Three-Dimensional Body Shape Measurement from Single Photographs

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Abstract

There is an extensive number of applications of human body shape measurement, for medical, apparel and other purposes, and there is a variety of means of undertaking this task, with a range of complexities, accuracies, and costs. This paper discusses one method, known as shape-from-shading, which emphasises simplicity and low cost for determining body shape. Measurement is based on a single photograph of the body area of interest, provided that the area is illuminated by a suitable point light source, typically provided by a camera's flash. The method requires neither specialised equipment nor special operator skills, so the procedure is cheap, portable, easy to use, not inconvenient for the patient, but still able to provide the three-dimensional information about a patient's body which is appropriate for various purposes.

The process is not simply a matter of presenting a photograph's grey-scales in three-dimensions, but it involves computing a numerical three-dimensional object shape, so that graphical views can be created, but, more importantly, measurements can be taken from the surface model which the method produces. The theory is not trivial, which creates severe practical limitations in many measurement cases, but many problems can often be avoided in many human body surface topography studies, because human skin surface is often evenly coloured, not especially shiny, and generally free from major colour changes. As well, the body shapes of interest can largely be assumed to be smooth, not too convoluted, and free from discontinuities and steep gradients, and this suits the photographic measurement method. It is foreseeable that the technique could be used for a variety of purposes such as providing breast volumes for apparel fitting, aiding scoliosis surveillance, but primarily by helping to create body moulds for radiation positioning and for prosthetic devices.

This paper provides a non-technical outline of the features of the technique, to present this method of measurement and its characteristics, with examples of successful measurement.

Keywords: shape-from-shading, photography

1. Measurement by Shape-From-Shading

1.1. Outline

The goal of this project has been to develop a means of determining numerical dimensions of small or large areas of human bodies from single photographs, providing measurements which may be useful in various applications - in medicine, anthropology, personal studies, apparel fitting, fitting of protective devices for sport or medical treatments, and so on. The demand for body shape measurement is apparent in the literature. The concept is demonstrated by Fig. 1 and Fig. 2, which show an example of an adult back, imaged at a close range. Although the back's three-dimensional shape may be apparent, numerical three-dimensional information is not immediately provided by the photography. But it is contended that, under certain circumstances, useful numerical three-dimensional models of suitable regions of the human body can in fact be created from such single photographic images, meaning that measurements can be taken from the surface model. It has to be appreciated that a person looking at the image is not necessarily directly observing the shape, but is inferring it from the grey-levels, but reflectance levels cannot be interpreted directly as a valid indication of slope or shape. That is, it might seem that is only necessary is to scale reflectance values to surface heights, but in fact the theory is complex. The shading method is an enhancement of simple observations of the reflectance values in the imagery. This project seeks a solution by making use of the combination of suitable conditions which can occur over areas of the human body:

- The human skin surface is generally evenly and often lightly coloured, not especially shiny, and generally free from major colour changes, albeit excluding some cases of certain skin hues, or abnormal levels of sheen, or perhaps tattoos.
- Body shapes can generally be assumed to be smooth, not too convoluted, and free from discontinuities and steep gradients.
- Body areas do not usually need to be measured to high accuracy, compared with industrial or machined parts for example.

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Fig. 1: The photograph suggests shape information, but it does not actually yield numerical dimensions.

