto the surface at a 45° angle to avoid the need to use any height correction coefficients [2]. A portion of the light source is interrupted by a razorblade, which casts a sharp shadow onto the surface. A rotary stage repeatedly moves the sample a small, known increment under the microscope. Successive pictures are taken until the entire surface has been captured. For objects with a circular cross section, an additional series of images is recorded. Instead of casting a sharp shadow onto the surface, the entire surface is illuminated to highlight the boundary of the surface. These images will be used to remove the data points that correspond to the edge of the surface.

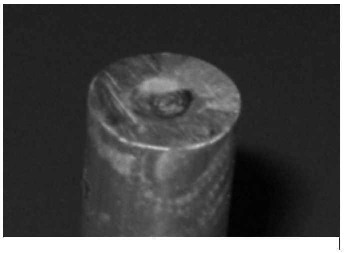

Figure 1: Physical Surface

2.2 Edge Detection

Once the image sequence is captured, each image is analyzed to determine the shadow's edge. Edge detection algorithms applied to the grayscale image (Figure 2) are a natural choice, but there are challenges to this. The algorithm must be able to distinguish between the dark region defining the shadow's edge and nearby dark regions created by neighboring surface irregularities. Before applying the edge detector to the image, the noise created by these neighboring irregularities must be removed.

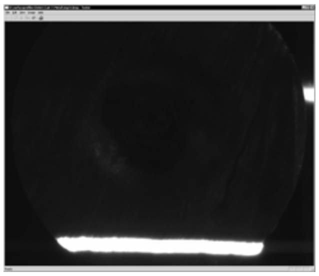

Figure 2: Captured Image

Although the majority of the illumination noise is removed by casting the light through a small slit, there is still enough noise present in the image to significantly reduce the effectiveness of the edge detection operators. Further noise reduction is achieved through a *thresholding* technique. Thresholding is a powerful method for segmenting images into regions of illumination and shadow [9], which is exactly what is required to reduce the amount of noise in the image. The majority of the remaining noise, which is in the form of regions of dark gray, is the result of neighboring irregularities in the surface. By applying a fixed binary threshold with a high threshold value to the image, this noise can be eliminated while still preserving the edge created by the shadow. For the samples used in this study, it was determined that threshold values in the range of 125-200 yielded the best results for an 8-bit grayscale image. The result is a monochrome image with a well-defined edge.

Next, a standard edge detection algorithm is applied to the binary image. Edge detection algorithms are used to highlight significant differences in the gray-scale image [3]. Since the image has been reduced to black and white, any derivative-based edge detection scheme will work well to highlight the desired edge. Due to it's inclusion in Intel's OpenCV software package, Canny's Edge Detection algorithm [4] was used and has performed well, resulting in fairly nice, continuous edges..

The Canny Edge Detection Algorithm works in three separate stages [4]. First a Gaussian Blur is applied to the image to reduce any noise. Next, a simple two dimensional derivative operator (such as the Sobel Operator) is applied to highlight regions of large change that would represent potential edge points. The final stage of the algorithm highlights the edge points by using two threshold values, T1 and T2. If a point is higher than T1, then the edge is traced in all directions until the points fall below T2. These points are then highlighted as an edge [4].

After the edge of interest has been highlighted, some remaining error may still be present in the image due to parametric choices made during the thresholding and edge detection processes. These points should not be used when generating the surface, and so must be discarded during the edge-discovery phase. To solve this problem, each highlighted edge pixel is treated as a node in an undirected graph. An edge pixel is selected, and the edge is walked using a depth-first graph search. Since the errors are generally small and cover a minute extent of the image, the edge which spans the largest amount of the image's width is selected.

In the case where both edges of the shadow created by the slit span the image, the bottom most edge was selected. In practice, this method is a fast and reliable way to detect the edge of the shadow cast on the sample. Unfortunately, for surfaces with circular cross-sections this presents some problem, since the boundary of the sample was being detected as an edge of the shadow which would create a crowning effect in the reconstructed surface. This problem was eliminated by capturing an additional set of images with no shadow being cast. These images were processed in the same was as the original set. The highlighted points in the boundary images were then removed from the set of edge points, effectively eliminating the crowning problem.

2.3 Reconstructing the Surface

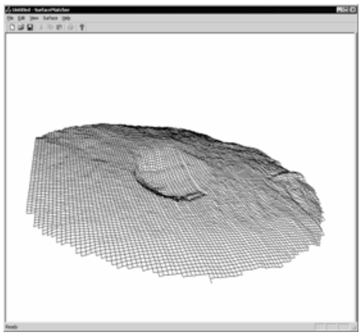

Figure 3: Constructed Surface

Once an edge has been collected from each of the images in the sequence, the lowest edge points in the shadow profile are plotted on a three dimensional wire frame graph. Each sequential image number becomes the x-coordinate, the individual column of pixels is represented on the y-axis, and the distance from the bottom of the image to the lowest point in the edge profile becomes the z-axis component, since no vertical scaling is necessary [2]. A wire frame mesh of the surface is generated by plotting the collected set of coordinates (Figure 3).

3. CONCLUSIONS

In this paper a method for reconstructing surfaces using shadow profilometry was discussed. The results of this research have proven to be very promising as an inexpensive means to reconstruct the surfaces of extremely small objects while maintaining the small features of the sample. This technique will play a large role in future research concerning the recombination of fractured surfaces.

4. ACKNOWLEDGEMENTS

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