Enhanced 3D Visualisation of Skin Disorders for Tele-dermatology

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Abstract. When observing a small object, the observer is usually able to interactively manipulate the object, dynamically changing its orientation, continually altering and improving the way light is reflected in order to best view details of 3D shape, colour and texture. Conventional photographs offer only a limited fixed viewpoint, dependent on the object pose and the lighting conditions prevailing at the time of image capture. Consequently, a photograph is often inadequate to satisfactorily convey a sense of shape colouring and subtle surface topography, especially when used to diagnose or document skin conditions for clinical purposes. This paper presents a novel, low cost imaging methodology to allow an enhanced interactive 3D visualisation of pigmented lesions through the transfer of efficiently encoded data via the internet, to provide a more realistic and intuitive visualisation of skin characteristics with particular application to tele-dermatology or enhanced medical records.

1 Introduction

Recent advances in low-cost optical sensor technology now afford the acquisition of high resolution (e.g. 12 megapixels or more) digital imaging for everyday photography. The internet has further facilitated the ability to readily disseminate photographic information around the world in a matter of seconds, allowing it to be viewed at leisure by its recipients. Digital data capture is also becoming increasingly popular in documenting the visual appearance of human skin, particularly for dermatology, pharmacology and cosmetic applications. Combining enhanced 3D visualisation, easy transmission over the internet and a set of tools for aiding the recognition of certain skin disorders [1-6], may make a novel and meaningful tele-dermatology system for the provision of improved remote health care an increasingly attractive possibility.

Here we concentrate on the first important steps in this process, data capture and enhanced visualisation. Standard 2D images often lack the detail necessary to reliably diagnose skin disorders, such as pigmented lesions (we use pigmented lesions as our case study). This is because photographs are illumination direction dependent and are therefore subject to fixed shadowing, specularity and occlusion from a single lighting configuration and viewpoint [7]. In order to overcome these limitations we present a method to recover both 2D (surface colour) and 3D (surface topography) skin characteristics for illumination invariant visualisation in an immersive virtual environment..

2 The problem with conventional clinical photography

Skin images acquired in a clinical setting often contain highlights associated with specular reflections, especially for oily and smooth skin. For raised skin lesions, strong shadows can also be present, that are dependent on the lighting direction. Even relatively minor topographic details can modulate the brightness and apparent colour of the skin surface. When a dermatologist examines the skin in a clinical environment, either with the naked eye or with a simple magnifying lens, these aberrations can be mitigated by both dynamically and interactively varying the lighting and viewing directions.

When examining photographs, however, the option to make such adjustments is no longer available, and the presence of such artefacts tends to severely limit the diagnostic usefulness of stored images. Strong pigmentation may exist within the lesion at various places around its margin, but it is not always easy to distinguish how much of the apparent variation in pigmentation is due to the shading caused by local curvature of the lesion surface or the colour produced by the pigmentation under the skin. A photograph taken with diffuse illumination, see Figure 1b, resolves these problems to some extent, and shows that a great many of the apparent brightness and colour variations apparent in Figure 1a were indeed due to surface topography rather than due to pigmentation per se, although illumination by

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diffuse light gives a characteristic 'unreal' appearance, with loss of perceived depth and fine detail. The fine scaling of valleys and bumps can hardly be discerned in Figure 1b due to the effects of the diffuse illumination, and specular reflection highlights remain a considerable problem. Clearly, neither the image with side lighting nor that with diffuse lighting is suitable alone, and one can begin to see why the storage of data enabling viewing in a virtual interactive environment is a desirable goal.

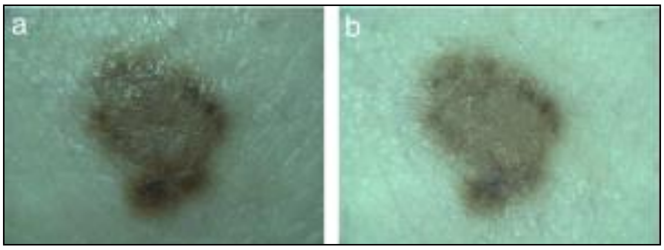

Figure 1. Two images of a pigmented skin lesion (see text for details): (a) conventionally photographed with side lighting by a single illuminate, (b) diffuse illumination by three evenly distributed light sources.

We have presented a new colour photometric stereo imager that relies on rapidly acquiring several images of a scene, with varying controlled lighting conditions, for documenting the appearance of skin and skin lesions in a more realistic fashion [7,8]. Experimental data indicates that the total information generated by the system, for use in visual or automated analysis, is potentially greater than that for either conventional photography or dermatoscopy alone [7]. Here its further development is considered to determine its usefulness and role in a wide range of dermatological tasks, including improved 3D visualisation for tele-dermatology applications.

