TIME DELAY ESTIMATION BETWEEN RETINAL ARTERIES AND VEINS PULSATIONS USING INSTANTANEOUS PHASE

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Abstract: The eye fundus suffers from many diseases such as glaucoma, central retinal venous occlusion or intracranial pressure rise. The fundus examination by video-ophthalmoscope can diagnose and reveal the assumption of these diseases, for example, from dynamic changes in the vascular system. This paper focuses on the determination of time delay between signals extracted from vein and artery pulsations obtained by experimental video-ophthalmoscope. The signal is further processed and the instantaneous frequency is utilized for time delay estimation. The observed time delay is in the range of 0 to 233 ms, which is in accordance with published results.

Keywords: retina, video-ophthalmoscope, delay between artery and vein pulsation

1 INTRODUCTION

The eyes, such as other body organs, suffer from many diseases. Several of them can be observed and diagnosed from eye fundus. The eye fundus retina is profusely supplied with blood. The blood distribution through the eye fundus causes pulsation of the veins and arteries. The spontaneous veins pulsation (SVP) is visible mostly at the hemiveins prior to their merge to the central retinal vein or directly in the central retinal vein [1].

The SVP phenomenon has been observed simultaneously with the ophthalmoscope invention and firstly described already in 1883 [2]. The pulsation occurrence is related to several diseases presence [3]. SVP decrease is associated with glaucoma disease occurrence [1], central retinal venous occlusion or intracranial pressure rise. Due to SVP relation with various diseases, many researchers have attempted to measure the degree of pulsation. The pulsations can be measured upon vessel diameter changes, lateral vessel displacement [4] or blood column densitometry [5].

Moret et al. [4] have utilized the cross-correlation of signals obtained from arteries displacements and veins diameters. The image sequences have been acquired with scanning laser ophthalmoscope and pre-processed by principal component analysis in the same way as has been suggested already in [6]. Unfortunately, the identical low frame rate of 9 fps has been used as well. The time delay between artery displacement and vein diameter pulsations for four subjects observed in [4] has been in the range of 0 to 200 ms.

In contrast, Spahr et al. [7] have utilized phase-sensitive full-field swept-source optical coherence tomography, which has high frame rate of 2,000 fps. The time delay has been estimated by two methods. One of them is based on pulse waves arrival delay at two specific locations. That determined delay is 19 ± 4 ms. The second one is more noise robust because the time delay is determined from the phase shift of two pulsation signals, which are filtered by bandpass at the cardiac frequency. The obtained delay is approximately 100 ms. Nevertheless, the data have been obtained from only one subject.

Another possibility for time delay estimation is also from phase shift at heart rate frequency of obtained signals. That has been published in [8], where the delay is measured between vein and artery pulsation in three different distances. The delays are presented in degrees of phase shift (0°– 95°). These values can be converted due to the average heart rate to range 0 – 473 ms.

This paper focuses on time delay estimation between artery and vein pulsations using an experimental video-ophthalmoscope, described in more details in [9]. The delay is measured from seven similar areas manually determined in specific retinal areas. The delay is estimated from extracted pulsation signals by means of the instantaneous phase and frequency approach.

2 MATERIAL AND METHODS

The methodology consists of several steps. First, the video-sequences of the eye fundus are acquired. Further, the signals from individual sequences are extracted and pre-processed. Lastly, the time delay from obtained signals is determined.

2.1 EXPERIMENTAL DATA SET

The left eyes fundus of seven subjects with no eye disease diagnose were captured by video- ophthalmoscope. Detail video-ophthalmoscope set up is described in [9]. The videos have 8-bit grayscale depth, frame rate 25 fps and resolution 1000×770 pixels. The videos last for approximately 10 s.

The hemoglobin, present in blood-vessels, has higher absorbance of orange light than others. Therefore the video contrast is naturally enhanced by illumination by 595 nm.

Due to minor eye movements, the shift and blur of several images are present. The shift of frames is removed by frame-to-frame registration method described in [10]. Blur removal is described below.

