Recovery of Fingerprints using Photometric Stereo

Abstract

We demonstrate the use of photometric stereo to enhance the recovery of both visible and plastic fingerprints. Examples are given that show the recovery of visible prints from rough surfaces and a plastic print from a patterned surface. This approach improves the quality of the print by reducing the effects of variations in the background surface. It provides a cheap and effective way to improve the quality of the image before enhancement and recognition algorithms are applied.

Keywords: fingerprints, photometric stereo, Gabor filters

1 Introduction

This paper describes the use of photometric stereo to improve the recovery of fingerprints. Photometric stereo (PS) is a method to recover surface shape and markings (albedo) from images of the surface lit from different directions. Fingerprints can be categorised into three groups: latent, visible and plastic (or *moulded*). The first two groups can be considered to be a function of albedo, the last is a function of shape. In this paper we use the ability of photometric stereo to resolve the albedo and topographical components of the image. Visible prints on rough surfaces are processed to suppress the effects of surface roughness. Plastic imprints on patterned surfaces are processed to remove the albedo component and enhance the ridge structure of the print.

Image processing and machine vision techniques have been used extensively for the enhancement and recognition of fingerprints. These techniques are applied to fingerprints obtained by traditional ink techniques or by scanners. In both cases the prints are deliberate and the conditions have been optimised as far as possible; for instance the prints are either imaged directly from fingers or made on a flat uniform surface. This paper considers prints that have been made on surfaces that are either rough or patterned. PS is used to separate components of the image that are caused by surface albedo and those caused by surface topography.

In this paper we will demonstrate the use of photometric stereo to recover both visible and plastic prints. The visible prints are formed on a rough surface. We will show that PS is able to suppress the image texture due to surface roughness while leaving the print unaffected. This technique gives a dramatic improvement over the original image. Adding the images—equivalent to circular illumination—gives a similar improvement. However, we show using theory and experiment that the photometric approach is significantly more effective in suppressing the roughness component. The recovered print is then filtered.

The recovery and enhancement of plastic fingerprints is described. Plastic fingerprints are imprints in a soft or viscous matrix, e.g. wet paint. Although much less common than latent prints, we find them interesting from a technical viewpoint. In this paper photometric stereo is used to estimate the shape of the imprint and to suppress the effect of the matrix albedo. The stages in recovery and enhancement are illustrated with an example. A plastic print is formed by pressing the finger into a soft surface. In order to demonstrate the ability of PS to resolve albedo and surface components of the image, the surface was spattered with paint before the imprint was made. PS recovers the surface derivatives. These are efficiently filtered, then integrated and the resulting height map shown. We believe that PS is most effective if applied to this type of print.

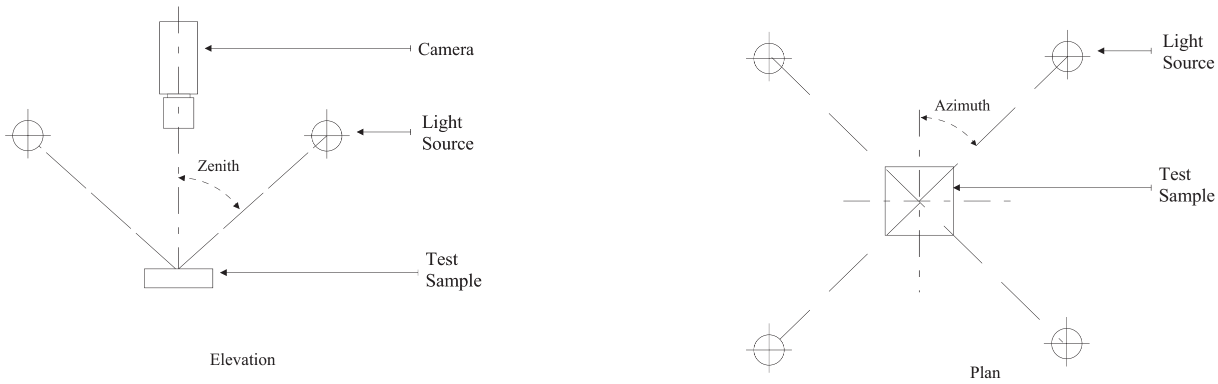

Figure 1: Image capture setup.

