Remote Optical Stereoscopic Multispectral Imaging during Cardiac Surgery

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Abstract

Within the near infrared (NIR), coronary arteries show higher contrasts against the myocardium than coronary veins. Also, NIR can penetrate deeper into tissue than visible light (VIS). This opens perspectives to enhance coronary vasculature by combining VIS and NIR images. This may be useful in instances like intramyocardial course of coronary arteries, increased epicardial fat, epicardial adhesions after previous surgery, or pericarditis.

Two cameras, with dual-band LED-arrays, alternately capture VIS color frames (400–780nm) and NIR grey-scale frames (910–920nm). Arterial NIR contrasts are distinguished from shadows and surface reflections, selectively enhanced, and back-projected in stereoscopic VIS color video. Proof of principle has been delivered on porcine and human hearts using off-line processing. We present these results and some of our work in progress.

1. Introduction

During cardiac surgery, a well lighted myocardium usually forms a sufficiently contrasting background to identify the dark coronary veins and the lighter coronary arteries. However, in some instances visibility of the coronary arteries may be impaired. Examples of such instances are intramyocardial course of coronary arteries, increased epicardial fat, epicardial adhesions after previous surgery, or pericarditis.

During previous research on photoplethysmographic imaging at 3 wavelengths [1] we noticed that subcutaneous vascular contrast improved when increasing wavelengths further into the near infrared (NIR). NIR imaging of superficial blood vessels in itself is not new and knows a long historical development with a large variety of applications [2-6].

It is obvious that real-time imaging of buried vasculature can be useful, but usually it is incorporated as a monochromatic and monoscopic technique (thus impairing depth perception) and without offering the possibility to also simultaneously obtain normal full color video. Therefore, we built a stereoscopic camera that offers a freely adjustable choice between normal color video mode (VIS-mode, from *vis*ible), grey-scale NIR-mode and a composite enhanced mode in which the extra contrast information derived from the NIR is back-projected into the normal color image.

Figure 1. A trolley with the device consisting of 2 CMOS cameras plus 2 VIS/NIR LED-arrays on a swivelling arm, all connected to a dual Xeon processor PC.

2. Methods

Figure 1 shows the device. Two modified RGB-color CMOS-cameras (Vector technologies, Belgium), with apochromatic lenses and dual-band LED-arrays, simultaneously streamed Left (L) and Right (R) image data to a dual-processor PC. Both cameras captured color images within the visible range (VIS, 400–780nm) and grey-scale images within the near infrared range (NIR, 910–920nm) by sequentially switching between LED-array emission bands. The Bayer filter pattern on the color camera chips was designed to be highly transparent within the NIR-range for all 3 filter pattern colors (Red, Green en Blue). Thus VIS and NIR images always were pixel-to-pixel matched. Image-size-settings of 1280x1024 for VIS & 640x512 for NIR produced 12 cycles/s (1 cycle = 1 VIS L&R-pair + 1 NIR L&R-pair). Decreasing image-size-settings (640x512 for VIS & 320x256 for NIR) increased camera-speed to 25 cycles/s.

NIR can penetrate deeper into the tissue than VIS and so can reveal superficial vessels. Contrasts obtained from the NIR-images can be used to enhance the corresponding VIS-images. This approach works fine for contactless imaging of superficial blood vessels through the intact skin (see figure 2) and an article solely dedicated to this application has been accepted for publication [7].

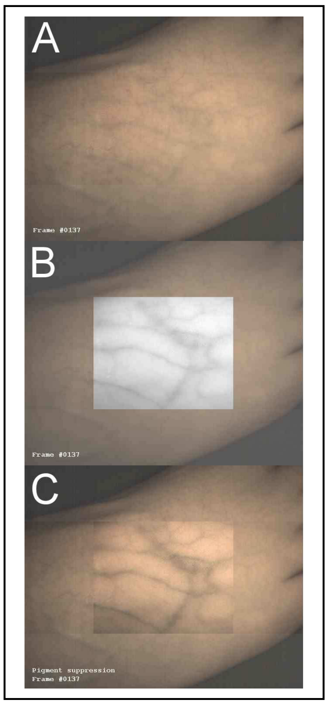

Figure 2. Raw VIS (a), NIR (b) & enhanced (c) foot.

Transcutaneous applications such as shown in figure 2 mainly reveal veins, simply because these are located closer to the skin than arteries.

When, however, applying the device during cardiac surgery on pigs, we noticed that compared to VIS-mode in NIR-mode a considerable contrast *increase* resulted for the coronary *arteries* against the myocardium background versus a contrast *decrease* for the superficial coronary *veins* (see fig. 3a & 3b). We wanted to exploit the improved arterial contrast *without* sacrificing venous contrast and therefore added a processing step calculating the ratio between the intensities of the NIR and the red channel, as well as the ratio between the intensities of the NIR and total VIS-image (thus R, G and B together).