3 Image acquisition – with an innovative skin imaging device

Image acquisition is achieved using a bespoke 3D image capture device, shown in Figure 2a and 2b. Briefly, this hand-held colour photometric stereo device, designed and prototyped at UWE and known as the 'Skin Analyser' consists of a small USB digital camera (UEYE) and a high-resolution compact lens (Schneider Xenoplan, 2.0/28mm, 1.5mm extension ring), surrounded by six high power LEDs (Luxeon, white). These components are encased in a rugged rapid prototyped ABS shell and connected to a laptop computer. A 3.7V rechargeable battery pack is used to power the LEDs. The working system is shown in Figure 2b.

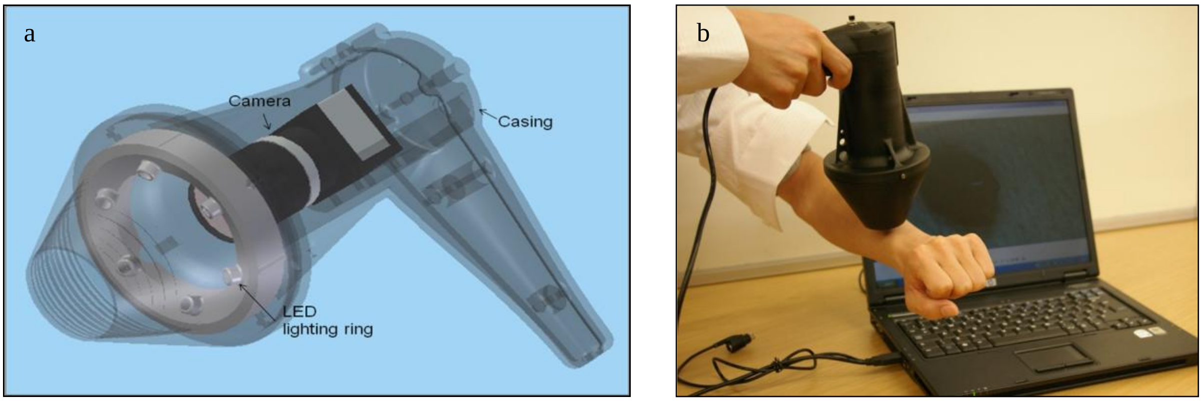

Figure 2. Model of the Skin Analyser and a picture of the actual device.

The six LEDs are individually illuminated and distinguished in succession and synchronised with image capture to provide six images of the scene under differing illumination conditions. A photometric stereo algorithm is then implemented to process these images for which a description now follows.

4 Photometric Stereo for surface recovery

We use a standard implementation of photometric stereo. We assume distant light sources (collimated light) and orthographic camera view. The image intensity, *I*, can be obtained from:

$$I_{(x,y)} = E\rho\cos\theta = \alpha\cos\theta \tag{1}$$

Where $I_{(x,y)}$ is the imaged intensity of the location (x, y), E is the strength of the light source, ρ is the reflectivity of the surface, i.e. albedo, $(0 \le \rho \le 1)$ and θ is the angle between the light source and surface normal vector. We combine E and ρ to give the composite albedo, α, related to the surface reflectance by assuming all imaging parameters are constant.

By definition:

$$\cos\theta = L \cdot N \tag{2}$$

Where L and N are column unit vectors of the light source direction and surface normal orientation respectively.

We use six input images to recover the topography and reflectance of the surface and separate the RGB colour channels, to give:

$$\begin{bmatrix} L^{1^T} \\ L^{2^T} \\ L^{3^T} \\ L^{4^T} \\ L^{5^T} \\ L^{6^T} \end{bmatrix}_{6\times3} \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix}_{3\times1} \begin{bmatrix} \alpha_R & \alpha_G & \alpha_B \end{bmatrix}_{1\times3} = \begin{bmatrix} I_r^1 & I_g^1 & I_b^1 \\ I_r^2 & I_g^2 & I_b^2 \\ I_r^3 & I_g^3 & I_b^3 \\ I_r^4 & I_g^4 & I_b^4 \\ I_r^5 & I_g^5 & I_b^5 \\ I_r^6 & I_g^6 & I_b^6 \end{bmatrix}_{6\times3} \tag{3}$$

Where L^{iT} is the transposed unit vector pointing to the i^{th} light source, α_R, α_G and α_B are the red, green and blue channel albedo respectively, and the suffices r, g and b describe the red, green and blue channels for the set of intensities respectively.

