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Infrared imaging of varicose veins

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ABSTRACT

It has been established that varicose veins are better visualized with infrared photography. As near-infrared films are nowadays hard to get and to develop in the digital world, we investigated the use of digital photography of varicose veins. Topics that are discussed are illumination setup, photography and digital image enhancement and analysis.

Keywords: vascular imaging, infrared photography, image processing.

1. INTRODUCTION

Already in the 1970s near-infrared recordings were made of the human (sub)cutaneous vascular structures with special infrared films [1], [2]. However, nowadays these special films are hard to get, mostly because in photography films are more and more replaced by charge coupled devices (CCDs) in digital imaging. For these reasons, we investigated the use of a digital camera for infrared photography of veins and how we exploit the digital image format by using digital enhancement techniques.

2. MATERIALS AND METHODS

To photograph an object with infrared light, one needs a light source which emits infrared light, a camera that is sensitive to infrared light and eventually optical filters to select a part of the infrared wavelength domain. We also look at the right technique to enhance the final photo.

2.1. Light source

To illuminate the object of interest, a light source is needed with sufficient intensity in the infrared domain. As most common light sources are used for the visible domain, they are generally not suited for near-infrared photography. There are special infrared light sources, such as light emitting diodes (LEDs) that are used for remote controlling the radio of tv set. However, a single near-infrared LED is generally not suited for infrared photography due to its low intensity and its non-uniform, focused light distribution.

To overcome these problems with one infrared LED, we looked whether an array of infrared LEDs would improve the overall intensity and uniformity. A picture of such a LED array, sold for night surveillance, is shown in figure 1.

Another way to solve the intensity and uniformity problems is to use a halogen bulb (photographic lamp, Hedler 1250W). Its spectrum ranges from UV to near-infrared; its intensity is so high that even in the infrared domain the lamp is brighter that the infrared LED array. The spectra of both the halogen bulb as the infrared LED array are shown in figure 2.

2.2. Camera

A digital camera is, contrary to what would expect, very sensitive to infrared light. As infrared light normally disturbs the normal picture, an infrared cut filter is placed inside almost every commercial camera in front of the CCD chip (Figure 3). In some cameras this filter is removed during night-shot photography, but often then a number of settings (like aperture or timing) are restricted by the manufacturer. A better but far more risky way is to remove the IR

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cut filter and replace it with a piece of glass to preserve the auto-focus capabilities. We bought our infrared enabled camera, a Sony DSC-717 (5 megapixel, figure 4), from LDP LLC, (15 Hunter Ridge, Woodcliff Lake, NJ 07677, USA, http://www.maxmax.com), a company specialized in adapting digital cameras for infrared photography.

Figure 1 Infrared LED array (http://www.conrad.nl).

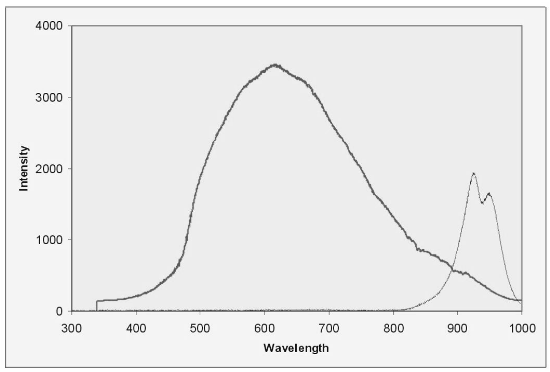

Figure 2 Light spectrum of a halogen bulb (bold line) and an infrared LED (fine line right). Note that the intensities are relative. The intensity of the halogen bulb is much higher than the LED, even in the infrared domain.

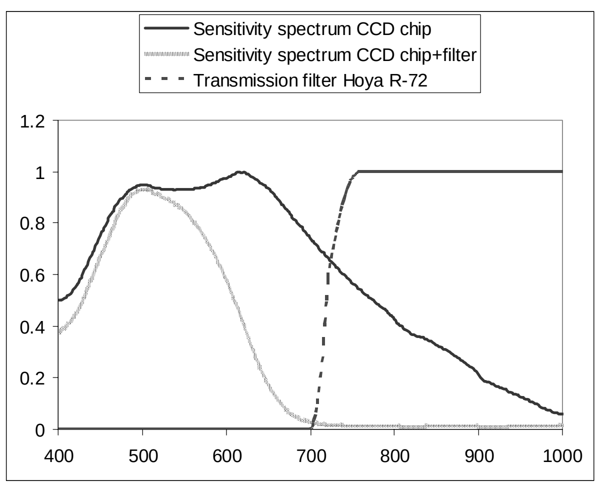

Figure 3 Sensitivity spectrum of CCD chip with and without infrared blocking filter. The transmission spectrum of the Hoya R-72 is showed with the dashed line.

