Stabilization and Enhancement of Microcirculatory Video Sequences

MAHER I. RAJAB\textsuperscript{1}, STEPHEN P. MORGAN\textsuperscript{2}, IAN M. STOCKFORD\textsuperscript{3}, AND JOHN A. CROWE\textsuperscript{4}

\textsuperscript{1}Computer Engineering Department, Umm Al-Qura University, P.O. Box 715, Makkah, KSA
\textsuperscript{2,3,4}Department of Electrical and Electronic Engineering, Applied Optics Group, University of Nottingham, Nottingham, NG7 2RD, UK

\textsuperscript{1}mirajab@uqu.edu.sa  \ http://www.uqu.edu.sa/mirajab
\textsuperscript{2}steve.morgan@nottingham.ac.uk, \textsuperscript{3}eezis@nottingham.ac.uk, \textsuperscript{4}eezjac@nottingham.ac.uk

Abstract: - Video capillaroscopy is useful in many studies of the microcirculation. Our research is currently focused on understanding sickle cell anemia, a disorder which causes red blood cells to become deoxygenated, polymerize and makes the transport of cells by the microcirculation difficult. Measurements are made with a hand-held microscope which is usually placed in the oral cavity, on the nail-fold or in the eye. Useful information can be obtained such as the shape of the capillaries and the flow rate of cells in the capillaries. There are challenges associated with making such measurements such as movement artifacts and low contrast. Image processing therefore has an important role to play in this application. In this paper video capillaroscopy movies from sickle cell disorder sufferers are processed. Firstly motion artifacts are reduced by correlating consecutive frames and using major features in the images to overlay them. Secondly image contrast is enhanced by linear transformation that expands the range of the gray-level map. Results will demonstrate improvements in image quality which should allow more accurate measurement of blood flow to be obtained.

Key-Words: - Microcirculation, video-capillaroscopy, video stabilization, sickle cell anemia, image enhancement.

1 Introduction

Video-capillaroscopy allows in-vivo observation of microvasculature structure at various sites around the body allowing recording of flow and application of numerical processing techniques to extract morphological information from the observed images. Most systems widely used in microvasculature research are essentially standard epi-illumination microscopes relying on the absorption of hemoglobin within the flowing red blood cells (RBCs) to provide contrast. The need for index matching fluids and suitable orientation of the sample to remove surface reflections, along with limitations on easily accessible sites around the body where capillaries are visible, has largely limited observation to the microvasculature around the nail-fold.

This approach has benefited examination and understanding of a wide range of conditions such as diabetes \cite{1}, Raynaud’s syndrome\cite{2,3}, sepsis \cite{4}, various connective tissue diseases\cite{5} and systemic sclerosis \cite{6} amongst others. This has been addressed through quantification of various morphological parameters such as capillary density \cite{6,7}, capillary shape \cite{3,5}, various vessel dimensions \cite{3,6} and RBC flow rate \cite{1}. To enable application to other sites around the body whilst overcoming surface reflections a number of instruments with modified methods of illumination have been developed. The two most prominent solutions are Orthogonal Polarization Spectral (OPS) imaging \cite{7} and Side-Stream Dark-Field (SSDF) imaging \cite{8} which employ cross-polar and spatial filtering respectively. The CytoScan and MicroScan are commercial video capillaroscope systems developed around these techniques and have enabled use in a clinical setting for monitoring the micro-vasculature on the floor of the mouth, lip, eye, brain and muscle but are still limited in the information they provide. The University of Nottingham (UoN) has developed a novel polarized light capillaroscope (Fig. 1) which has been used to monitor sickle cell anemia sufferers.

![Fig. 1 Novel capillaroscope developed by UoN.](image-url)
Obtaining the properties of red blood cells in vivo is important in understanding diseases such as sickle cell anemia and delivery of oxygen to tissue. Video-capillaroscopy measurements are made with a hand-held microscope which is usually placed in the oral cavity, on the nail-fold or in the eye. Useful information can be obtained such as the shape of the capillaries and the flow rate of cells in the capillaries. There are challenges associated with making such measurements such as movement artifacts and low contrast. Image processing therefore has an important role to play in this application. In this paper we aim to process video capillaroscopy movies from sickle cell disorder sufferers obtained by the University of Nottingham. Firstly motion artifacts are reduced by correlating consecutive frames and using major features in the images to overlay them. Secondly image contrast will be enhanced by linear transformation of image intensities. The enhancement of all frames will insure the each frame is expanded in the range of the gray-level map such that visual improvements in image quality will be allowed.

2 Methodology

Image correlation has been applied to the captured capillaroscopy images. The main features of the image are well correlated when the frames of the movie are overlaid. Correlation of consecutive movie frames is therefore used to find the location(s) where the frames are best overlaid. This helps to remove effects due to motion artifacts. The table below describes the video stabilization and enhancement algorithm that is applied to stabilize and reduce motion artifacts by correlating consecutive frames and using major features in the images to overlay them.