We can therefore recover the surface topography as a set of surface normal vector components, n_x, n_y and n_z and the composite colour albedo by combining α_R, α_G and α_B. Furthermore, pixels subject to shadowing or specularity are removed using a redundancy method proposed in earlier work [8].

5 Transmission and visualisation

With our method we obtain two data sets, one containing the composite albedo free from shadow and specularity and the other containing the surface normal information, described as a dense array of vectors or bump map. The composite albedo can take the form of a standard image, e.g. a Windows bitmap. The bump map file contains ASCII data describing the topography of the captured surface which can be, along with the albedo, readily transmitted over the internet in a compact form. To obtain full 3D geometry of the surface the bump map can be remotely integrated. Many robust algorithms exist [9-12] to integrate surface gradient data for 3D reconstruction. Our method is based on enforcing the integrability of the surface to be reconstructed and by globally determining a least square mean surface. Though some very fine detail may be lost with this method, in our experience, it preserves a level detail that is sufficient for our scale of dermatological feature extraction and viewing. Once transmitted the two data sets can be stored, or held in memory, on the remote terminal for viewing, Figure 3 illustrates this concept. The remote user can then choose to display the information in several ways, depending on his/her personal requirements.

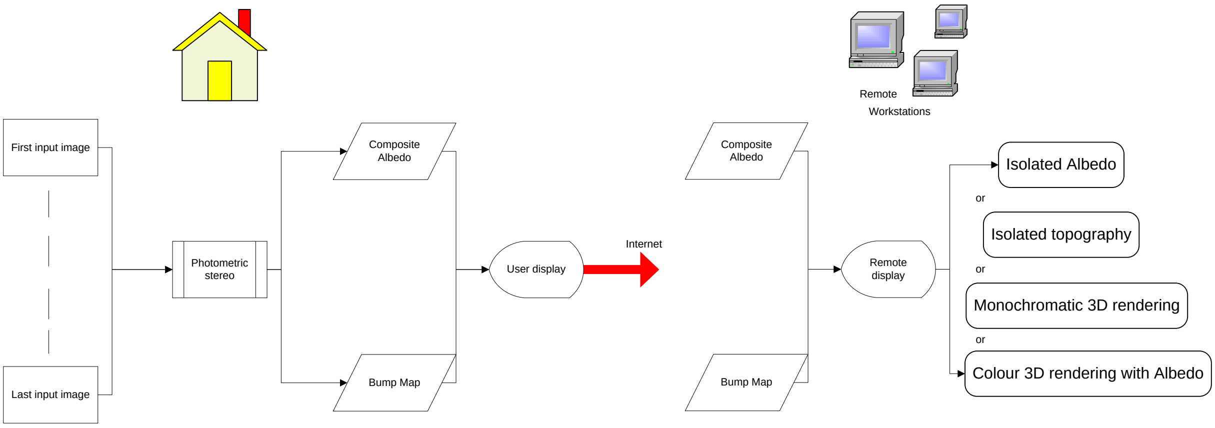

Figure 3. A flow chart describing the concept of the tele-dermatology system.

The richness of the data sets offers a unique utility to view in isolation the albedo, and/or a monochromatic bump map rendering, and/or a monochromatic 3D rendering of the topography and/or a realistic combined colour and topography rendering of the object. Examples of some of early renderings are given by Figures 4a – 4d.

