Chapter 7
Computer–Aided Analysis of Nailfold Capillaroscopy Images

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ABSTRACT

Nailfold capillaroscopy (NC) is a non-invasive imaging technique employed to assess the condition of blood capillaries in the nailfold, and is routinely used for the detection of scleroderma spectral disorders, Raynaud's phenomenon and other connective tissue diseases. In this chapter, we present computer-aided approaches for capillary inspection, in particular focussing on the tasks of image enhancement, binarisation and skeletonisation. We evaluate the performance of a number image enhancement/noise removal techniques for NC images, as a pre-cursor to edge detection aimed at identifying capillaries. Results show that bilateral filters and enhancers provide the best overall image quality. Following noise removal, NC images typically get converted into binary form. For this purpose, we employ a difference-of-Gaussian approach before thresholding. The final stage is that of skeletonisation, which can be effectively performed using a rule-based thinning algorithm. Thus the complete imaging pipeline of pre-processing, binarisation and skeletonisation is represented in this chapter.

INTRODUCTION

Nailfold capillaroscopy (NC) is an in-vivo method for observing micro blood vessel characteristics. Diseases which particularly involve the morphological alteration of capillaries, for example Raynaud's phenomenon (Cutolo et al., 2003), systemic sclerosis (SSc) (Grassi et al., 2001), and other connective tissue diseases, such as dermatomyositis, antiphospholipid syndrome (Cutolo et al., 2006), and Sjogren's syndrome (Tektonidou et al., 1999), are all typically diagnosed using NC.

NC diagnosis is conventionally based on counting and/or identifying particular capillary types and other features(Cutolo et al., 2005). Enlarged and giant capillaries, haemorrhages (microbleeding), loss of capillaries, disorganisation of the vascular array, and ramified/bushy capillaries are morphological features observed in NC images that might indicate an underlying disease, and that have

been classified into specific NC patterns (Maricq & LeRoy, 1973), and later refined into early, active and late patterns in (Cutolo et al., 2000).

Manual measurement of morphological parameters is time consuming and difficult, even for experts. Furthermore, as based on human judgement, it is affected by a certain ambiguity and limited repeatability. Automated extraction of this information becomes challenging due to image noise, dust on lenses, micro-motion of fingers and air bubbles in the immersion oil. Several approaches for automated analysis of capillary images are reported in the literature. For example, in (Allen et al., 1999), a panoramic mosaic image is generated from several video frames, which in turn helps to extract capillary shapes. (Paradowski et al., 2009) focus on semi-automatic extraction of morphological features using various algorithms for vessel tracking, thickness analysis, and curvature analysis. Approaches of vessel extraction and skeletonisation are reported in (Wen et al., 2007, 2008; Lo et al., 2011).

In this chapter, we provide a quantitative evaluation of the performance of different de-noising techniques for nailfold capillaroscopy images. In particular, we benchmark ten image enhancement techniques as a precursor to edge detection aimed at identifying capillaries. We evaluate edge maps obtained from images processed using these techniques and compare them to a manually defined ground truth. Results on a variety of NC images show that the best image quality and subsequent capillary definition is achieved through the application of bilateral enhancers, bilateral filters, non-local means, and anisotropic diffusion.

Reliable segmentation of capillaries is a crucial step to extract morphological features and hence allow for accurate diagnosis. Thus, in this chapter, we present a novel method for skeletonisation, i.e. extracting the centre line(s) of nailfold capillaries. Our method is based on image enhancement followed by binarisation and subsequent skeleton extraction using a thinning algorithm. We demonstrate that our algorithm works well on a variety

of NC images and that it clearly outperforms, both qualitatively and quantitatively, previous methods.

ENHANCEMENT OF NAILFOLD CAPILLAROSCOPY IMAGES

In general, any kind of image analysis starts with an image enhancement process. The choice of enhancement technique has a direct impact on the final result, since the image quality greatly influences the subsequent analysis. For example, accurate extraction of capillaries will typically be easier on quality enhanced images than their original counterparts. However, in the literature relatively little attention has been given to this pre-processing step. In the following, we briefly discuss the ten enhancement techniques that we evaluate in our study.

Enhancement Techniques

In total, we examined ten image enhancement/denoising methods regarding their usability for NC images.

1. *Median filter (Gonzales & Woods, 2008)*: a commonly employed noise removal technique, also known as order-statistic filter, which replaces the value of a pixel by the median of the intensity values in the neighbourhood of that pixel.

2. *Gaussian filter (Gonzales & Woods, 2008)*: a smoothing filter, defined by a Gaussian kernel, which shows lower blurring effects compared to simpler averaging filters.

3. *α-trimmed filter (Zhong et al., 2000)*: a nonlinear window-based filter. It can be considered as a hybrid filter derived from mean and median filters. If the pixel values x_k within a window around location (i, j) are sorted in ascending order $x_1 \le x_2 \le ... \le x_N$, then the output of the α-trimmed filter is defined as

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