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Video magnification for intraoperative assessment of vascular function

Abstract: In neurovascular surgery the intraoperative fluorescence angiography has been proven to be a reliable contact-free optical imaging technique to visualize vascular blood-flow. This angiography is obtained by injecting a fluorescence dye e.g. indocyanine green and using an infrared camera system to visualize the fluorescence inside the vessel. Obviously this requires a medical approved dye and an additional camera setup and therefore generating risks and costs. Hence, the aim of our research is to develop a comparable technique for assessing the vascular function. This approach would not require dye nor an additional infrared camera setup. It is achieved by first preprocessing the video data of a camera that records only the visible spectrum and then filter it spatially as well as temporally. The prepared data is again processed to extract information about the vascular function and visualize it. This method would provide an option to compute and visualize the vascular function using the data recorded in the visible spectrum by the surgical microscopes. Given this contact-free optical imaging system, physiological information can be easily provided to the surgeon without an additional setup. In the case of comparable results with the state-of-the-art, this technique provides a straightforward optical intraoperative angiography. Further no drug approval is needed since no dye is injected.

Keywords: camera-based, intraoperative, diagnostic, intraoperative angiography, blood flow, video processing

https://doi.org/10.1515/cdbme-2017-0036

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1 Introduction

In recent years researchers have developed new methods for non-contact physiological measurement using digital cameras and image processing. These methods provide the possibility for many novel applications in monitoring and diagnostics. Generally it relies on principles of measurement of light reflectance or transmittance through the body similar to the photoplethysmography. The captured signals derive from changes of blood flow and blood oxygenation within the vessels [1]. Most research was spend on computing physiological information by analyzing skin color changes. This work deals with data recorded while surgery where vessels where exposed. It addresses the issue of visualizing blood movement/pulsation inside a vessel. Though our work is at its beginning we will show in this paper that the assessment of vascular function is feasible. As example we used an intraoperative video of an aneurysm being clipped. Within the procedure indocyanin green (ICG) and an infra-red (IR) camera setup is needed to visualize blood circulation inside the vessel [2]. Our idea is to use only the RGB video data of the surgical microscope and magnification algorithms to emphasize the reflectance changes on the surface of the vessel to derive information about circulative behavior of the blood inside it. The results will be compared to the ICG-IR recordings.

2 Methods

2.1 Video data

For a proof of concept a public available intraoperative video was taken from the website of Carl Zeiss Meditec AG [3]. Its resolution is 560*470 pixels. It is recorded with 25 frames per second and in RGB and gray values. It shows an aneurysm before and after clipping in RGB. After the ICG is injected, the infra-red (IR) camera is activated and the records switch from a RGB to intensity video. The video got edited into parts contain either the RGB or the intensity data. The part used here for further investigations is exclusively the RGB part before clipping and is about 3 seconds long. The intensity (ICG-IR) part is only used for validation.

2.2 Image processing

All processing was done in MATLAB R2016.

Preprocessing is needed since the scenery has movement artifact. We used the minimum eigenvalue algorithm and the feature-matching algorithm to detect corners and allocate them. A rectangle around the aneurysm was used to focus the stabilization hence pulsatile movement of the vessels got suppressed. This is crucial for the Eulerian approach of video processing mentioned below.

For image processing we used spatial and temporal filtering based on recently published research of the MIT [4]. Spatial filtering is necessary to reduce noise and was performed by Gaussian blurring with a 5x5 mask. The filter size is reasonable since our object of interest is omnipresent in the frames and smearing effects are so far acceptable. Then time course filtering of each pixel was performed using an band-pass filter with cutoff frequencies at 50/60 Hz and 80/60 Hz. Those frequencies are based on *a priori* knowledge of physiological reasonable heart rates and also on the investigation of the most present frequency after calculating the Fourier transform of the mean signal of a region of interest (ROI) containing the whole aneurysm. After temporal filtering a magnification factor is multiplied to the spectral band. In this case we multiplied it with 50 to get an evaluable result, this was done empirically. Is the factor too high, the noise in the desired band will be magnified as well and disturb the result. Is the factor too low, no remarkable effect will be noticeable. After magnifying the spectral band of interest we add it up to the native video data. At the end of this processing chain we get a video with enhanced physiological information.