Figure 4 The Sony DSC-717 where the infrared blocking filter has been removed.

2.3. Filters

A long pass filter (Hoya R-72) with a cutoff at 720 nm was used to remove the visible light. Its transmission spectrum is shown in figure 3 with a dashed line.

2.4. Image enhancement

In addition to the contrast gained through infrared photography, the contrast of varicose veins can be enhanced by digital image processing techniques. The simplest technique is to normalize the image (set lowest pixel value to zero, brightest to 1). The general formula is:

$$p_{i,new} = (p_{i,old} - o) * f \qquad \forall i \in \{R,G,B\},$$

with o the offset and f the multiplication factor. Normalization of the image is then given by $o = p_{\min}$, and $f = 1/(p_{\max} - p_{\min})$. Normally, the user controls the o and f values manually to enhance the varicose veins as the darkest and brightest pixel values do not correspond to varicose vein and skin respectively, but for example to shadow and background of the photo.

In addition to image enhancement, we also looked at ways to segment the varicose veins. One would first think of thresholding the image by selecting the pixels below a certain pixel value. This works for a flat object where the illumination distribution is homogeneous, but as the legs have a three dimensional shape, light is not coming back to the camera in a uniform way. That is why we devised a method to remove the illumination trend before the threshold step.

A simulation of the method is shown in figure 5. The upper line denotes a line profile in the original image where the veins are the valleys lying on a linear slope of gradually changing background. Random noise had been added to simulate photon and electronic noise. The bottom big dashed line shows the result of our method where we applied a 2D Laplace filter $\left(\frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}\right)$ based on a Gaussian to smooth and take the second derivative. One sees that the zero crossings now correspond to the bending points of the upper line thus corresponding to the edge of the varicose veins. As in practice the bending point does not form exactly the edge of the veins, the user can set a threshold value somewhat below or above the zero crossing to dilate or erode the varicose vein segmentation.

3. VISUALIZATION OF VEINS IN THE FOREARM

Examples of digital enhancement and our varicose vein segmentation technique are shown in figure 6. The figure shows the results on applying these techniques on a digital photo of the forearm which is illuminated with a LED array light source. One sees that it is easy to enhance the contrast in an image, just by changing contrast settings. One also sees that our varicose vein algorithm segments the vein quite well. Only small veins with low signal appear difficult to segment due to their low signal.

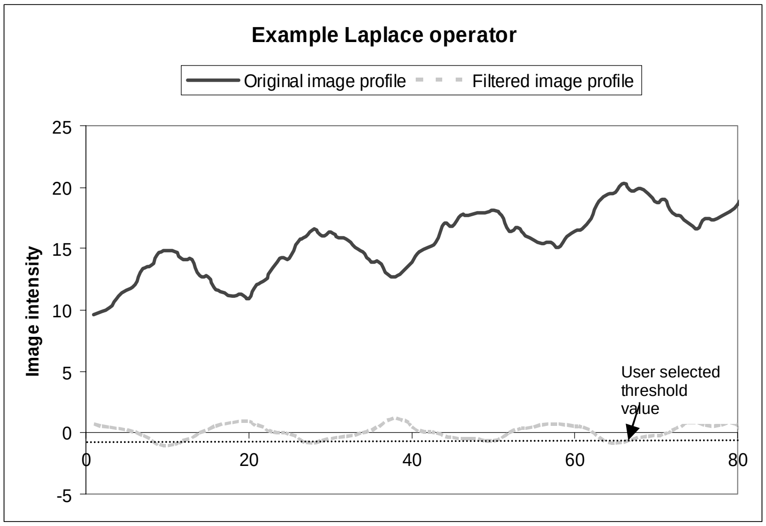

Figure 5 Segmentation of the varicose veins (i.e. valleys) using the Laplace operator.

