REMOTE AND NON-INVASSIVE BLOOD FLOW MONITORING SYSTEM FOR ASSESSING VASCULAR FUNCTIONS-STATE OF THE ART

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Abstract - Blood flow measurements have become an indispensible technique to study vascular function in vivo. Laser Doppler Flowmetry (LDF) and video imaging are the two non-invasive methods to estimate the blood perfusion in the microcirculation level and has taken an emerging and more and more preponderant place in clinical and research applications. They have become crucial to develop tools for diagnosis and follows-up of many physiological and pathophysiological cases and to provide both qualitative and quantitative information on vascular function. This project is designed to assess the vascular function in relation to the blood flow perfusion using Laser Doppler flowmetry and video imaging technique. This also extracts heart beat pulse from the live streaming of human face.

Key words-Laser Doppler Flowmetry, Blood perfusion, Micro circulation, Vascular function, non-invasive

I. INTRODUCTION

Monitoring vascular system is important because it can help to perform diagnosis and patients' follow-up, to understand the cardiovascular physiology, and to monitor positive or adverse effect of treatment. The vascular system is composed of a pump, the heart followed by a blood distribution system and the blood vessels. The majority of the vessels are made of three distinct layers which are from the lumen to the periphery- the endothelial layer or intima, the media or the muscular layer and the fibrous layer or the adventitia. Since capillaries contain only the endotheliar layer, vascular function can easily be assessed by notifying movement of blood perfusion in the skin.

Vascular dysfunction is a disorder of the vascular system characterized by poor function of the blood vessels. This can appear at the heart level or at the macrocirculation level and/or at the microcirculation level. For example arterial wall abnormalities in larges arteries can induce an increase of the arterial stiffness. At the microcirculation level, hypo-perfusion can appear in the case of antiangiogenic treatment or ischemia found in peripheral artery disease or in ischemic stroke. Further several vascular dysfunctions are found in many nonvascular diseases such as Alzheimer disease , carpal tunnel syndrome, diabetes, schizophrenia etc. Patients will experience a reduction in blood flow, making it harder to get oxygen and nutrients outlying cells. In addition, it is harder to remove wastes when the circulation is impaired. As a result, people with vascular dysfunction can experience cell death in cells that are not getting enough blood. This may be localized in a small area associated with particular impaired vessels. This paper explains how the vascular function can be assessed in micro level using two state of -the- art techniques- Laser Doppler Flowmetry and video Image Processing.

II. LASER DOPPLER FLOWMETRY

Laser Doppler Flowmetry is one of the important optical methods for microvascular studies. LDF was introduced in the 1970s after the development of laser technologies and fiber-optic systems. Since the 1980s, the laser Doppler technique has been used in a wide range of applications including assessment of skin reactions, intra-operative monitoring of myocardial blood perfusion in relation to bypass surgery, and recently also for intra-operative measurements of microcirculation in relation to aneurismal subarachnoid haemorrhage and deep brain stimulation (DBS) implantation. It is now an established technique for the noninvasive monitoring of micro vascular blood perfusion in tissue.

Laser Doppler flux signals show temporal fluctuations caused by physiological phenomena like heartbeat, respiration, and local tissue vasomotion. These fluctuations are often filtered out in the data analysis process. These Laser Doppler fluctuations caused by the heartbeat contain clinically useful information. LDF relies on the Doppler frequency shift (f) that appears when light is scattered by moving blood cells. The LDF perfusion is defined as.

$$\text{Perfusion} = \frac{\int_{\omega_1}^{\omega_2} \omega P(\omega) d\omega}{P_{DC}} \quad (1)$$

where $\omega = 2\pi f$ (f is the frequency) and $P(\omega)$ is the power spectrum of the photocurrent fluctuations. In order to remove the effects of the laser power fluctuations and skin reflectance variations, the integral is normalized by the power of the DC signal (P_{DC}). Most of the laser Doppler flowmeters use a

780-nm wavelength to obtain good skin penetration independently of skin color and oxygen saturation. LDF evaluates the perfusion in a small volume (the measurement depth is around 1 mm, depending person the tissue optical properties, LDF probe, and laser wavelength). It is a very useful technique to detect perfusion modifications in response to stimuli (vascular occlusion, heating, etc.).