2.3 Evaluation

First we will show that the signal to noise ratio (SNR) has improved after the processing chain. The desired signal is assumed to be the highest peak in our defined spectral band. Secondly we will compare the computed video with the ICG-IR video of the aneurysm. Therefore the time course variance of each pixel will be computed and saved into a matrix. This matrix (containing Var(x,y)) will be compared to a frame out from the ICG-IR video since it is quite static. For comparison the correlation coefficient will be calculated using the equation below. The variance matrix is represented by A and the ICG-IR reference by B, $\bar{A}$ is the mean of all values of A. Finally we will investigate the phase shift of the pulse signal pixel wise in the magnified video and the ICG-IR video.

$$r = \frac{\sum_x \sum_y (A_{xy} - \bar{A})(B_{xy} - \bar{B})}{\sqrt{\left(\sum_x \sum_y (A_{xy} - \bar{A})^2\right)\left(\sum_x \sum_y (B_{xy} - \bar{B})^2\right)}}$$

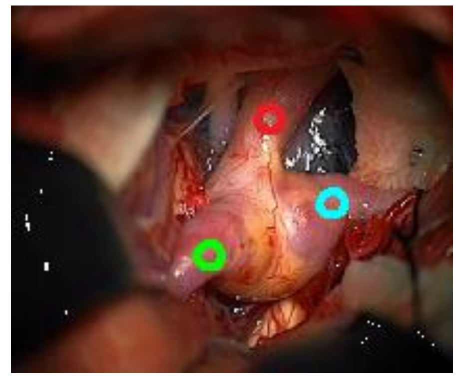

Figure 1: Aneurysm with three ROI (red, green and blue)

3 Results

The magnification is visualized in the graphs in figures 2 & 3 showing the signal of the pixel in the middle of the green circle (figure 1) before and after video magnification.

Regarding the plotted signals, there is clearly an improvement. Before magnification the SNR is -3.4 dB and after magnification 21.6 dB.

Before calculating the correlation coefficient between the computed variance matrix with the ICG-IR frame, the ROI (the whole aneurysm with the incoming and out coming vessels) got segmented (see figure 4 & 5). The correlation coefficient is 0.724. Lastly we show the phase shift in the 3 ROI of the magnified and the ICG-IR video in figure 6 & 7. The phase shift is clearly visible and can be used as indicator of blood flow direction as the red signal is ahead of the green and blue one and the signals are related to a certain position on the aneurysm. Since the RGB and the ICG-IR video were captured sequentially the heart rate of 59 bpm (ICG-IR) and 66 bpm (magnified RGB) don't match but are in the same scale. Further a phase-shift-map is shown in figure 8 & 9 of both cases. Here the colormap visualizes the shift to an empirically set trigger and it indicates the direction of blood flow.

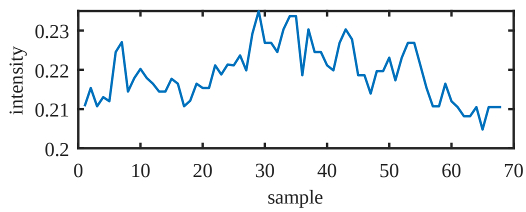

Figure 2: Time course signal of the pixel in the middle of the green circle before video magnification

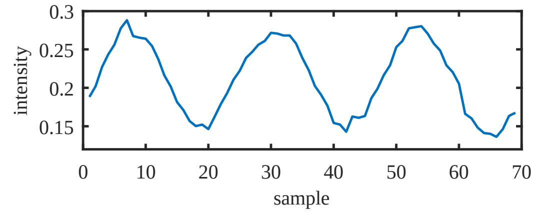

Figure 3: Time course signal of the pixel in the middle of the green circle after video magnification