In this paper we demonstrate the use of photometric stereo to recover fingerprints. Visible prints were resolved from surface roughness, and plastic prints were isolated from surface patterns. The technique is simple, easy to implement and it improves the quality of test images on which enhancement algorithms will work. We conclude it is a useful complement to existing enhancement algorithms.

2 Visible Prints

In this case we want to recover the surface albedo and suppress the effect of surface topography. Photometric stereo estimates surface derivatives and albedo using multiple images of the same scene lit from different directions. In this work we use four photometric images, Figure 1. Although only three images are required for estimation of a Lambertain surface we have found that a fourth image makes the estimates more accurate. The four light sources are arranged around the sample at 90° intervals of azimuth with a zenith angle of 30°.

We assume both the print and the underlying surface reflect according to Lambert's Law. The intensity of a surface facet will be described with Equation (1)

$$i(\tau,\sigma) = \rho \frac{-pcos\tau sin\sigma - qsin\tau sin\sigma + cos\sigma}{\sqrt{p^2+q^2+1}} \tag{1}$$

where,

i is the intensity of the facet.
τ is the angle of illuminant azimuth..
σ is the angle of illuminant zenith.

ρ facet albedo.
p surface derivative in the x-direction.
q surface derivative in the y-direction.

$$i(\sigma) = \frac{\rho cos\sigma}{\sqrt{p^2+q^2+1}} \tag{2}$$

If we illuminate the surface from two points, τ and $\tau + \pi$, or equivalently use circular illumination, the facet can be described using Equation (2). In most rough surfaces the majority of surface facets have surface derivatives that are much smaller than one, and this approach significantly reduces the effect of topography. However, the p and q terms in the denominator introduce intensity variation. Photometric stereo allows us to remove this effect—at least in theory.

To measure the effectiveness of these approaches we consider an area of surface that has constant albedo Figure 4. In these regions the algorithms should remove image variation. As a figure of merit we use the mean of the image region divided by its standard deviation. The more