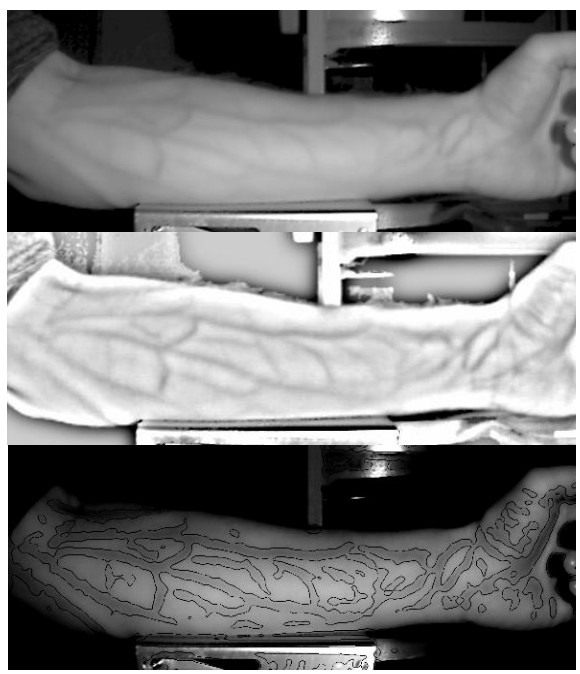

Figure 6 Effect of digital enhancement on an infrared picture of the forearm: Top, original infrared image. Middle: Enhanced image by changing contrast settings in Microsoft Word. Bottom: Results of vein segmentation using Laplace operator (Threshold value=0).

4. VISUALIZATION OF VARICOSE VEINS

We currently use infrared photography (in addition to duplex ultrasound and normal photography) to quantify the effects of different treatment methods of varicose veins like sclerotherapy, ambulatory phlebectomy, and transilluminated powered phlebectomy.

A photo of the varicose veins with and without the infrared filter is taken with the Sony DSC 717 5 mega pixel camera with the photographic light source. This light source is so intense that is enables sharp and fast photography of the slowly moving leg of the patient. To evaluate the effectiveness of the different treatment methods, the digital picture of the leg taken with the infrared filter is divided into rectangular blocks, where in each block the percentage of varicose veins is determined. In medical practice, this is done with duplex ultrasound, where one can measure the dimensions of the cross section of the varicose veins and the determination of venous incompetence.. Overall ratios are obtained from the digital image using special computer software. This software has a portable user interface written in Java and contains many advanced image processing and visualization functionality written in C++ and C (http://www.ph.tn.tudelft.nl/DIPlib/documentation.html, [3], [4]). This software is used to segment the varicose veins and calculate the varicose vein surface ratios. The procedure to calculate the varicose surface ratios is as follows:

- The user indicates the position of the block grid using a transparent sheet with blocks on the edges (Fig 7a). An infrared picture is taken and loaded into the computer.
- The computer uses the Laplace operator to segment the varicose veins (Fig. 7b). The user can control this process using a threshold value. One sees that this results in artifacts on the boundaries, just where the blocks are visible on the transparent sheet. This is the main reason to leave the interior of the transparent sheet blank. The blocks on the boundary are discarded in the further analysis.
- The computer shows an artificial grid which is scaled, rotated and aligned by the user on top of the blocks of the transparent sheet (Fig. 7c).
- The computer calculates the surface ratio of varicose veins per grid block. The results are exported to an Excel file for further analysis (Fig. 7d).

