Practical Procedures for Breast Profiling Using Shape-from-Shading

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https://doi.org/10.15221/20.42

Abstract

The measurement of female breast shapes appears to be a useful procedure for a number of medical purposes. Achieving this measurement by the numerical analysis of a single digital photograph of the breast, by utilising the principle known as shape-from-shading (SfS), is appealing because of its advantage of simplicity: the technique requires the analysis of only one image. However, the advantage of simplicity can be lost if practical implementation becomes complicated. This paper examines the practical steps required to implement the SfS measurement, in order to reflect on its feasibility.

The SfS method seeks to deduce surface gradients across an object - the breast in this case - by using the reflectance levels which are apparent in the image of the breast. From the gradients, shape can be deduced. But, because it is theoretically impossible to deduce the two parameters of surface slope from the single reflectance level at individual pixels, the method followed here is restricted to obtaining profiles which pass through the breast centre, when the theory is then simple.

Practical implementation involves a number of complications: the imagery must be taken with a flash in dark conditions, in order to provide a known illumination model; the centre of the breast should be at the centre of the image; the focal length of the camera is needed for use in the mathematical model; a means of scaling the resultant breast shape is required if a single image is used; the analysis needs to be undertaken on a monochrome image, which needs in turn to be transformed into a text file for numerical analysis; the method requires that the object has smooth physical texture and light even colouring, as the breast generally does, but the irregularly textured areola region needs to be excluded from the shape analysis; the analysis also requires finding the breast's limits, defined as occurring when the breast rises from the background chest shape. If all these practical requirements tasks can be satisfied, the subsequent analysis is easy, involving little more than simply fitting a simple cubic or quadratic function to the reflectance levels across the breast cross-section.

Each of these practical steps is assessed in this paper, which reports on the feasibility and costs of procedures followed by the writer so far in attempts to achieve the measurement goals. It is shown that none of the problems is impossible to solve.

Keywords: shape-from-shading, digital imagery, breast measurement

1. Introduction

In a previous paper [1], the writer has argued that the concept of determining the shape of breast cross-sections by using the challenging concept of "shape-from-shading" (SfS) could be successful in certain circumstances. That paper concentrated on the feasibility of concepts and the accuracy of the method, not on realistic practical implementation. This paper now considers the practical implementation, in order to show that, not only is the concept simple and the theory undemanding, but that equally uncomplicated practical procedures can be devised to make practical implementation viable.

1.1.Background to Shape-from-Shading

The previous paper explained that the principle of SfS is that, if an object of interest is illuminated by a single light source (as distinct from general ambient lighting), then the image intensity value (i.e. grey-level or reflectance) at any pixel on a monochrome digital image of that object, is related to the gradient of the equivalent element on the surface of the object. The goal of SfS is normally the determination of the surface gradients across the object from such an image, so that the three-dimensional surface shape can be deduced from the surface gradients. SfS theory mathematically relates the image reflectance at a pixel to the two gradients of the surface of the object at that pixel. The major predicament with the SfS method is that two gradients are needed to define the direction of the surface element at any one pixel, but only one reflectance value is available at each pixel, so that, for any pixel there is an infinite number of solutions for the two gradients given the one reflectance.

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A solution is often feasible if a suitable assumption can be made about the surface. The discussion here centres on profiles, because determining profile shapes for some objects by using SfS is seen to be feasible and useful. Profile measurement of a breast is seen to be feasible if the centre of the breast is the centre of the image, and if the surface gradients across the profile are small relative to the gradients along the profile. If so, a mathematical solution is achievable. Using a number of profiles, in different radial directions, would provide a more complete breast shape.

The practical procedures currently used by the writer are workable to obtain experimental results but they are not suited to routine use. The purpose of the paper is to show that practical implementation for the foreseeable applications is feasible.

1.2.Applications

The key problem in this paper derived from the recognition that possible applications clearly influence the acceptable cost and complexity of the practical processes. Of all foreseeable applications of SfS for measurement for any part of the body, breast measurement is seen as most likely to be workable and useful; other body measurement applications could follow if breasts profiling can be successfully implemented. The simplest applications are seen to be for the fitting of undergarment apparel, which currently may be made by simple tape measurements of circumferences around the body, one over and one below the breast. The SfS methods could provide more detail and be of better accuracy than tape measurement, but the SfS method would need to be very simple, quick, and cheap. The demand for breast measurement for medical purposes, including for cosmetic reasons, is implied by the number of breasts measurement methods that have been developed; see, for example, Kaya et al. [2]. In medical cases, the measurements would presumably need to be comprehensive, but they may not be required instantaneously, and some costs and operating complexity may be tolerable if it would supply the required accuracy and detail, and the work may be undertaken by a technically competent user, making SfS attractive for this purpose.