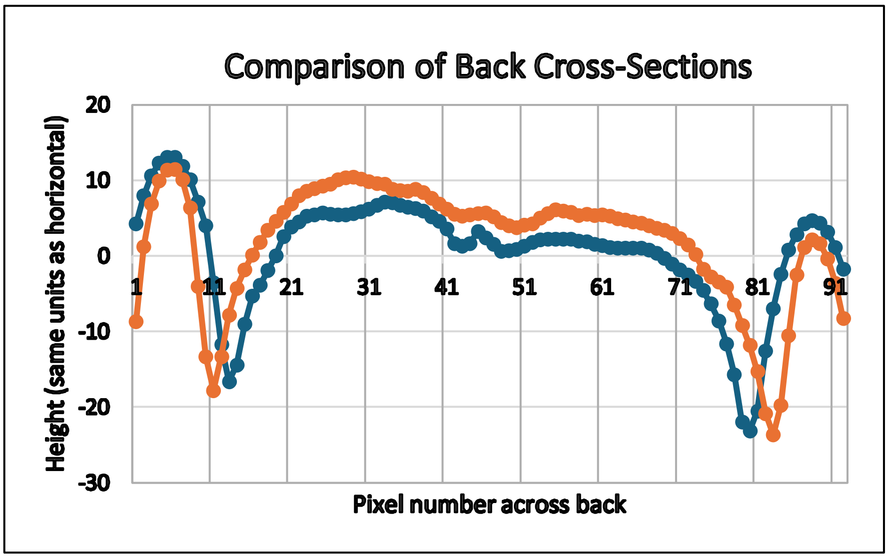

Fig. 2: A profile across the body shown in Fig. 1, indicating that numerical three-dimensional body-shape information can be generated.

Fig. 2, in which the axes are shown with a measurement scale is an indication that numerical information can be obtained. The associated three-dimensional surface model can be rotated to optimise the view; slices can be taken from it, or the model can be processed to reveal features of interest; the shape model can be mathematically compared with other three-dimensional patient shapes, obtained on one patient at different epochs, for example. More details of this particular case are given along with other case studies below. The work described in this paper is a continuation of work reported previously; see Mitchell, [1],[2],3],[4],[5],[6].

1.2. Concepts

The theory by which a surface model is created from a single photographic image was espoused by Horn [7], according to Wikipedia, using the name “shape-from-shading”, or SfS as it is called here. The principle behind SfS is that the image intensity value (i.e., grey-level or reflectance) at any pixel on an image is related by a simple mathematical relationship to the surface gradient of the small area on the object which corresponds to that pixel on the image, assuming that that surface element is illuminated by a known light source. The surface gradients, and hence the object shape, may be deduced in certain circumstances.

It might seem that is only necessary is to scale reflectance values to surface heights, but in fact the theory is complex. According to SfS theory, the reflectance at any pixel on an image is a function of the mathematical dot-product of two unit-vectors, one vector defining the ray reflected from the surface and the other defining the normal to the surface. This reflectance level, or simply reflectance, is related by the physical laws of reflection in three-dimensions to the angle between directions of the light ray from the light source and the surface normal. Both vectors are, of course, defined by two parameters, such as gradient and direction. Obviously, two gradients are needed to define the direction of the surface element at any one pixel. The gradients are generally being sought in SfS, assuming that they can then be used to deduce height coordinates. But deducing the two parameters which define the direction of the surface normal – and hence the surface direction – is normally not possible given just one dot-product value, as there is generally an infinite number of solutions for the gradient and direction of the surface at any observed point. It can be impossible to find a solution for the shape unless additional information is available or if constraints are applied.

Overcoming the problem of an infinite number of solutions is thus the main challenge in this work. A solution may be sought if some assumption can be made about the surface. But solutions are often possible in cases of body shape by using some approximations. In the case of human body measurement, a solution is possible by using some prior knowledge about the characteristics of the object surfaces.

The method proposed here has advantages and disadvantages in comparison with alternatives. Its main advantage is that it has almost no cost. Body shape measurements of the three-dimensional shape of some external surfaces of the human body are seen as being among the small number of applications which can make use of the method’s capabilities while also overcoming the disadvantages. The demands in these cases are not identical and various solutions which are appropriate in the different cases are apparent. However, the most useful applications for this measurement of the human body are seen to arise when cheap, quick and easy observation is sought. Techniques such as laser scanning, photogrammetry, structured light methods and even Moiré fringe methods, which provide data which may be more accurate and comprehensive and more easily comprehended than this method is, but they require the use of specific equipment, which is not necessarily easily operated, and they are usually a resource which is relatively expensive and not necessarily accessible.

The proposed measuring technique is not of high accuracy, but it is attractive because of its simplicity in both imaging and processing: it needs no equipment other than a camera with a light source in a known position, as provided easily in practice by most flash cameras, and it clearly involves the numerical analysis of just a single image of the object. It is non-tactile.

The method should not be confused with measurement of surface shape by stereoscopic photogrammetry using multiple images of the surface; see, e.g., Fryer *et al*, [8]. No attempt is made here, of course, to refer to any interpretation of the measurements to provide medical or other information, which clearly remains the province of the user.

