The method of compensation for local displacements of images of capillaries in the evaluation of capillary blood flow parameters

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Abstract. The paper discusses the features of applying the method of local compensation of video frame displacements in the study of microcirculation parameters by the methods of video capillaroscopy (VCS) and microphotoplethysmography (micro-PPG). The results of the assessment and compensation of local displacements of images of the capillary network in the region of the hand of a conditionally healthy volunteer are presented. The result of the computation of the synthesized image of capillaries with equalized contrast based on the processing of a locally-combined sequence of video frames is shown. An example of capillary visualization using the frequency analysis of locally aligned video frames is given. The effectiveness of the method of local image stabilization within the study of the capillary network of mucous membranes using a laparoscope is demonstrated.

1. Introduction

Studies of the parameters of capillary blood flow are important for the diagnosis of many socially significant diseases such as diabetes, Raynaud's disease, psoriasis, cardiovascular diseases. A number of diseases (for example, psoriasis, scleroderma) are characterized by local disorders of the morphology of the capillary network in an arbitrary area of arms [1-3]. Capillary network visualization and automation of capillary counting in the affected skin areas are the tasks to be solved in order to conduct diagnostics. This requires observing capillaries over an area of a few square millimeters. Preliminary studies have shown that it is not possible to solve these problems when analyzing a single frame due to the low image contrast and the local frame area defocusing. The task of visualization and counting of capillaries can be solved on the basis of analyzing the sequence of video frames, but the application of such methods requires compensation of local displacements of the capillary network in the process of recording video frames.

In contrast to the study of hand skin using a video capillaroscope, mobile devices such as a laparoscope are required for the study of the mucous membranes of the oral cavity or internal organs. At the same time, in the process of measurements, projective distortions of images are added to the local displacement of capillaries due to the displacement of the device relative to the study object. For
this reason, processing and analyzing of video frames obtained with a laparoscope constitute a significant problem.

2. Methods and experimental results

In [4, 5], the usage of the method for full-frame stabilization and compensation for capillary blood flow video frames displacement in video capillaroscopy and photoplethysmography was considered. The implementation of the full-frame method has significant limitations, since it does not allow compensating for local distortions of the skin geometry in the studied area. The full-frame stabilization method was used in order to solve problems of restoring blood flow velocity in the capillaries of the nail bed. Note that in this area, the skin (and the capillary network) is well attached to the nail plate; therefore, in most experiments, the use of the full-frame stabilization method is justified. At the same time, in separate experiments during functional tests, local distortions of the geometry of the capillary network were observed. In such cases, it is necessary to apply the method of local displacement compensation in order to restore the blood flow velocity.

The skin areas outside the nail bed and the capillary network are more susceptible to local displacement than within the nail bed. Capillary displacement during the recording of video frames is a significant problem. Traditionally, such problems are solved involving the methods based on the selection of key points of the image (SURF [6], SIFT [7]). Such methods are ineffective to compensate for the displacements of biological objects due to the difficulty of tracking the key points.

The proposed method is based on the detection of displacements of local areas of images by the criterion of the minimum root mean square deviation. A feature of the proposed method of compensating for local displacements is the use of several key frames, which makes it possible to increase the accuracy. This allows applying the method of local displacement compensation for the considered tasks. The method of compensation for local displacements is as follows. Local points are set, in the neighborhood of which the estimation of displacements is performed. The obtained displacements are interpolated at each point of the frame and a continuous coordinate translation matrix is formed. After determining the local displacements for the constructed set of points for each frame and for each point of the frame, the interpolation of the displacement vector is performed. For each frame, a coordinate translation matrix is calculated, which makes it possible to compensate for local distortions of the geometry relative to the selected key frame. As a result of applying the coordinate translation matrix to the original video frames, compensation of local displacements is provided.

A study of the method of compensation for local displacements for capillary video frames was conducted in the hand area of a conditionally healthy volunteer. The investigated skin area has a size of about 2 square millimeters. A video sequence with 2000 video frames at the speed of 100 fps was recorded. In the course of the experiment, mechanical action was carried out on the skin (a shift in different directions) to ensure capillary displacements. Figure 1 shows video frames with local displacements of capillary images; for the first frame, 1 mm measure is displayed. Figure 2 shows the results of assessing local displacements for those video frames. It is seen that the detected displacements exceed typical size of the capillary. Figure 3 shows the locally aligned video frames, calculated using the coordinate translation matrix.