The goal in the profile measurement here is not to obtain full breast shape but to derive a parameter which characterises the shape. The provision of a single parameter appears to be useful in line with the argument by Lee et al. [3] who suggest that benefit can be derived from single parameters indicating breast shape, noting that, in their work, the "*the purpose of the proposed measure is to quantify the overall shape of the breast contour, rather than tracing local contour variations*".

2. Shape-from-Shading Theory

According to SfS theory in the case of flash illumination, there is, for each pixel on the image, a straight-forward relationship involving

- i) the reflectance level on the image at that pixel,
- ii) the maximum level of reflectance which occurs on the object for that type of surface,
- iii) parameters defining the direction of the illuminating light ray from the light source to the object,
- iv) the focal distance of the lens, and
- v) the required unknowns which define the direction of the normal to the object's surface at the pixel in question.

A review of the practical steps which can be used to determine the surface normal directions, and hence the breast profile, is the essence of the discussion below.

3. Summary of Practical Stages

Practical implementation of the SfS theory to enable the shape of the surface in the image to be deduced by following the relationship mentioned in Section 2, is currently achieved by the writer by the following steps.

<u>Step 1: Imaging</u>

- Imaging, in the dark, with the breast located in a suitable position on the image.
- Image transfer from the camera to computing device.

<u>Step 2: Image format conversion</u>

- Conversion of the large colour digital image to a text file which can be used for numerical analysis.

Step 3: Processing of the pixel reflectance values according to an appropriate algorithm

- Selection of parameters defining breast limits.
- Selection of parameters defining areola limits.
- Specification of the maximum reflectance level for the surface in question.
- Calculation of surface gradients using the reflectances at each pixel on the breast cross-section, according to SfS theory.
- Conversion of surface gradients to the graphical or numerical information required by the user.

The writer's processing uses a combination of proprietary software, short programs based on high-level programming languages, and programmed spread-sheet programs, with image analysis processes controlled by a batch file, once the image file has been downloaded. Manual input of a small number of parameters is needed. Details are as follows.

4. Step 1: Imaging

The image is of one breast. The centre of the areola needs to be at the centre of the image.
An illumination source is required, and it must be close to the camera lens. The imaging needs to be undertaken in a dark environment, so that the illumination of the object will be based on the flash only. These imaging requirements are not seen to be demanding. Costs are negligible, requiring the use of an ordinary camera, even a mobile phone camera.

5. Step 2: Image Format Conversion

Once obtained, the image needs to be transferred to the computing device which is to be used for undertaking the calculations. This can be achieved by any one of a number of obvious means.

The image, which will invariably be a large-sized colour image in an image format, typically *.jpeg*, then needs to be converted to a text file for numerical analysis.

Currently, this process involves various steps, which are not yet optimal:

- the image is converted from coloured to monochrome, using a commercial image processing program (PaintShop Pro X6 software, version 20.2.0.1, 2018, from Corel Corporation, 1600 Carling Avenue, Ottawa, Ontario, K1Z 8R7, Canada);
- to create a more manageable array size, the image is re-sized, using the same commercial program as used in the previous step;
- the image is converted to a text array, using a high-level language program written in-house.

Processing costs are limited to the operator's time.

6. Step 3: Processing

Implementation of the theory to find the required cross-section shapes is carried out using an Excel spreadsheet (Microsoft Corporation, USA). The appropriate rows or columns are transferred manually from the text array described in the previous section. The theory to convert reflectances to surface gradients is quite simple, but there are some minor aspects which provide practical challenges:

- The start and end limits where the breast can be distinguished from the surrounding regions of the image need to be specified. This is currently achieved by manual inspection; see Figure 1. The manual selection is easy, but the process deserves to be automated.
- The limits to the areola region are needed as the areola's texture must be is excluded from the profiling; limits are currently defined by manual inspection of a figure such as Figure 1, and/or by inspection of the raw image. As with the selection of the breast limits, automation is warranted, but this could again be difficult.
- The maximum level of reflectance which would occur on the object for the surface in question is a required parameter. That maximum reflection only applies to the surface of interest, and occurs when the surface is perpendicular to the path of the light ray from the camera optical centre to the surface. It is possible that the maximum value does not appear on the image, or that the maximum reflectance is contaminated by some specular reflection. In the case of the breast, a quadratic function (suitable for the horizontal section) or cubic function (preferable for a vertical section) is fitted to reflectance values on the breast to find the maximum reflectance value. The curve fitting involves the reflectances in the profile of the breast only, and excludes the areola, as shown in Figure 2. The figure shows that the maximum expected reflectance on the normal breast surface is not given by the maximum reflectance value seen on the raw image. The curve fitting algorithm is quite straight-forward.