2.2 SIGNAL EXTRACTION FROM VIDEO-SEQUENCES

Five pairs of artery and vein regions were selected from each video- sequence. The selection is shown in Figure 1. The regions of interest (ROIs) were selected manually and nearly in similar positions for measurement robustness. Size of ROs is 30×30 pixels. The ROIs for veins pulsation were selected inside the optic disc including one hemivein. The ROIs of artery pulsation were defined further of the optic disc edge.

The extracted pulsation signal is determined for each frame as an average brightness inside each ROI. The signal from one pair of ROIs is shown in Figure 2 – A, where blue line denotes the pulsation of average brightness in vein ROI and red line marks the pulsation of average brightness in artery ROI.

2.3 TREND CORRECTION

The changes of illumination light intensity due to minor eye movements and the loss of the optimal eye alignment cause signal fluctuation - signal trend. The trend $I_a(n)$ is removed by procedure suggested in [9]. Firstly, the trend is estimated as:

$$I_a(n) = \sum_{m=n}^{n+q-1} \frac{I(m)}{q}, \forall n \geq 1, \tag{1}$$

where $I(m)$ denotes original signal and q the size of the average window. For our purpose is q defined equal to 25 frames, i.e. 1 second. The obtained trend is further removed from the original signal according:

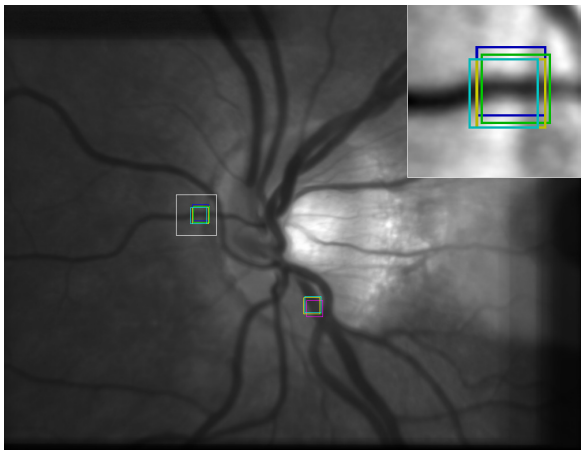

Figure 1: The region selection from the fundus image - the bottom-right boxes mark ROIs of the pulsating vein and the top-left boxes mark five selected ROIs, where is the artery. In top-right corner is zoom in of artery ROIs.

$$T(n) = 1 - \frac{I(n)}{I_a(n)} \tag{2}$$

After trend removal, several undesirable peaks, caused by blurred frames, are still present. Thus the signal is filtered by mean filter of window size 3. The filtered signal without trend is shown in Figure 2 – B. The expected delay is in range of ms, thus the signal is further up-sampled to 50 Hz sample rate and interpolated by cubic interpolation for aliasing avoidance.

2.4 TIME DELAY

The time delay between artery and vein pulsation is estimated from the instantaneous phase. First of all, the signal is multiplied by Hann window. The analyzed signal $x_A(t)$ is further converted by Hilbert transformation. After Hilbert transformation, the analyzed signal $x_A(t)$ has the real part $x(t)$ and the imaginary part $x_h(t)$. The instantaneous phase $\varphi(t)$ is then determined according [11] by equation:

$$\varphi(t) = \arctan \frac{x_h(t)}{x(t)}, \tag{3}$$

The time delay between artery and vein pulsation is estimated as a difference between the instantaneous phase of both signals in each frame. The mean phase difference value $\overline{D_P}$ is converted to the time delay D_T according (4)

$$D_T = \frac{\overline{D_P}}{2\pi \cdot f_h}, \tag{4}$$

where f_h denotes heart rate frequency, obtained from magnitude spectrum of the analyzed signal. The heart rate frequency f_h is determined as the position of maxima in the range between physiological values (0.5 – 3 Hz).