![Figure 1. Video frames of the hand capillaries obtained at various displacements of the skin as a result of external exposure.](image)
During the diagnosis of diseases associated with impaired microcirculation, the tasks of assessing the morphology and counting capillaries per skin area unit are relevant. Normally, capillary analysis is performed for a single image. When registering skin areas of several square millimeters in the hand area, it is extremely difficult to ensure the same focus and contrast of the capillaries for the entire frame. Figure 4 shows examples of video frames with various locally defocused areas. Processing of the locally-combined sequence of video frames allows estimating a synthesized image of capillaries that does not contain defocused areas, see figure 5 (a). The synthesized image does not contain the noise of the camera matrix and random capillary distortions due to the characteristics of the blood flow typical of individual video frames. The capillaries in figure 5 (a) are contrast. It is seen that the displacements of capillary images in the processed sequence of video frames are substantially smaller than the typical size of capillaries.

Capillaries can be visualized via analysis of the micro-PPG signal [8], which can be evaluated for a sequence of video frames. The result of capillary visualization based on Fourier analysis of the micro-PPG signal at each point of the frame is shown in figure 5 (b). With such a processing, one can select the capillaries and provide their visualization with suppression of other contrasting details of an image, such as skin folds, hair, pigment spots.
Figure 4. Examples of video frames with a local decrease in the contrast of capillaries (a) in the upper right corner and (b) in the lower left corner.

Figure 5. The result of processing a sequence of aligned video frames: (a) a synthesized image with focus recovery over the entire field, and (b) the result of computation and visualization of capillaries by frequency methods.

The use of a laparoscope [9] allows exploring the parameters of microcirculation in the oral mucosa. The capillary network of the mucous membrane of the mouth of a conditionally healthy volunteer was registered on an area of approximately 3 square millimeters. Totally 1000 video frames were recorded at 66 fps.

Data processing is performed in two stages. At the first stage, the full-frame alignment method is used, which allows compensating for significant displacements of the laparoscope relative to the object of study, as shown in figures 6, 7.
At the second stage of processing, local displacements of images of the capillary network and projective distortions associated with displacements of the device are compensated. The detected local displacements and the results of their compensation are shown in figures 8 and 9.
The efficiency of local alignment of images of capillaries can be estimated from the results of additional processing of video frames. An example of such processing based on calculation of the synthesized image with aligned capillary contrast is presented in figure 10. The synthesized image contains more details of the capillaries with complete suppression of the video camera matrix noise compared to the original video frames. Consequently, the local method for local alignment of video frames allows obtaining additional information about the capillary network under study and improving the quality of diagnostics.

![Figure 10](image)

(a) Video frames sample and (b) synthesized image estimated based on a pre-processed sequence of video frames.

3. Conclusion
The paper presents examples of applying the method of local compensation for local displacements of images of capillaries in the processing of video frames sequences recorded for hand and mucous membrane of the human mouth skin areas. It is shown that this method provides fairly accurate alignment of images of capillaries. The examples of processing locally-aligned sequences of video frames with the calculation of the synthesized image with aligned focus and maximum contrast are demonstrated. An example of capillary imaging based on frequency signal processing is presented. It can be concluded that the considered method for assessing the morphology of the capillary network is effective.

The considered method of local alignment of images of capillaries in video frame sequences is important for improving the quality of diagnostics of microcirculation disorders.

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References
[1] Hern S and Mortimer P S 2007 In vivo quantification of microvessels in clinically uninvolved psoriatic skin and in normal skin Br. J. Dermatol. 156 1224–29
[2] Campanati A, Moroncini G, Ganzetti G, Pozniak K N, Goteri G, Giuliano A, Martina E, Liberati G, Ricotti F, Gabrielli A and Offidani A 2013 Adalimumab modulates angiogenesis in psoriatic skin Eur. J. Inflamm. 11 489–98
[3] Grassi W, Core P, Carlino G, Blasetti P and Cervini M 1993 Labial capillary microscopy in systemic sclerosis Ann. Rheum. Dis. 52 564–69
[4] Karimov K A and Volkov M V. 2015 The phase correlation algorithm for stabilization of capillary blood flow video frames SPIE Videometrics, Range Imaging, and Applications XIII
9528 952810

[5] Volkov M, Margaryants N, Pimenov A, Potemkin A and Gurov I 2018 High-speed video capillaroscopy method for imaging and evaluation of moving red blood cells Opt. Lasers Eng. 104 244–51

[6] Bay H, Ess A, Tuyltaars T and Van Gool L 2008 Speeded-Up Robust Features (SURF) Comput. Vis. Image Underst. 110 346–59

[7] Juan L 2010 A Comparison of SIFT , PCA-SIFT and SURF Int. J. Image Process. 3 143–52

[8] Volkov M V., Margaryants N B, Potemkin A V., Volynsky M A, Gurov I P, Mamontov O V. and Kamshilin A A 2017 Video capillaroscopy clarifies mechanism of the photoplethysmographic waveform appearance Sci. Rep. 7 1–8

[9] Machikhin A S, Khokhlov D D, Batshev V I and Pozhar V E 2018 An Acousto-Optic Endoscopic Module for Nondestructive Testing Bull. Russ. Acad. Sci. Phys. 82 1403–05