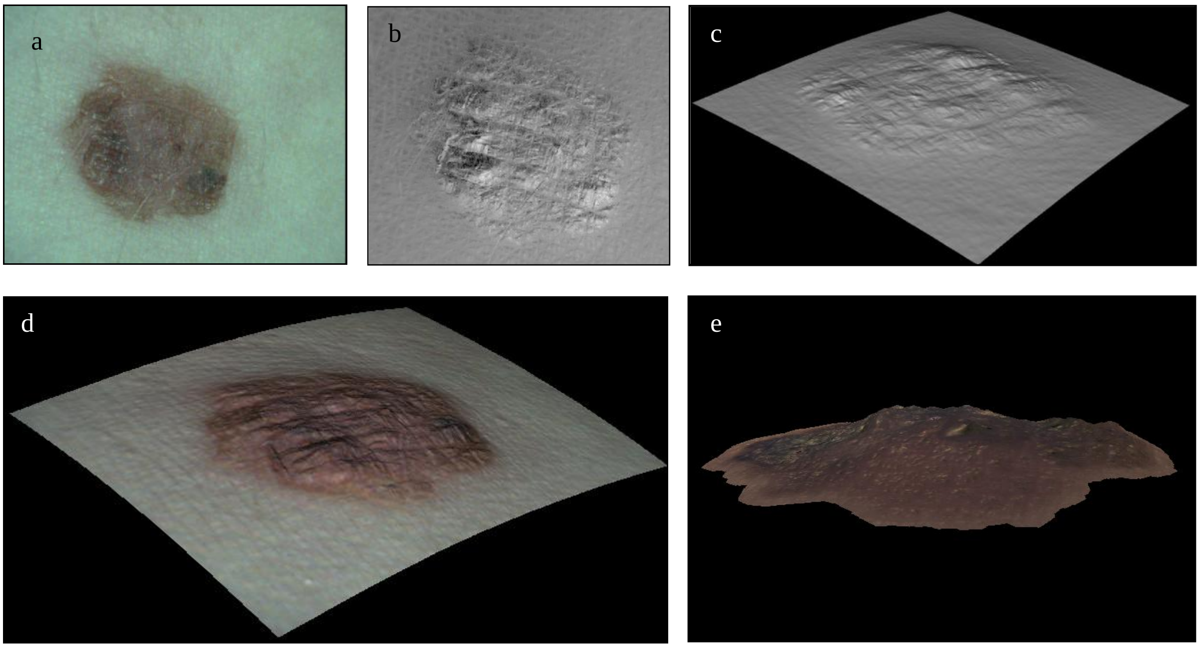

Figure 4. Five images depicted the different ways in which the photometrically recovered data of pigmented lesions (real data) can be visualised: (a) Composite albedo, (b) Bump map data rendered with light source emanating from an east-west direction, (c) 3D reconstructed surface in a virtual environment, (d) coincident albedo and reconstructed topography in a virtual environment, (e) Segmented 3D representation of an arbitrary lesion.

It can be seen that Figure 4a provides clear chromatic information about the surface of the lesion and importantly this is void of shadowing and specularity. Whereas Figures 4b and 4c represent snapshots of two different types of shape visualisation, the former is an image of a synthetically rendered bump map, as imaged by the sensor and the latter shows an arbitrary view of a reconstruction of the surface of the lesion. Both of these environments can be interactively controlled by the user, for example the lighting direction can be changed and/or the viewpoint can be manipulated in real time. This, therefore, mimics the possible actions of the clinician in order to obtain an optimum view when working with the patient. Furthermore, these particular illustrations aid the observations of subtle topographic variations by reproducing fine detail at a level that surpasses other techniques. Figure 4d provides the full interactive rendering of the lesion and Figure 4e shows a view of an automatically segmented lesion. By adding existing and new heuristic tools to the process we have a potential utility for a comprehensive computer assisted diagnosis system.

6 Potential utility for diagnosis of melanoma

Previous work [1-6] has shown a significant interest in classifying melanoma. With tele-dermatology in mind, and a view to developing computer aided diagnosis of malignant melanoma (MM) the skin analyser has been used to image patients with pigmented lesions. In order to characterise the 3D skin texture, two separate numerical methods have been proposed by Ding et al. [13] which quantify surface direction and magnitude disruption, which we believe may be a possible indicator for MM. Preliminary studies have resulted in 80% specificity. This demonstrates that 3D texture analysis can provide potentially very useful MM indicators in addition to existing 2D feature analysis.

7 Discussion and conclusions

We have shown how a software based interactive virtual 3D visualisation environment, combined with a low-cost 3D image acquisition system, can offer a richer and more informative viewing experience than is possible using conventional static 2D photographs for remotely visualising a patient's skin. A 6-light photometric stereo acquisition method combined with a dynamic interactive synthetic viewing environment allows fine surface details to be more readily perceived. The interactive control of synthetic viewpoints and lighting conditions in real time gives a more immersive and intuitive viewer experience, closely replicating the natural interaction with the patient's skin. For diagnosing skin tumours, it is also helpful to be able to visualise true skin pigmentation variation in isolation from 3D topographic influences and surface highlights; indeed, this is a major component of standard techniques, such as epiluminescence microscopy and dermoscopy systems. Our technique appears to be a plausible method of achieving an appearance that is part-way towards that possible using oil immersion or polarized light, but has a potential advantage over these methods in that a natural optical transmission coefficient at the air–skin interface is preserved. As a result, there is no unnatural appearance of excessive penetration of light into the skin or distortion of the skin. This work is on-going and further developments, such as improved resolution and improved graphics capability are in progress.

Acknowledgements
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