In LDF, the tissue under study (skin, for example) is illuminated with a low-power laser light and photo detector collects skin information in the form of signal. The time-varying part of the photocurrent is band-pass filtered in order to reduce noise. This filtering can unfortunately also remove a noticeable part of the signal in some special cases. A too low upper cut-off frequency may dampen frequency components from many multiple shifts and/or red blood cells with very high velocity, which can reduce the increase in perfusion signal from increased blood perfusion. We have used high Q active band pass filter for this purpose. The steps involved in this process are plotted in figure 1.

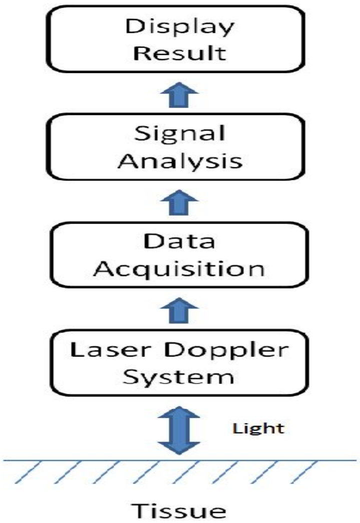

Fig. 1 Block diagram of LDF

III. VIDEO IMAGE PROCESSING

The human visual system has limited spatio-temporal sensitivity, but many signals that fall below this capacity can be informative. For example, human skin colour varies slightly with blood circulation. This variation, while invisible to the naked eye can be exploited to extract pulse rate. Similarly motion with low spatial amplitude while hard or impossible for human to see can be magnified to reveal interesting mechanical behavior. The success of these tools motivates the development of new techniques to extract invisible signals in videos. The extracted signals can be used to estimate vascular function by converting into a known golden standard like ECG.

Basic approach is to consider the time series of colour values at any spatial local (pixel) and amplify variation in a given temporal frequency band of interest. For example, we automatically select and then amplify a bunch of temporal frequencies that includes plausible human heart rates. For this application temporal filtering needs to be applied to lower spatial frequencies to allow such a subtle input to rise above the camera sensor and quantization noise. Temporal filtering approach not only amplifies colour variation but can also reveal low-amplitude motion.

Previous attempts have been made to unveil imperceptible motions in videos. Liu et al., analyze and amplify subtle motions and visualize deformations that would otherwise be invisible. propose using the cartoon animation filter to create perceptually appeling motion exaggeration. These approaches follow a Langrangian perspective, in reference to fluid dynamics where the trajectory of particle is traced over time. As such they rely on accurate motion estimation, which is computationally expensive and difficult to make artifact-free, especially at regions of occlusion boundaries and complicated motions. Moreover Liu et al., have shown that additional techniques including motion segmentation and image in-painting are required to produce good quality synthesis. This increases the complexity of the algorithm further. In contrast, we are inspired by the eulerian perspective where properties of a voxel of fluid such as pressure and velocity, evolve over time. In our case we study and amplify the variation of pixel values over time, in a spatially-multiscale manner. In our eulerian approach to motion magnification we do not explicitly estimate motion but rather exaggerate motion by amplifying temporal color changes at fixed positions.

Temporal processing has been used previously to extract invisible signals and to smooth motions. For example Poh et al extract a heart rate from a video of a face based on the temporal variation of the skin colour, which is normally invisible to the human eye. We use temporal processing similarly to select signal of interest, but in addition we extends it to translate colour variation to spatial motion when amplifying motions. Fuches et al, use per- pixel temporal filters to dampen temporal aliasing of motion in videos. They also discuss the high pass filtering motion but mostly for non-hotorealistic effects and for large motions. In contrast, our method strives to make imperceptible motions visible using a multiscale approach. Spatial filtering has been used to rise signal-to-noise ratio of pulse signal. Poh use spatial pooling of the whole face region to extract pulse signal and relay on independent component analysis to eliminate noise induced by motions for higher SNR. Where as we use localized spatial pooling and band pass filtering to extract and reveal visually the signal corresponding to the pulse. This primal domain analysis allows us to amplify and visualize the pulse signal at each location on the face. This has important potential monitoring and diagnostic applications to medicine where for example the asymmetry in facial blood flow can be a symptom of arterial problems.

A. Heart Rate Extraction

To extract frequency of a periodic pulse signal from a noisy signal we investigated two different approaches- Fourier frequency analysis and peak detection. Fourier frequency analysis is a standard approach to examine signal strength at each frequency. FFT can be performed on temporal signals to produce a power spectrum. If the pulse signal strength rises above noise strength level, we can simply detect the peak in our frequency band of interest and read off the frequency position of the peak as our measurement of pulse rate. Peak detection is commonly used for heat rate extraction using electrocardiogram. In a typical ECG signal, there is a high amplitude R wave in every heart beat. The time interval between successive R waves is used to estimate instantaneous heart rate. We can also average over several RR intervals to estimate average heart rate. The same methodology can be applied to the temporal colour series which we obtained from eulerian preprocessing. To get the peak positions, we select the maximum point within a local temporal window. The size of the temporal window would be chosen carefully because if the window size is larger than the true peak interval, then a peak with smaller amplitude will not be detected. Peak detection gives us the segments of the heart beat waveform. We can use them to estimate the instantaneous heart rate, average heart rate.

IV. EXPERIMENT SET UP

The test set-up was designed in a way to eliminate most of the interfering environmental influences, as we wanted to find the relation between the heart rate and the information extracted from video-data. The participants were placed right in front of a webcam (1.3 Megapixels (mp), 24 Bit RGB, 8 Bit per channel) and colour-videos were recorded with a length of 2 minutes at 30 frames per second (fps), and a resolution of 640x480 pixels. All of the participants were seated at a distance of about 0.5 m from the webcam with indirect sunlight as the only source of illumination in the 1st setting whereas in the 2nd setting we added office fluorescent lights to the indirect daylight. Each setting consisted of phases, in the first phase the participants were completely recorded at rest (around 60 Bpm), in the second phase the participants started on a higher heart rate level (around 100 Bpm to 140 Bpm). For reference, measurements from a wrist type Heart Rate were chosen.

Processing and analysis of both the video and physiological recordings were done using custom software written in Python. An overview of the general steps in our approach to recovering the blood volume pulse is illustrated in Fig. 2. First, an automated face tracker was used to detect faces within the video frames and localize the measurement region of interest (ROI) for each video frame. We utilized a free Python-compatible version of the Open Computer Vision (OpenCV) library to obtain the coordinates of the face location. The OpenCV face detection algorithm is based on work by Viola and Jones, as well as Lienhart and Maydt . A cascade of boosted classifier uses Haar-like digital image features trained with positive and negative examples. The pretrained frontal face classifier available with OpenCV was used. The cascade nature uses a set of simple classifiers that are applied to each area of interest sequentially. At each stage a classifier is built using a weighted vote, known as boosting. Either all stages are passed, meaning the region is likely to contain a face, or the area is rejected. The dimensions of the area of interest are changed sequentially in order to identify positive matches of different sizes. For each face detected, the algorithm returns the x- and y-coordinates along with the height and width that define a box around the face. From this output, we selected the center 60% width and full height of the box as the ROI for our subsequent calculations. To prevent face segmentation errors from affecting the performance of our algorithm, the face coordinates from the previous frame were used if no faces were detected. If multiple faces were detected when only one was expected, then our algorithm selected the face coordinates that were the closest to the coordinates from the previous frame.

The ROI was then separated into the three RGB channels and spatially averaged over all pixels in the ROI to yield a red, blue and green measurement point for each frame and form the raw traces $x_1(t)$, $x_2(t)$ and $x_3(t)$ respectively. Subsequent processing was performed using a 30 s moving window with 96.7% overlap (1s increment). We normalized the raw RGB traces. The normalized raw traces are then decomposed into three independent source signals using ICA (Independent Component Analysis). In this report, we used the joint approximate diagonalization of eigenmatrices (JADE) algorithm developed by Cardoso. Although there is no ordering of the ICA components, the second component typically contained a strong plethysmographic signal. For the sake of simplicity and automation, we always selected the second component as the desired source signal. Finally, we applied the fast Fourier transform (FFT) on the selected source signal to obtain the power spectrum. The pulse frequency was designated as the frequency that corresponded to the highest power of the spectrum within an operational frequency band. For our experiments, we set the operational range to Hz (corresponding to bpm) to provide a wide range of heart rate measurements.

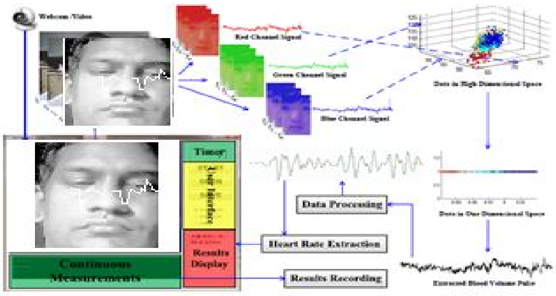

Fig. 2 Block diagram

V. RESULT AND DISCUSSIONS

Laser Doppler Flowmetry set up was tested in two different conditions such as rest and movement. The result is plotted on figure 3. It is observed that at rest the mean value of blood perfusion was 141.6 and at active state it was raised to 671.2. Any extreme deviation can be concluded as early warning of vascular dysfunction.

It is noted that the pulse wave, which is initiated by a heartbeat, travels through the whole arterial body vascular system and reaches the face, where it causes a short-termed volume change of blood. Since the value of blood perfusion and heart rate go hand in hand, in video processing technique directly we extract the pulse rate from blood perfusion in the skin. Figure 4 shows a comparison between measurements obtained through video image processing and conventional processing method (wrist type pulse detector). The efficacy of this new technology was tested and compared with standard wrist type tester. It is observed that the result of heart beat extraction through video imaging does not give much deviation from the conventional methods. Besides, it provides easiness for both patients and examiners. Test was also conducted in different conditions to study the functionality of the technique and plotted in figure 5.

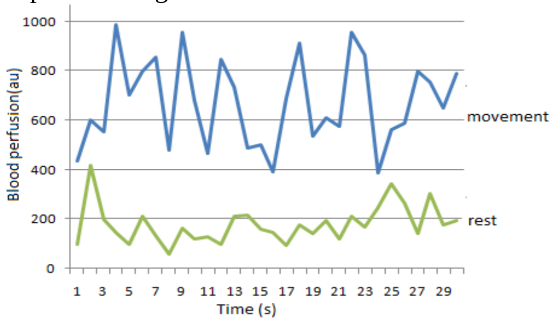

Fig. 3 Blood Perfusion at two conditions

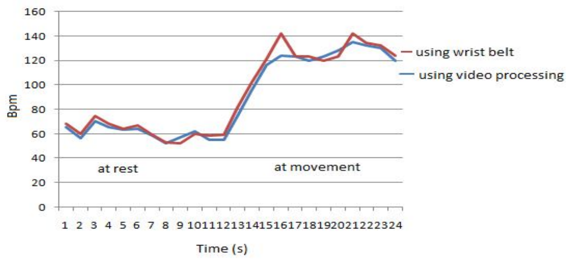

Fig.4 Heart Beat Rate- A Comparison

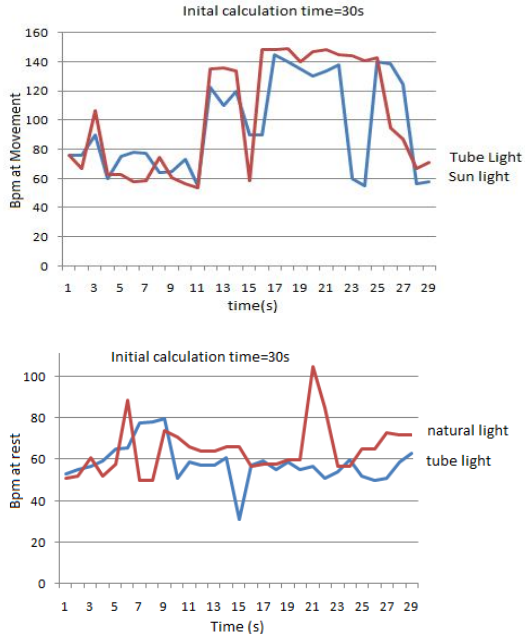

Figure 5 Bpm at various conditions

CONCLUSION

Though the physics behind LDF and Video Imaging are well known today, however they are not yet well established in relation to vascular functions. Though, LDF is used in various applications till now no golden standard is derived. Non linearity of LDF at the high blood concentrated area can be improved. Video imaging allows extracting the changeable component containing information of the heart rate remotely. The presented algorithm seems to be quite effective and easy to use in the daily monitoring of home care patients. Further this study can be performed in moving persons. This can also extended to multiple extraction of heart rate at multiple faces.

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