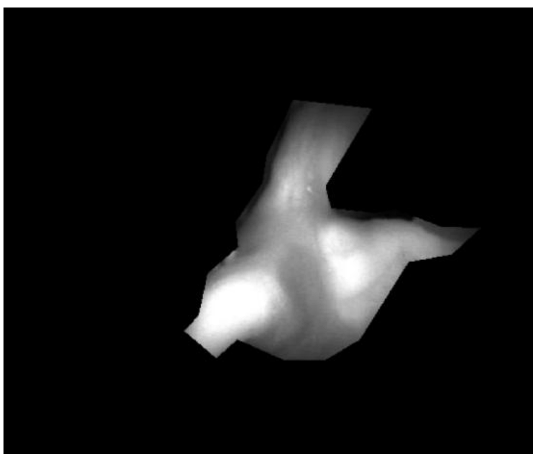

Figure 4: Screenshot of the ICG-IR video where clear hotspots are visible

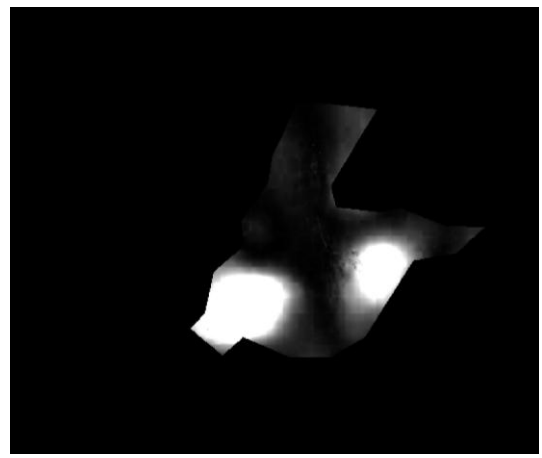

Figure 5: Pixel wise time course variance of the magnified RGB data of the video

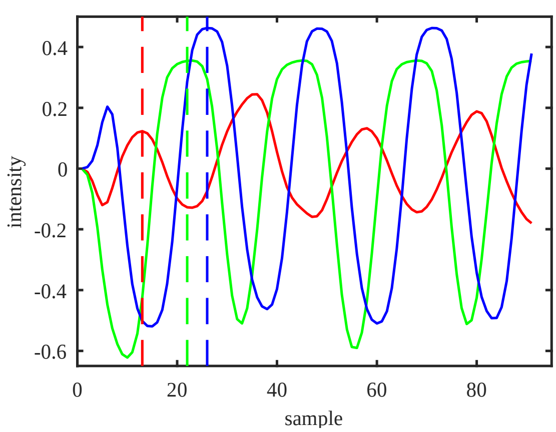

Figure 6: Phase shift of the pulse signal in the ICG-IR video in the 3 circles in figure 1

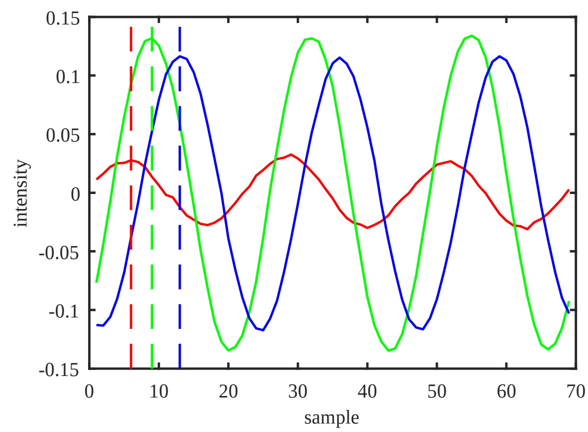

Figure 7: Phase shift of the pulse signal in the magnified video in the 3 circles in figure 1

4 Discussion

The concept of remote measurement of physiological parameters has been mainly applied on surfaces of the body like the skin. This concept got proven by several studies [5, 6]. Camera based intraoperative diagnostics is also used in some studies concerning neurosurgery [1,7]. Using the presented method for intraoperative assessment of vascular function is new. This work shows that it can enhance superficial vascular signal quality from -3.4 dB to 21.6 dB. Further the compared computed and reference picture have similarities that can be quantified by the correlation coefficient of 0.724, which indicates similar information content. The comparison of the phase shifts between the magnified and ICG-IR video reveal the flow direction of the blood which match in both formats. The blood flows from the upper vessel into the lower left and land then into the right.