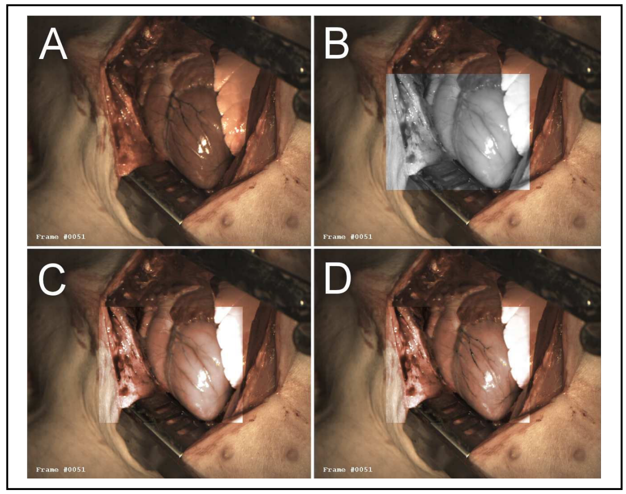

Figure 3. Raw VIS (3a), NIR (3b) and enhanced images of a porcine heart either without (3c) or with (3d) addition of the extra $(I_{NIR}/I_R) < (I_{NIR}/I_{VIS})$ processing criterium.

Figure 4 shows the number of pixels as a function of both calculated ratios. The ratios are compared to a variable threshold setting so that for each pixel it can be decided individually from which spectral range the contrast information should prevail.

Figure 3c shows an enhanced image without using this criterium, whereas figure 3d shows the result with this extra criterium added.

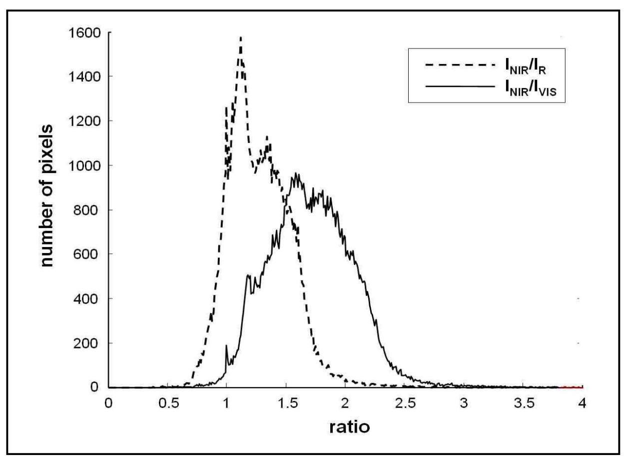

Figure 4. The number of pixels as a function of ratio for I_{NIR}/I_R (dashed curve) and for I_{NIR}/I_{VIS} (continuous curve).

In addition to vascular enhancement we continued our research aimed at SpO2-camera technology with an in-vitro experiment to determine in how far quantitative oxygen saturation data can be measured using our proposed multispectral approach [8]. Preliminary results of this experiment will be shown during our slide presentation.

3. Results

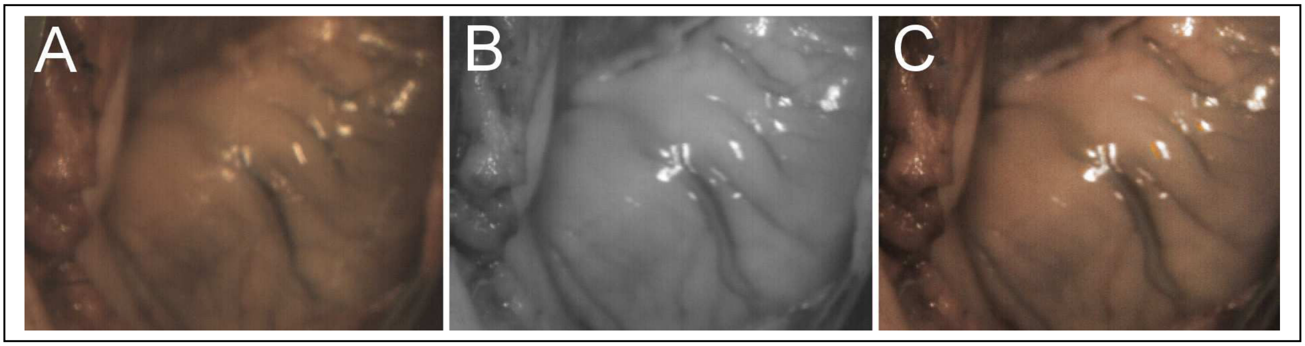

Figure 5. Human heart with thick epicardial fat layer. The VIS image (5a) shows 1 vein, but the NIR (5b) reveals a parallel artery, leading to an enhanced view (5c). Note that shadows are not enhanced and also reflections remain natural. Stereo version available at: http://www.erasmusmc.nl/ThoraxcenterBME/html/research/additional/bloodvesselcamera.htm

Application of the device during open heart surgery on patients revealed that indeed coronary vasculature hidden below the surface could be visualized (see fig. 5).

A full paper with our first results, obtained during routine heart surgery on patients in combination with post-processing, will be published in November 2006 [9].

4. Discussion and conclusions

The method looks promising and the pending patent [10] can in principle be combined with a previous patent for SpO_2-imaging [8]. The applied I_{RED}/I_{NIR} ratio dependent enhancement criterium has a rough qualitative relationship with blood oxygen saturation.

Apart from eventual future combination with SpO_2-imaging, the enhancement method needs improvements. Due to the alternating acquisition of VIS & NIR images, the enhanced images contain some movement artefacts. Also, real-time processing is clearly preferable above off-line processing. To solve these issues, the device is being upgraded to parallel VIS & NIR acquisition at a higher frame rate combined with real-time processing.

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