- A minor requirement is for the distance from the lens optical centre to the image, being the camera focal length value altered for focussing on the object, is needed. The focal length can be obtained by a simple calibration process based on the SfS principles for a camera which is used repeatedly in a medical situation.
- The final shape along the breast needs to be scaled from image size to real object size, i.e., to convert the units from pixels to a distance unit, a step which can be achieved by one of a number of obvious and simple methods.

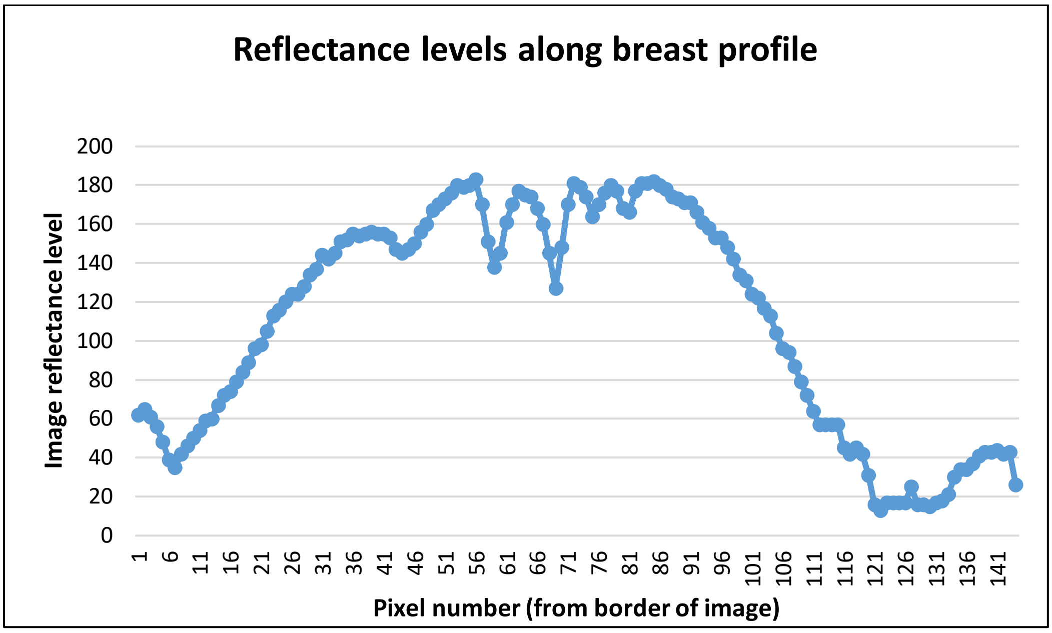

Fig. 1. Reflectance levels along the horizontal profile form a left breast image, exhibiting apparent breast limits and areola limits. Figure created using Microsoft Excel.