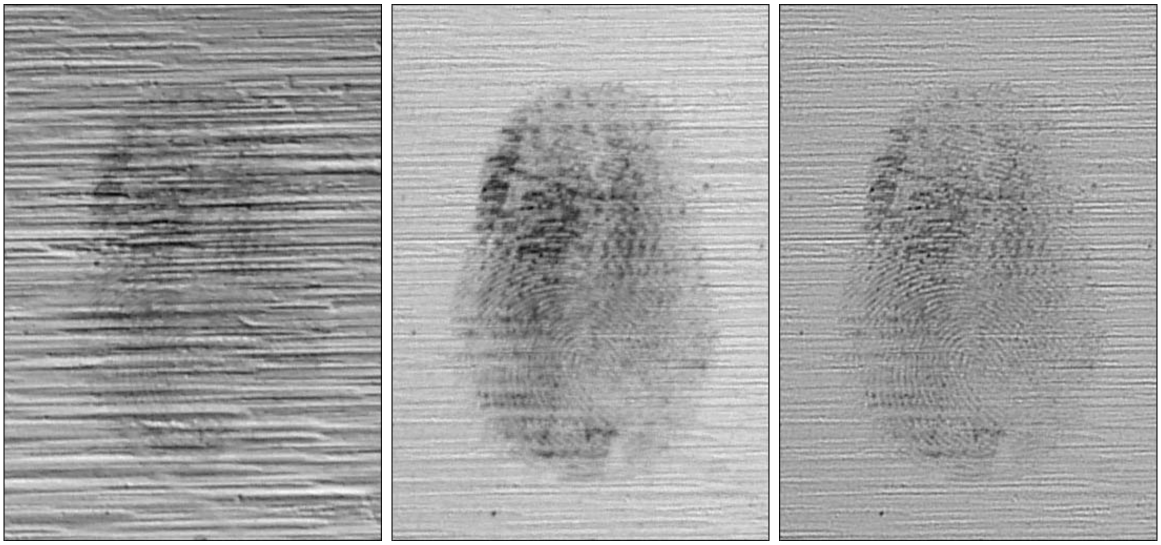

Figure 2: Visible print on directional surface. Original image (left), recovered albedo image (centre) and filtered albedo image (right).

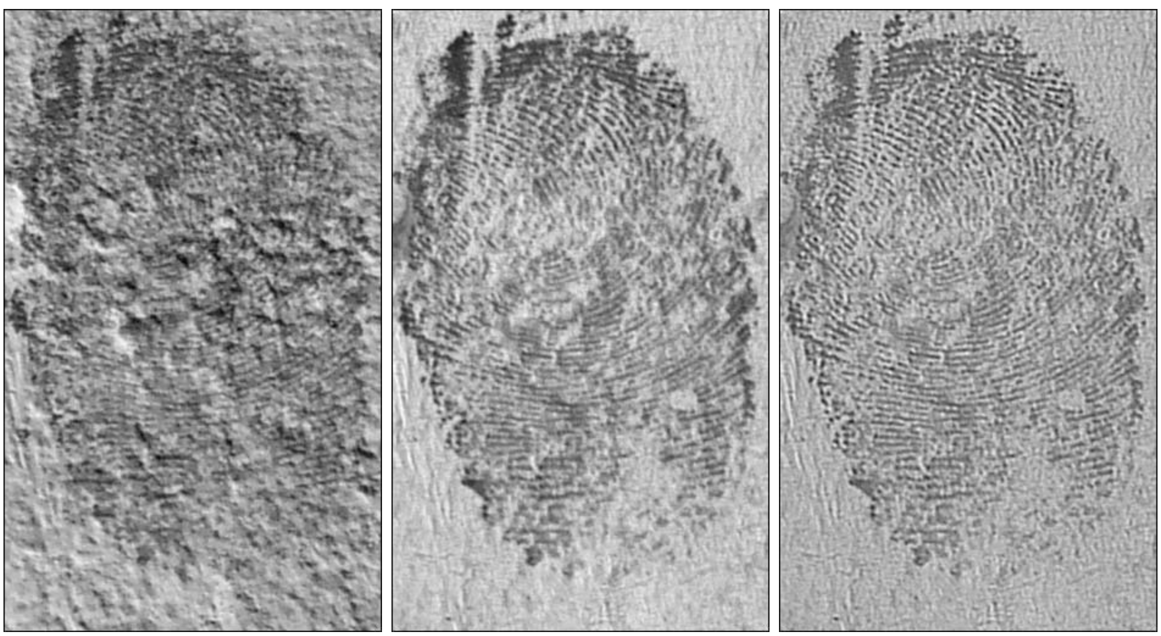

Figure 3: Visible print on isotropic surface. Original image (left), recovered albedo image (centre) and filtered albedo image (right).

Region	Intensity	Albedo	Improvement (%)
1	6.97	8.44	18.39
2	5.21	5.46	4.51
3	5.69	6.18	7.89
4	5.54	5.81	4.63

