Real-time Visual Analysis of Microvascular Blood Flow for Critical Care

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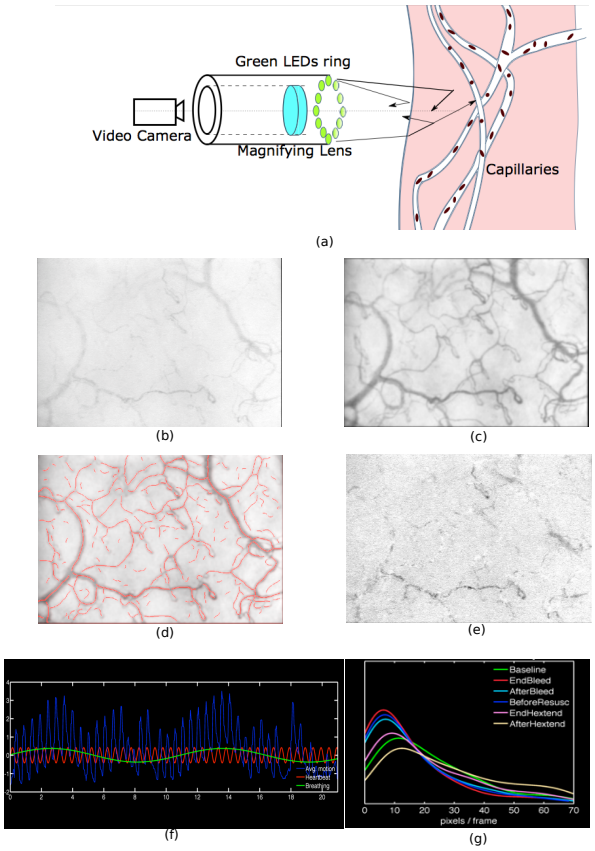

Figure 1: Given the low contrast, textureless microcirculatory video of a subject under varying hemodynamic status, we propose a framework to estimate physiological measurements such as blood flow velocity distribution, respiratory rate, and heartbeat rate. The microcirculatory videos are captured using a SDF imaging device. (a) Schematic of a portable SDF imaging device used for microcirculatory monitoring. The LEDs, arranged and optically isolated around the lens system, emit light optimized for red blood cell absorption. (b) One frame from the original video. (c) Vessel enhanced image from the video. (d) Extracted vessel skeletons. (e) One frame from the motion magnified video for blood flow velocity evaluation. (f) Heartbeat and respiratory rates estimated from the observed global motion. (g) Estimated blood flow velocity distributions for different hemodynamic statuses of the patient. Please refer to the paper for more details.

Side-stream Dark Field (SDF) [1] video imaging has been developed as a non-invasive imaging tool for real-time visualization of superficial microvascular flow. However, analysis of these videos is currently limited by manual or semi-manual operation and coarse sampling techniques, which makes quantitative analysis of microcirculatory status and response to disease and treatment highly subjective [2]. In addition, due to subsurface scattering within the tissue, transparency of plasma, imaging noise and lack of distinctive features, it is difficult to obtain reliable physiological data from SDF videos.

In this paper, we present an end-to-end, automated framework for real-time analysis of micro-circulation including vessel detection, heartbeat rate, respiratory rate, blood flow velocity estimation as well as variation of flow distribution over time. Our work can enable new research in critical care, helping correlate heartbeat rate and breathing cycle with flow distributions as well as study the effects of interventions and protocols in real-time for bed-side patient care. In comparison, most previous works either included significant manual interactions and were not real-time, or were tailored to high quality 2D images or 3D volumes that do not work well for SDF videos. The proposed method includes stages of video stabilization, enhancement, and micro-vessel extraction, in order to automatically estimate the statistics of the micro blood flows from SDF videos.

We use patch-based video stabilization method to eliminate the motion due to heartbeat, breathing and sensor position drift. In our method, we select the patches in which the variance of intensities is above a pre-set threshold such that the selected patches include enough texture for matching. Heartbeat and respiration rates can be obtained in the video stabilization process as well. Those physiological measurements can be used along with the microcirculatory blood flow parameters to further aid diagnosis and patient monitoring processes.

After stabilization, we have registered frames from which the skeletons of vessels are extracted. Based on the fact that the capillaries with red blood cells are usually darker in the frames, we take the minimal value of each pixel across all the frames followed by an anisotropic diffusion filtering process to get the vessel enhanced image. The vessel skeletons are extracted as minimals of the profiles across the vessels in the vessel enhanced image. One frame of the microcirculation video, the vessel enhanced image and the extracted vessel skeletons are shown in Fig. 1.

Even though we have vessel-enhanced images with improved contrast, it is still difficult to determine blood flow from video because signal to noise ratios in individual frames are still low due to subsurface scattering and high imaging noise. To make the blood flow more detectable, we use the motion magnification method proposed in [3]. Blood flow velocity is estimated from the motion magnified video and the vessel skeletons. Since the diameters of capillaries in the microcirculatory videos are small, the blood flow can be reliably approximated by 1D motion along the vessel skeletons. With this approximation, blood flow velocity is estimated from the EPI images along the vessel skeleton.

In the experiment presented in the paper, 18 healthy pigs have been anaesthetized and subjected to controlled bleeding for 2 hours. Then the subjects were fluid-resuscitated to expand the plasma volume. The distributions of the blood flow velocity estimated from the corresponding videos are consistent with the biological observations: as the blood pressure decreases due to bleeding, a general reduction in blood flow velocity manifests through a shift of the distribution of velocities across vessels towards lower values. On the other hand, one would expect that if resuscitation efforts were successful, then microcirculatory blood flow should return to baseline values, as indeed is shown in Fig. 1(g).

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