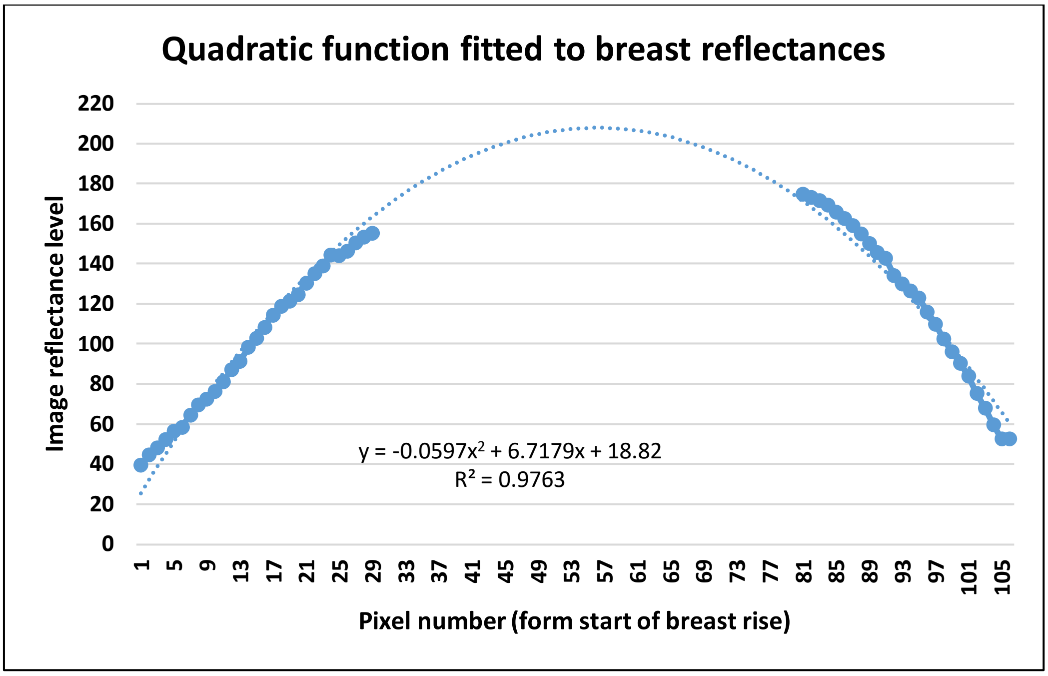

Fig. 2. Reflectance levels along the horizontal breast profile shown in Figure 1, limited to the breast area, with areola region excluded, with fitted quadratic function shown by the dotted line and the given equation. Figure created using Microsoft Excel.

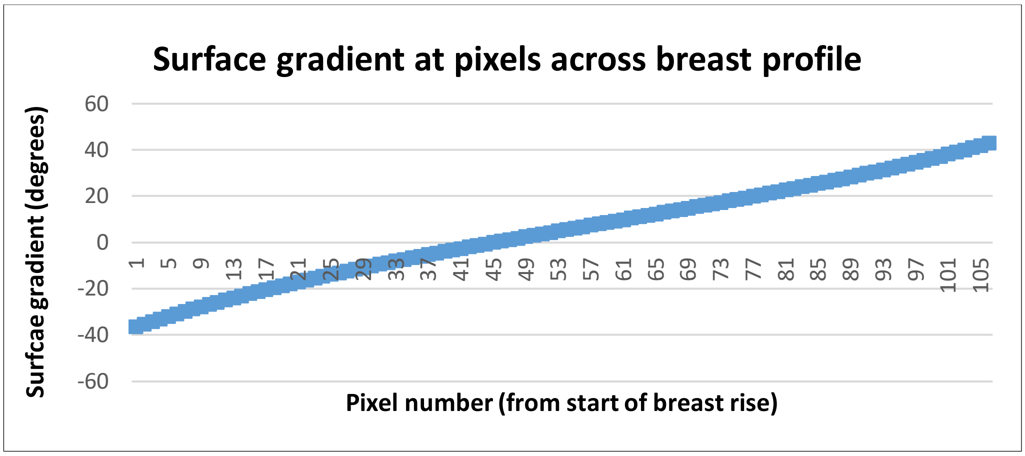

Fig. 3. Breast surface gradients along horizontal cross-section, derived from reflectances shown in Figure 2, excluding points beyond the breast (beyond range 8 to 113 in Figure 1) and with interpolation over the areola. Figure created using Microsoft Excel.

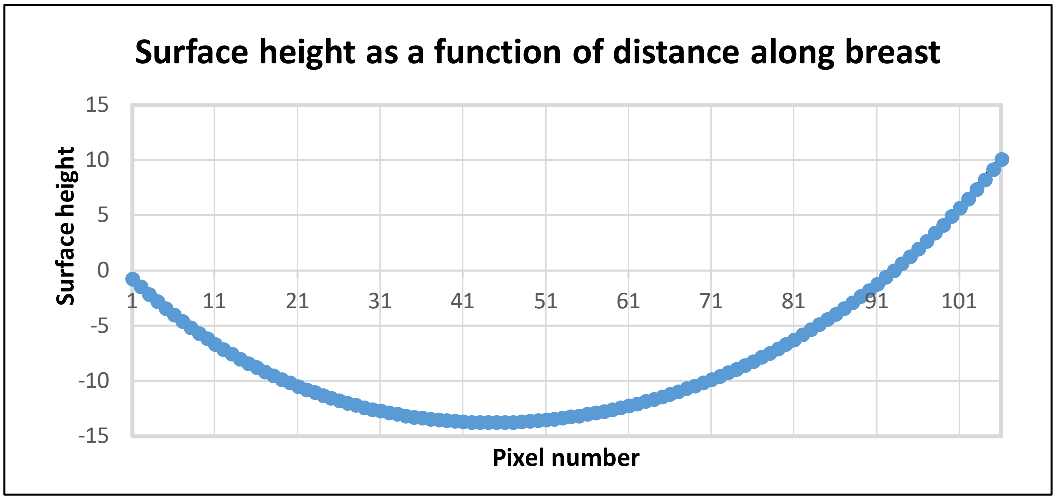

Fig. 4. Breast horizontal cross-section derived from reflectances shown in Figure 2, excluding points beyond breast (beyond range 8 to 113) and interpolating over the areola. It should be noted that the scales are not the same in each direction in this figure, and that the profile does not cover the full breast width. Figure created using Microsoft Excel.