Table 1: Ratio of image mean to standard deviation

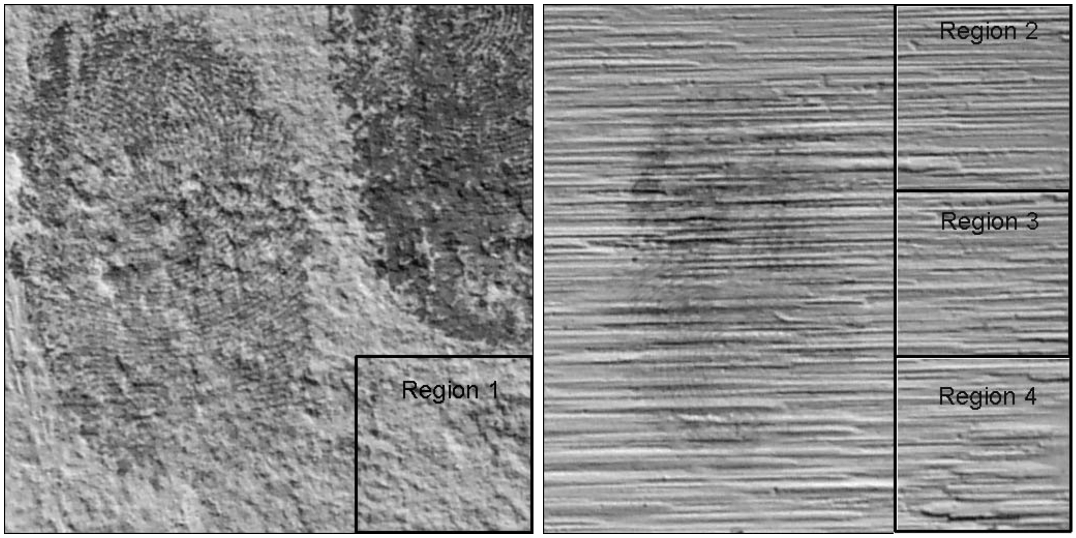

Figure 4: Regions of constant albedo.

effective the algorithm the larger the ratio. The results are shown in Table 1. Depending on the surface, the photometric approach gives an increase in the ratio of between 4 and 18%. To further improve the print quality we filter the image. Several authors have found it convenient to resolve the two dimensional transfer function of the filter into an isotropic radial function and a frequency independent orientation function. Ideally the print should be binary and a one dimensional profile should resemble a rectangular wave. In order to accentuate this characteristic we used a filter with a radial frequency response that approximated a Sinc function. We decided not to alter the orientation properties of the images and leave this to enhancement algorithms later in the process. Rather than completely attenuate the other signal components we found more pleasing results could be gained by adding a scaled version of the filtered image to the original image.

In both examples the filter has significantly improved the quality of the image, Figures 2 (right) and 3 (right). The image taken from the isotropic surface is crisper and the ridge structure more apparent than before filtering. However, the filter is most effective in the case of the directional surface, in which the fingerprint is of poorer quality. Filtering has brought out the ridge structures that were barely visible in the albedo image. Clearly albedo recovery is only the first step in the enhancement of the fingerprint.

3 Plastic Prints

Photometric stereo has three advantages for plastic prints. First, it isolates the surface topography (due to the fingerprint) from the surface albedo (a property of the matrix). This will be demonstrated. Secondly, this approach allows the estimation of a continuous function (surface height) instead of the binary function of an ink print. This simplifies processing: many enhancement and recognition algorithms first convert the binary signal into continuous form, e.g. [Jain et al., 1999]; Tico and Kuosmanen go further and describe the filtered image as a topographic surface [Tico and Kuosmanen, 1999]; and the synthesis algorithm proposed in [Cappelli et al., 2000] initially operates on a continuous signal before thresholding as a final stage. We argue that, *where possible*, it is preferable to achieve a continuous signal by measurement rather than inference. Thirdly, since we estimate the height function, the image is no longer affected by the directional effects of illumination (see [Chantler, 1995] for description of the effect). This is particulary important if the orientation of the fingerprint cannot be controlled.

We believe this method can be applied in three areas. First, the algorithm can be used for the recovery of unintentional plastic prints (i.e. for forensic purposes). Secondly, this approach may also be useful as a basis for modelling fingerprints and their interaction with surfaces. Thirdly, if the surface structure can be estimated directly from the fingertips this approach could be used as a robust, real-time, biometric technique.