1.3. Foreseeable Applications suited to Shape from Shading

Body shape measurements of the three-dimensional shape of some external surfaces of the human body are seen as being among the small number of applications which can make use of the method's capabilities. The most useful applications for this measurement of the human body are seen to arise when cheap, quick and easy observation is sought, such as for the following purposes.

i) *Torso measurement for clothes fitting and tailoring purposes, including for medical and sports applications*; (see e.g., D'Apuzzo, [9]), but notably for *prosthetics and orthotics fabrication*, (*see* e.g., Treleaven & Wells, [10], including moulds for use during radiation therapy, and protective sportswear for women.

ii) *Female breast measurement for medical purposes, for which there are few ideal measurement systems*.

iii) *Female breast measurement for clothes-fitting purposes, notably for sporting apparel* (see e.g., Colaianni et al., [11]). The demands of the measurement system are for speed and simplicity, perhaps suited to unskilled operators, but not necessarily demanding high accuracy, when there is a paucity of alternatives which are able to satisfy these requirements. Hutton *et al*. [12] report a project which involved recording of the breast shapes of over 2000 subjects, and attempt "*to highlight potential opportunities for clothing manufacturers addressing this niche area*".

iv) *Useful applications in scoliosis studies of the human back* (see e.g., Scoliosis Australia, [13]; Kandasamy et al, [14]. The most useful applications for this sort of measurement of the human body are seen to be for the back, for scoliosis detection or monitoring, or population screening, when the possible existence of early scoliosis is the main concern, and when easy observation is wanted. Scoliosis detection and monitoring is vital among adolescents, and predominantly girls, who are subject to idiopathic curvature of the spine. Programmes to detect the condition as early as possible by widespread screening have been instituted at various times in various countries, but they have often been abandoned due to costs. Widespread screening clearly needs to be cheap and easy. A wide range of measurement techniques of various levels of complexity, cost and accuracy, currently exists for taking the measurements which reveal spine shape, especially lateral curvature, for medical specialists, all with their advantages and disadvantages. The simple forward bend test is widely used. However, it is not amenable to providing a numerical model of the back shape; it does not provide a quantity which permits a good comparison of back shape from one time to another. Kandasamy *et al* provide extensive coverage of many techniques for observing scoliosis, outlining their advantages and disadvantages, but, notably, they conclude, among other things, that "*A cheap portable system providing three-dimensional information of patient's posture and back shape could thus help to better understand the three-dimensional nature of the spinal deformities*". The shape-from-shading process seems to be ideally suited to this application; see the example below. This application demands only simple imaging and requires only simple output, and SfS seems to be suited to expediting simple scoliosis detection and monitoring at early stages of the condition.

v) *The monitoring of body shape, and notably obesity, at medical, community health and personal levels*, *and epidemiological and anthropological studies of body shapes*.

Quantified information provides the option of undertaking comparisons of two or more measurements of a body area taken over time (see e.g., Mitchell *et al* [15]; Mitchell & Ang, [16]), and/or of comparing the shape of the left side and right side of the body, or even comparing one person's shape with another's. Such options are not conventionally offered by a simple photographic image.

2. Example: Back Shape

The aim of this example is to illustrate the practical effectiveness of the concepts covered above. The figures are intended to indicate the sort of shape information that can be deduced from the processing, but which is not available by simply examining the original photographic image.

In this example, a flash photograph of the human back of a young male (free from scoliosis) was imaged from about two metres, with a good quality digital camera (Canon EOS DSLR). The image, comprising 576 horizontal x 384 vertical pixels (giving an aspect ratio of 3:2) is shown at Fig. 1. The image was decreased in size to a smaller size of 144 x 96 for convenient handling, giving a focal length of 160 pixels.

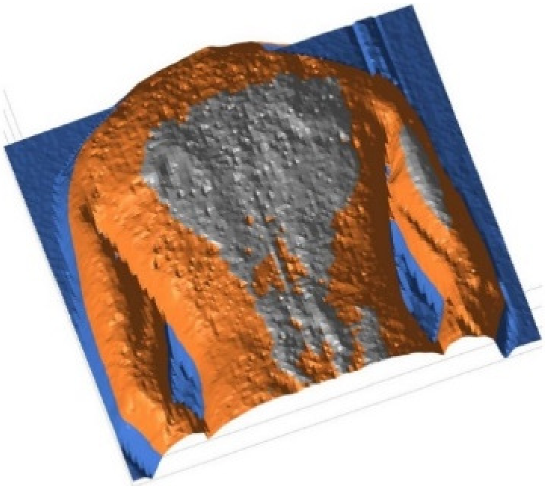

Fig. 3: The shape of the human back, after processing of Fig. 1 by the procedures proposed here, emphasizing that the numerical three-dimensional figure can be rotated to illustrate features.