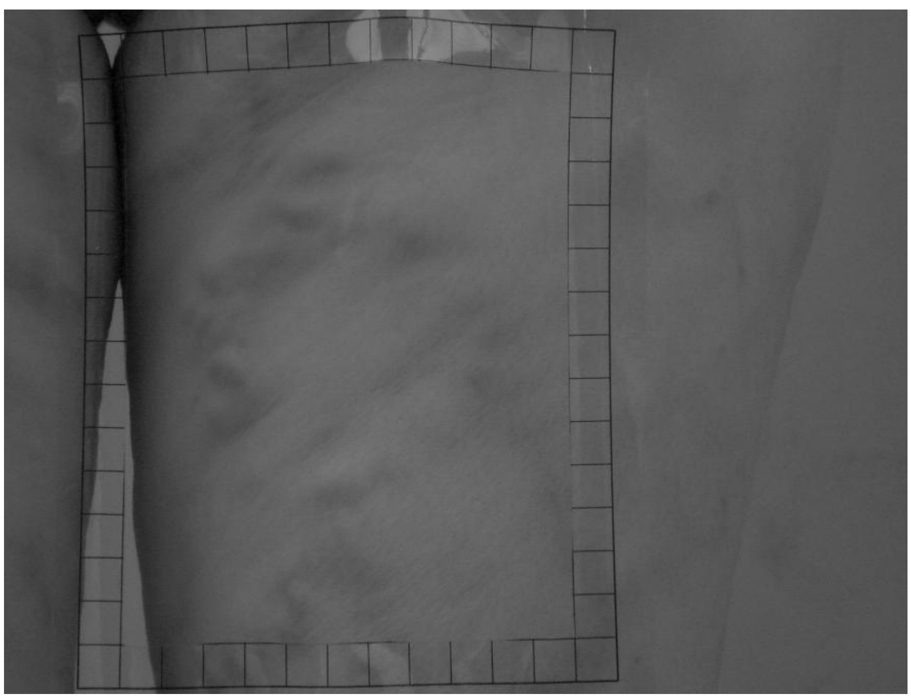

Figure 7a

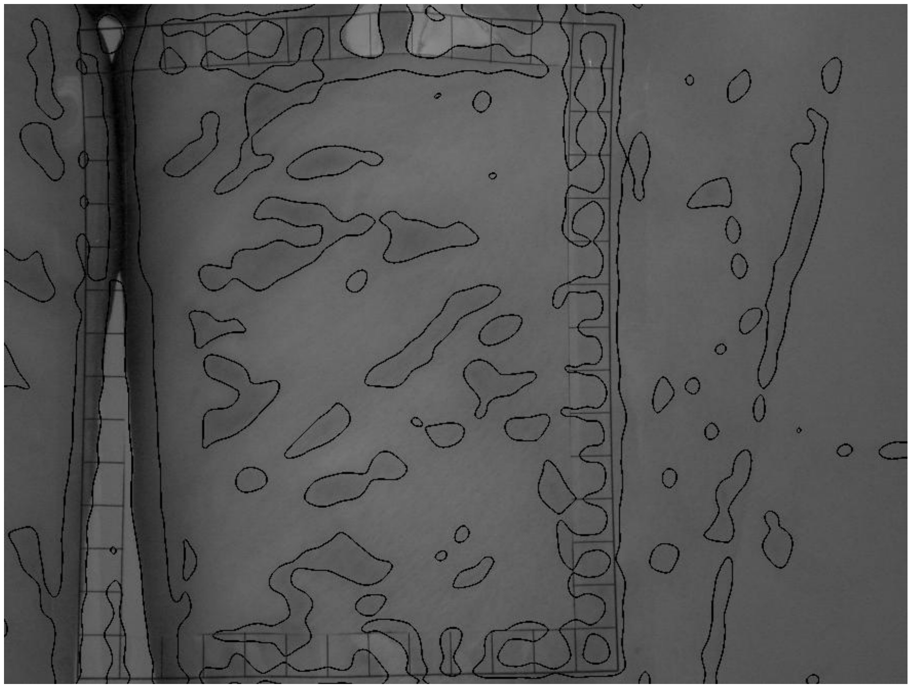

Figure 7b

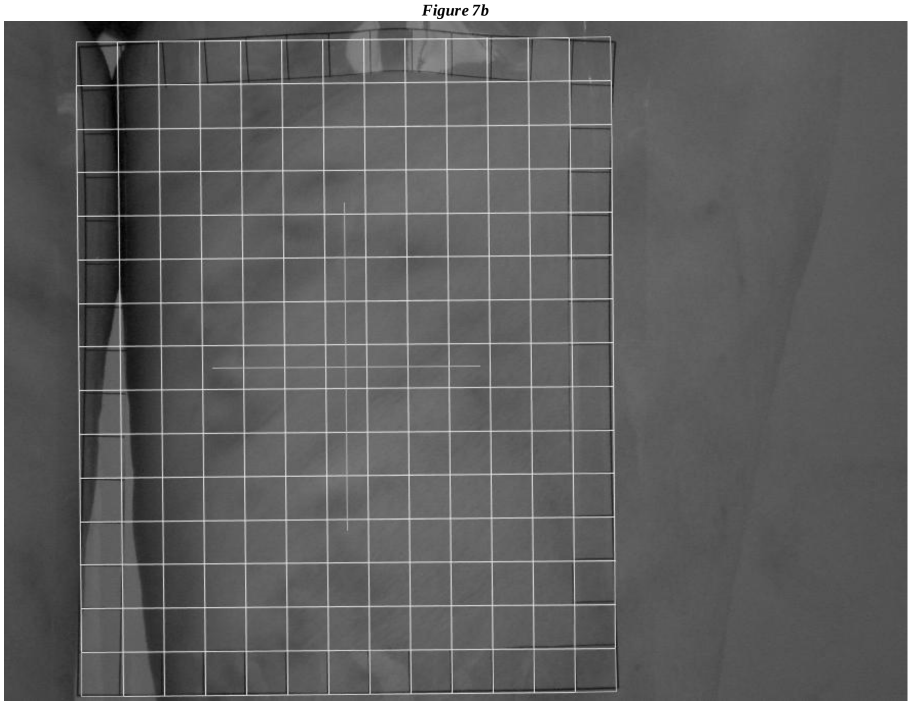

Figure 7c

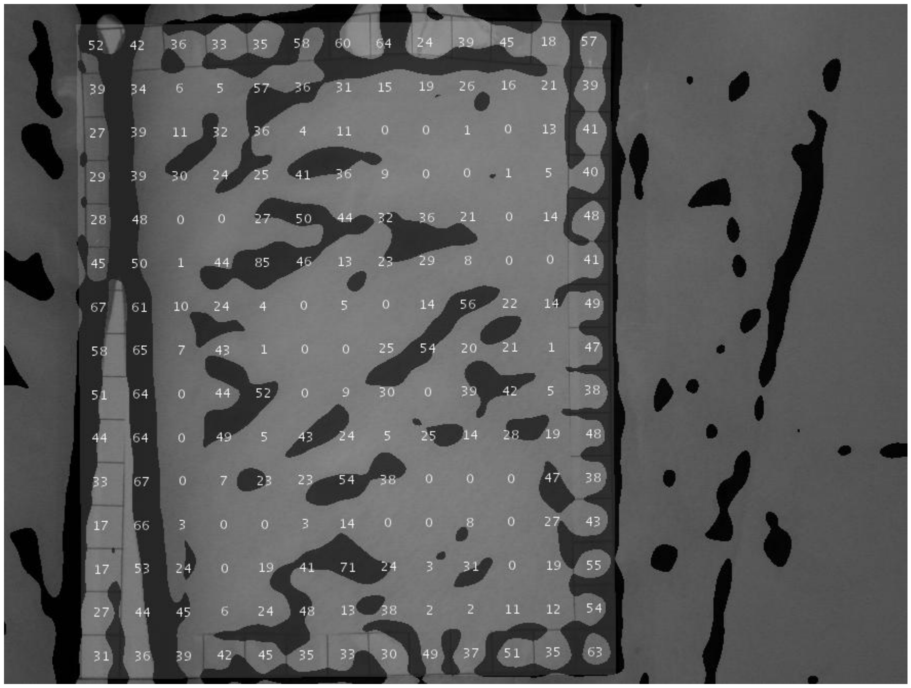

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Figure 7 Determination of varicose vein surface ratios. (a) Infrared photo of the leg of the patient where a transparent sheet with blocks denotes the area of interest. (b) Segmentation of the varicose veins by converting the image to a grey-valued image and thresholding the result of the Laplace operator to calculate the inflection points of the image intensity profile. (c) Alignment of an artificial grid to the grid blocks of the sheet. (d) Calculation per block of the varicose vein surface ratios.

5. OUTCOMES AND RECOMMENDATIONS

We showed that digital consumer cameras are relatively easy to adapt for infrared photography and form an appropriate replacement for infrared films. As the photos are already digital, they are easy to enhance further with image processing algorithms. Our research on the treatment method of varicose veins will start in the nearby future and will include about 600 patients in the next three years.

The optical setup can further be improved by reducing the scatter from the surface of the skin by crossed polarizers or illumination from a 30 degree angle [5].

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