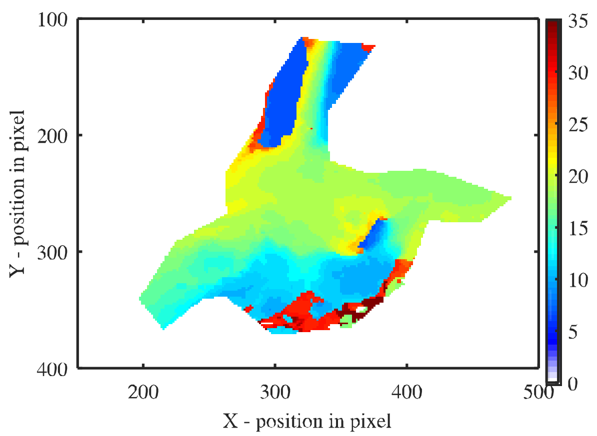

Figure 8: Phase-shift-map of the ICG-IR video

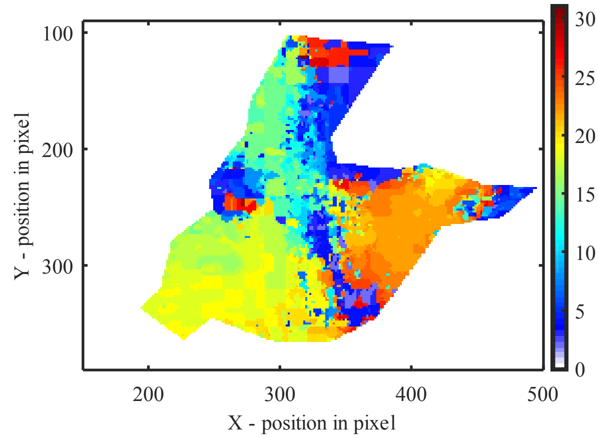

Figure 9: Phase-shift-map of the magnified video

This corresponds to the phase-shift-maps in figure 8 & 9. The pulse rate of the reference and the magnified video are within the same scale and reasonable. However, this algorithm needs as input a frequency band containing the desired signal. It is crucial to determine it correctly. Here we used a band around the most present frequency of the mean signal of the whole aneurysm. This relies on the assumption, that the pulse is constant over the ROI, which is reasonable since it is an intraoperative scenery. Further some other parameters such as the degree of blur in spatial filtering and magnification factor need to be set. For investigation those two parameters more data is needed to find a trend or an optimal setting.

5 Conclusion

A method for determining the flow direction out from RGB video data without a dye is yet not accessible and would be a helpful tool for physicians. This work shows that there is the possibility to substitute the ICG and the IR camera setup through a well-designed video processing chain of the RGB video data. Still there is scope for improving and validating the procedure. An automated registration of the structure of interest (SOI) would increase its effectiveness. Finding the spectral band of interest could be assisted by defining a general range (e.g. pulse of 20 - 300 beats per minute) and then searching for the most present frequency in the mean of the SOI in that range. Statistical evaluation of the blood flow direction is required and in need of a large and diverse set of data. The results are promising but nevertheless, all results must be handled with care since it is a single case study. Finally we propose the hypothesis, that the assessment of vascular function such as pulse rate and flow direction with the presented methods is possible.

Author's Statement

Research funding: Mr. Ady Naber receives a scholarship of the Karlsruhe School of Optics & Photonics. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent is not applicable. Ethical approval: The conducted research is not related to either human or animals use.

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