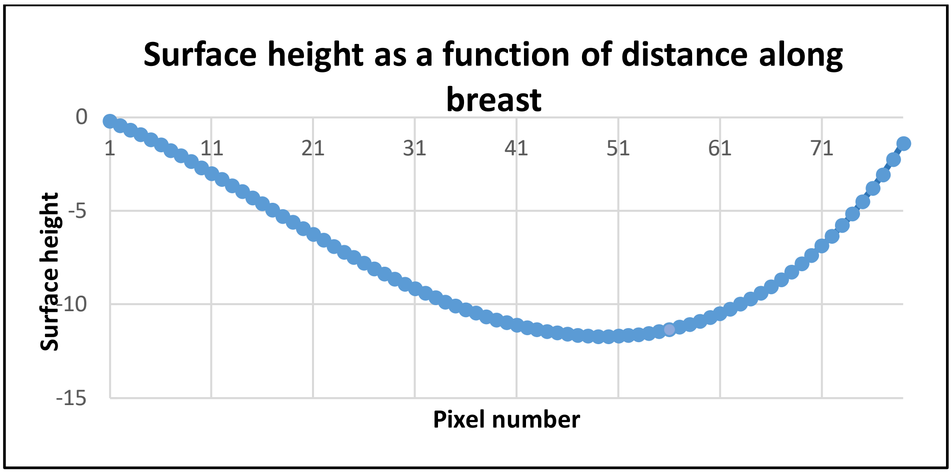

Fig. 5. Breast vertical cross-section derived from reflectances, excluding points beyond breast and interpolating over the areola. It should be noted that the scales are not the same in each direction in this figure. Figure created using Microsoft Excel.

7. Step 4: Provision of Results

The required surface profile needs to be provided in a format suited to the user. The surface profile (as in Figures 4, shown in pixels, before scaling) is easy to derive from surface gradients. However, the figure does not cover the entire breast. The nature of the shape of the breast means that steep gradients may occur at the outer limits of the breast, and the imaging of the flash illumination in those regions can be unsatisfactory. The limits to the breast in the above figures are therefore not the breast boundaries. The surface gradients at the breast limits in Figure 3 above are seen to reach about 40 degrees, which is less than actual values at the breast rise. It is also apparent that the gradients in Figure 3 tend to a straight line for the horizontal profile, an outcome which follows from the fitting of the quadratic function in Figure 2. If so, the curve information provided in Figure 4 can be replaced by a single parameter which describes the radius of curvature of the breast profile. In the case of the breast shown in the figures above, the radius of curvature is 85 pixels. This paper shows that the parameter can be determined from the single image of the breast.

Figure 5 shows a profile evaluated through the breast's centre, but in the vertical direction.

8. Discussion

Improvements are needed for realistic implementation. Ideally processing would be carried out using a high-level programming language, rather than a spreadsheet, in order to reduce the manual involvement. The calculating algorithm is quite simple, but means of pinpointing the limits to the breast and the limits to the areola deserve to be developed.

Operational costs for the data processing stage are again negligible, being only the operator's time.

Calculating the surface gradients (as in Figure 3, which has been derived from the data in Figure 2), using SfS theory, is easy. The function fitted to the breast shape is used here, but the raw reflectances can be used instead.

Note that the accuracy of the method has been considered in the previous paper by the writer, [1]. Cross-sections may also be calculated along lines which are not along the principal axes, but with some complications.

It has been concluded from earlier work by the writer that breasts profiles can be deduced using shape-from-shading. This paper concerns the practical processes involved in determining breast profiles from single images in order to consider whether the measurement technique can be made suitable for practical use.

The advantages of the concept are firstly that hardware requirements are nothing more than a camera, a mobile phone being usable if necessary, and that other hardware costs are negligible; secondly that the theory is quite simple; and thirdly that processing is not difficult. Medical applications are seen to be feasible; sporting apparel applications could follow from successful medical work; casual apparel applications – perhaps involving a mobile phone app – might arise from work on the other applications. If the foreseeable medical and sporting applications involve reasonably frequent use by a technician, it is suggested that the current measurement processes can be tailored to requirements to make the process acceptable. The drive for such developments depends on the demands of the foreseeable applications.

The paper emphasis profiling of female breast shapes, but the practical issues of SfS would also relate to other applications of shape-from-shading that were possible for human body measurement, by profiling methods or otherwise.

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