3.1 Photometric Recovery

All four light sources have a zenith angle of 70°. Illuminating from a shallow angle increases the probability of shadowing, however, it also accentuates the subtle topography of the print and reduces the amount of specular reflection reaching the camera.

One of the images used for photometric estimation is shown in Figure 5 (left). The print is corrupted by 'noise'—actually spots of dark paint applied to the matrix before the imprint. Figure 5 (right) shows the estimated derivatives rendered using Lambert's law. There is an obvious improvement. The effect of the noise is most clearly seen on the matrix (Region A)—the estimated surface is pock-marked. In the region of interest, a large spot (Region B) suppresses the topography of the print. This is partly due to the fact that the paint is very dark—a lighter shade would have allowed the algorithm to make a better estimate of the surface. The effect of smaller spots (Region C) is much less pronounced.

3.2 Enhancement

The signal magnitude of the estimated derivatives is shown as a function of radial frequency in Figure 6. The spectrum is bimodal: it consists of a high power, low frequency component due to the indentation of the print, and a low power, mid-frequency component due to the ridges and furrows of the print. We are interested in the latter. Several authors, e.g. [Jain et al., 1999], [Lee and Wang, 1999], use Gabor filters which convert the binary ink print into a continuous signal. We found that a Gabor filter fits the second (mid-frequency) peak well, Figure 6. Unlike other authors we have used isotropic Gabor filters to filter the surface derivatives—this approach was used in [McGunnigle and Chantler, 1999] for texture classification.

The filtered derivative fields were integrated into a surface using the technique proposed in [Frankot and Chellappa, 1988]. The resulting height field was then normalised using a simple adaptive filter of the form shown in Equation (3). The threshold term and the regularisation term were set to 0.2 and 0.1 respectively. The enhanced image is shown in Figure 7. The algorithm has achieved varying degrees of success: Region A (which is attenuated by the effects of directional illumination in two of the photometric images) has been enhanced; in Region C the signal power fell below the filter's threshold and this region was not accentuated. Region B is intermediate: the processing has enhanced the ridge and furrow structure, though the estimate is noisy. A detail of Region B, before and after filtering is shown in Figure 8.

$$n(x,y) = \begin{cases} \frac{1}{(k+s(x,y))} & s(x,y) \geq threshold \\ 1 & s(x,y) < threshold \end{cases} \tag{3}$$

where,

- $n(x,y)$ is the filter transfer function.
- k is the regularisation term.
- $s(x,y)$ is a local estimate of the standard deviation of the signal.

4 Conclusions

This paper describes work aimed at recovering fingerprints from non-ideal surfaces. For this reason we have applied a much more physical approach to the recovery and enhancement of fingerprints than other researchers. We base our recovery and enhancement techniques on the physical characteristics of the print and of the surface it lies on. By optimising lighting we improve the quality of the image at the imaging stage—this means that subsequent enhancement processes will have a more reliable input and should be more robust. The techniques therefore complement much of the existing literature.

We have shown that photometric stereo offers a significant improvement in the quality of visible fingerprints taken from rough surfaces. This approach also has applications for recovery of prints from fabrics where the weave structure of the fabric can disrupt the print. However, we believe the most interesting application of PS is to plastic prints. Plastic prints can be enhanced by removing albedo variation. The ability to estimate the shape of the print may also be useful for the modelling of reaction diffusion processes that form the skin topography as well as the interaction with surfaces that give rise to fingerprints.

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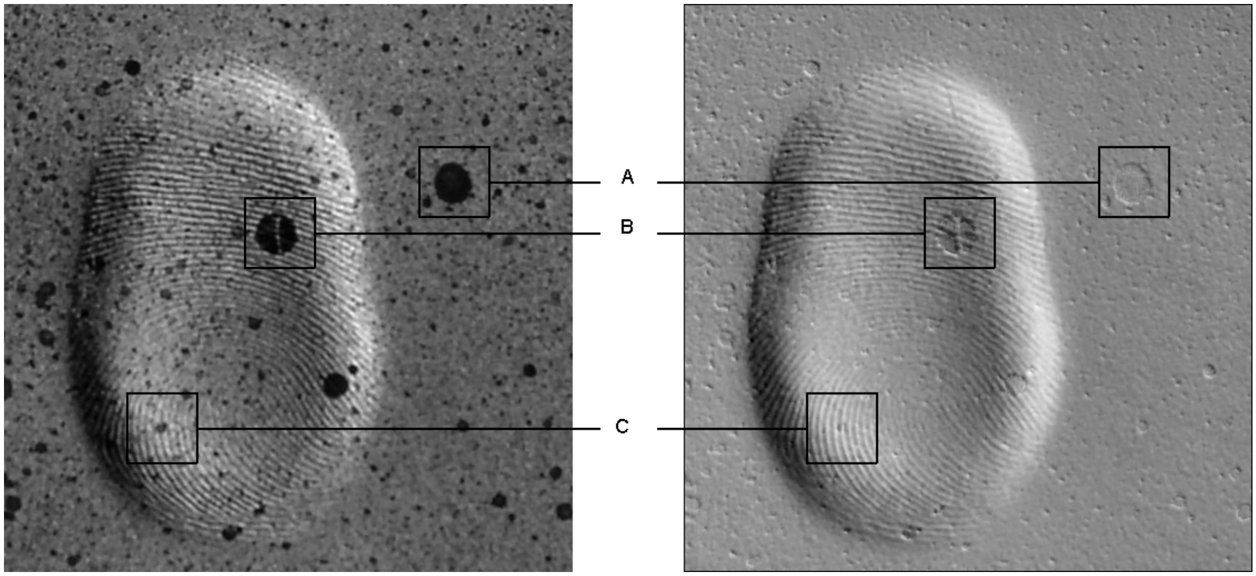

Figure 5: Original image (left) and rendered estimate (right).