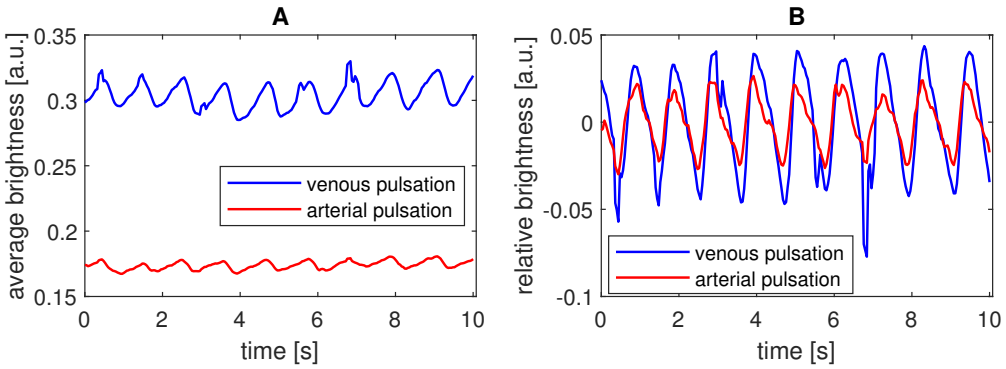

Figure 2: a) The extracted signals from the artery (red) and the vein (blue) region from one subject show clearly recognizable pulsations. The pulsation frequency corresponds with heart rate pulsations. b) The filtered signal of artery (red) and vein (blue) ROI pulsation

3 RESULTS AND DISCUSSION

The estimated delays, obtained as is suggested above, are shown in Figure 3. Each box depicts five measurements of delays between artery and vein pulsation of one subject. The mean values of delays are in range from 12 ms to 209 ms.

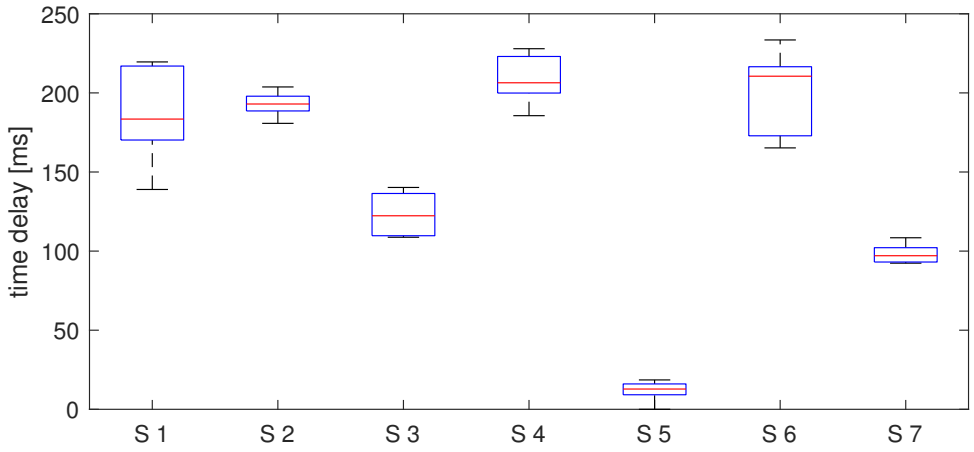

Figure 3: The measured time delay for seven subjects S1Â–S7. The inner line inside each box displays the median value of five measured delays corresponding to five pairs of ROIs. The bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points.

The measured delays are in the range published by another papers, e.g. [8] listed range 0 – 473 ms, which is slightly higher and analysis described in [4] lead to range 0 – 200 ms. On the other hand, our delays are twice as higher as results published in [7]. Nevertheless, in papers [4] and [7], the experiments have been conducted on small number of patient (from 1 to 4).

4 CONCLUSION

The suggested method measures the time delay between artery and vein pulsations. The method utilizes video-sequences of eye fundus for pulsation curves extraction. The time delay is determined

due to instantaneous phase determination. The measured delays are in the range 0 ms to 233 ms. That values are in physiological range and are also in agreement with presumed values according to [8], [4].

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