3. Example - Female Breast

The case of breast measurement has certain idiosyncrasies which influence processing. The image of the breast can include extraneous contiguous areas, so there can be a need to identify and eliminate such sections. As well, aspects of the measurement procedure can be affected by the areola. On the other hand, the regular shape of many breasts can offer opportunities in the processing algorithm.

Fig. 4: The breast photograph does not immediately yield any dimensions, even though the grey-level image suggests shape information. (The original image has been converted from colour to monochrome, re-sized and re-formatted using PaintShop Pro 2023 software, version 20.2.0.1, from Alludo, Canada.)

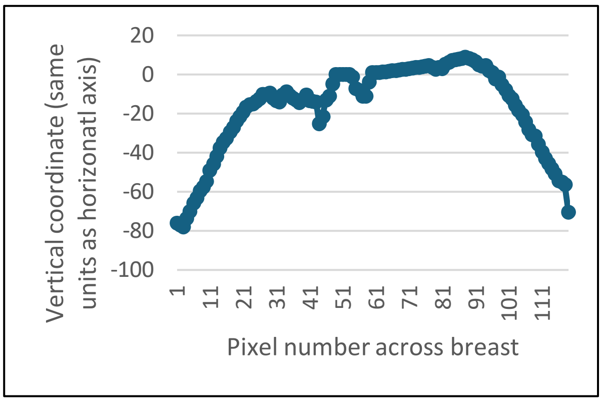

Fig. 5: Cross-section derived from the photograph in Fig. 6, illustrating the sort of numerical three-dimensional information, which can be provided. Distance measurements are in pixels, but scales are the same in both directions.

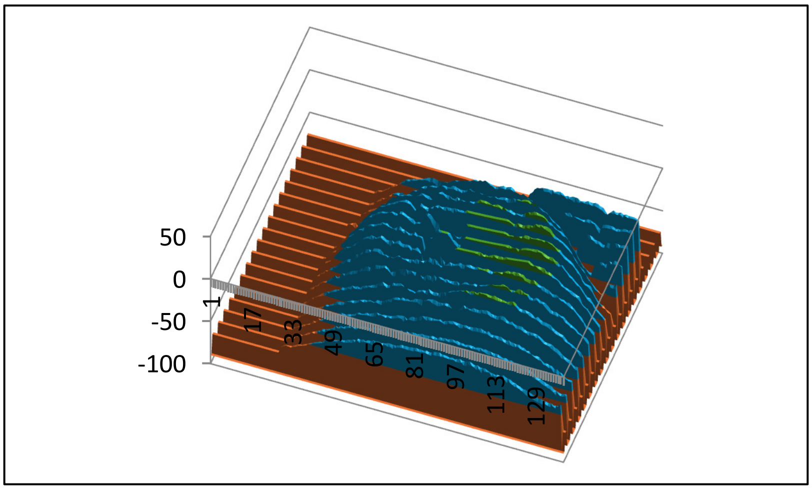

Fig. 6: A three-dimensional figure has been created from surface heights across the breast shown in Fig. 5 using the method discussed in this report. The figure is intended to emphasise that numerical information of various sorts can be extracted from the calculations which were used to create these figures. (Graphical views have been created using Microsoft Excel software.) The figure suggests that other forms of three-dimensional shape can be provided.

4. Conclusions

The proposed measurement method requires neither specialised equipment nor special operator skills, so that shape data can be collected by non-professional users. The equipment cost is negligible, and it has the advantage of quick recording, circumventing body movement. These attributes may be valuable in those cases for which cheapness and simplicity and non-specialist use is advantageous. The technique appears to be simpler and cheaper than many of the measurement techniques which are available for measuring human shapes to an accuracy which is satisfactory for many purposes.

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