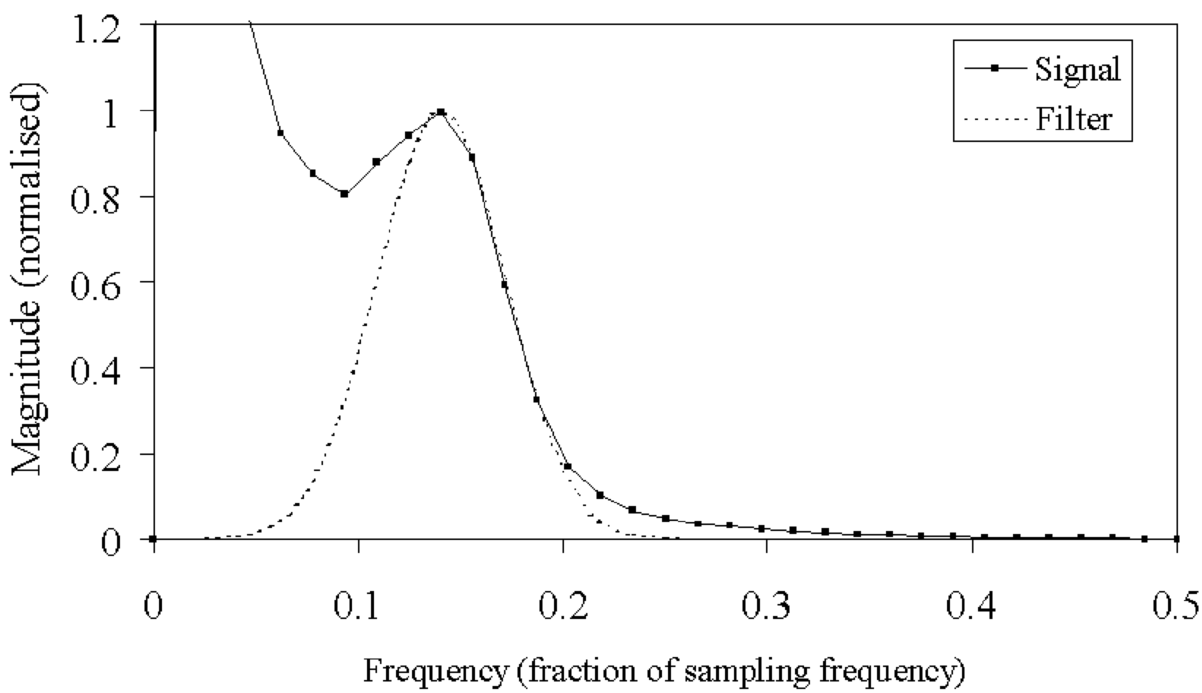

Figure 6: Magnitude radial spectrum of surface derivative fields.

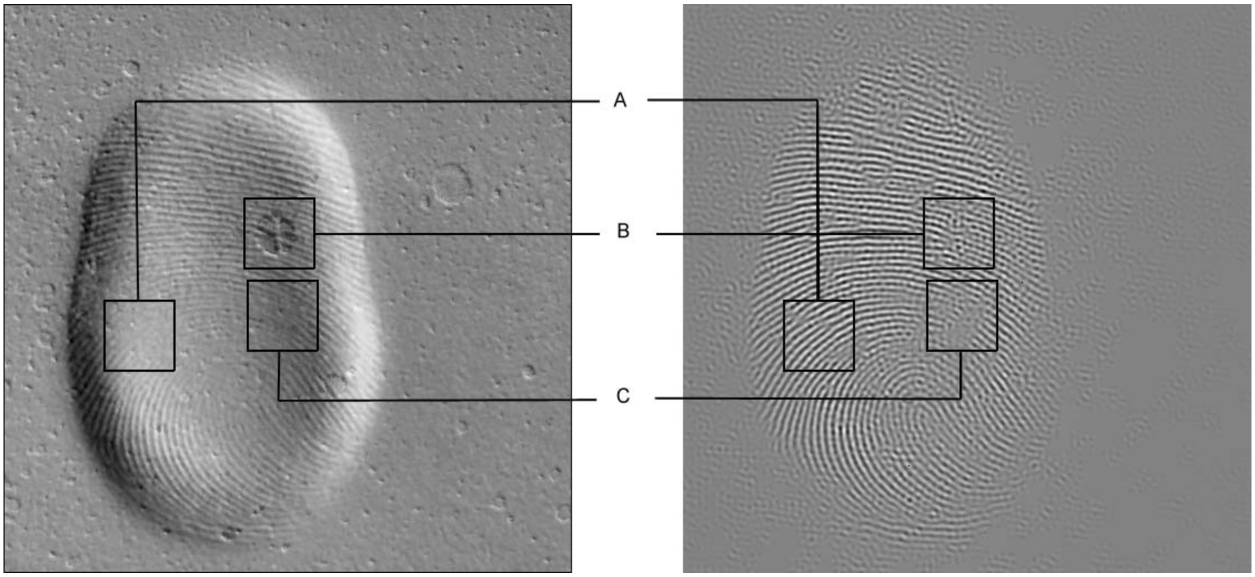

Figure 7: The original photometric estimate (left) and the processed estimate.

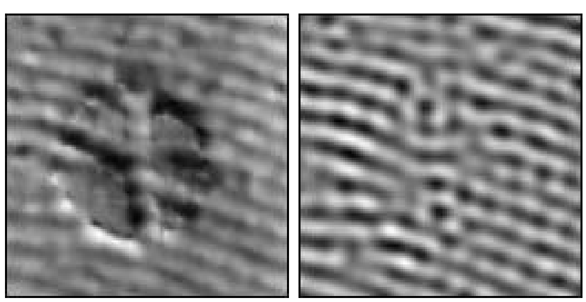

Figure 8: Detail of Region B estimate before (left) and after (right) processing.