3 Results

The image processing steps illustrated in the algorithm described in Table 1 is applied to stabilize the video-capillaroscopy movies from sickle cell disorder sufferers. Figure 2 shows some samples of frames after running the stabilization algorithm without including the image enhancement (step 2(d)). To accurately overlay the images, we need to find the position of the maximum value of the image correlation. This is performed by applying image correlation between a base frame and the frames fm to fn. The algorithm is implemented using mainly Matlab functions: incrop, dftcorr, circsfift. The Matlab circular image shift function is used to demonstrate the maximum distance a frame needs to be shifted in x and y directions to overlay the images (as shown in Fig. 2(b-c)). For example for the analysis results of the video capillaroscopy shown the maximum shifts in the x-direction is Max_x= 55 pixels (Fig. 2(b)), while the maximum shift found in the y-direction is Max_y=67 pixels (Fig. 2(c)). The Matlab image crop function is also applied to all sequence of frames to define a region of interest ROI in a frame fi such that the maximum x-y shifts are discarded from the borders of the frame (Fig. 2(d)).

<table>
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<th>Table 1. Video Stabilization and enhancement Algorithm.</th>
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<tr>
<td><strong>Step 1.</strong> Choose size of a ROI to use in the correlation between two consecutive frames. Select base frame f₀.</td>
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<td><strong>Step 2.</strong> Loop to correlate base frame f₀ with all other frames.</td>
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<tr>
<td><strong>Begin</strong></td>
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<tr>
<td>a. For frame fᵢ = fᵢₙ to f₀</td>
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<tr>
<td>b. Correlate the two consecutive frames fᵢₙ and f₀ and check if there is shifts in x or y then shift frame fᵢₙ to overlap the base frame f₀.</td>
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<td>c. Find maximum correlation peaks at x and y coordinates. Keep the two peak shifts in shiftx(i) and shifty(i) arrays.</td>
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<td>d. Enhance contrast of frame fᵢₙ.</td>
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<td><strong>End</strong></td>
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<td><strong>Step 3.</strong> Find maximum shifts in x and y directions between all frames; find maximum values in the two arrays shiftx and shifty.</td>
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<tr>
<td><strong>Step 4.</strong> Apply image Crop to discard the frame shifts at the four image margins (left, right, top, and left) according to the maximum possible x-y peak shifts in all frames.</td>
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![Fig. 2 (a)](image1)
![Base frame f₀ is chosen at frame no. 320.](image2)
![Max. shift x is found at frame fᵢ (55 pixels and at e.g. frame no. 258).](image3)
![Max. shift y is found at frame fᵢ (67 pixels and at frame no. 347).](image4)
![Image crop is applied to frame fᵢ or image (c) to discard xy shifts outside the ROI.](image5)

Fig. 2 (a) Base frame f₀ is chosen at frame no. 320. (b) Max. shift x is found at frame fᵢ (55 pixels and at e.g. frame no. 258). (c) Max. shift y is found at frame fᵢ (67 pixels and at frame no. 347). (d) Image crop is applied to frame fᵢ or image (c) to discard xy shifts outside the ROI.
All the image processing steps illustrated in the algorithm described in Table 1 are applied to stabilize and enhance the video-capillaroscopy movies from sickle cell disorder sufferers. Similarly, Fig. 3 shows some samples of frames after running both the stabilization and enhancement algorithm. Figure 3 shows the maximum shifts in x and y directions after applying image correlation between base frame and the frames fm to fn. Fig. 3(b-c) demonstrate the maximum shifts found in x-y directions. Visual comparison between Fig. 2(d) and Fig. 3(d) illustrates that improvements in image quality which should allow more accurate measurement of blood flow to be obtained.

Some of the captured capillaroscopy images do not establish enough contrast between different features of a scene. Thus, it may be possible to override some of the hesitation in enhancing images by comparison between the histograms of cluster images. K-means clustering is applied to produce cluster images by performing pixel-based segmentation to video-capillaroscopy frames. Pixels are grouped by their proximity to cluster's centroids. It may be hypothesized that the scene of capillaroscopy images is classified into four clusters which may be interpreted as oxygenated RBC, non-oxygenated RBC, wall of capillary, and other possible objects like muscles. Preliminary results of clustering are illustrated in Fig. 4. The two histograms images (e) and (f) represent the count of clusters in images (c) and (d), respectively. It is clearly showed that the stretched grey levels in histogram (f) indicate that image (d) has also sufficient contrast between their clusters.

4 Future Research Directions
Further collaboration between our research groups will investigate further analysis of video capillaroscopy frames to obtain the properties of red blood cells such as flow rate. Image analysis is an important in vivo application to obtain the properties of red blood cells. It will also support the understanding of blood diseases such as sickle cell anemia and delivery of oxygen to tissue.

5 Conclusion
The following conclusions can be deduced:
– correlating frames is an essential step in reducing motion artifacts. The method uses the major features in an image to overlay them.
– Enhancement results for the images can be expected using linear mapping.
– Accurate overlaying of images offers the potential for accurately characterizing video capillaroscopy movies. This is an important step in obtaining
properties such as blood flow in the microcirculation.

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References: