A study of noise reduction method on capillary images by utilizing OpenCV

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Abstract
Capillary images can be effective indicators since correlations have been established between the status of capillaries and certain diseases such as cancer and diabetes. Traditionally, capillaries observations have been conducted through visual observations by medical experts. Purpose of this study is to develop a noise reduction method to extract clearer capillary images for a quantitative evaluation method. Experiments were conducted with four subjects. The proposed method utilizing OpenCV platform produced clearer capillary images compared to the original images. The results have shown the effectiveness of the proposed noise reduction method.

Key words
capillary image, noise reduction, filtering, mask processing, OpenCV

1. Introduction

Recently, correlations have been established between shapes of capillaries and cancer and between granular stream in capillaries and diabetes (Ogawa, 1994), leading to strong interests in capillaries for its predictive characteristics for various diseases including cancer and diabetes. However, capillaries observations have been generally executed through visual observations by medical experts such as orthopaedists. Evaluation methods of the observations are strongly influenced by experiences and sensory evaluation of each observing expert. Therefore, quantitative evaluations have been largely neglected.

This study aims to fill the gap by extracting capillaries characteristics from nail bed capillaries images by using OpenCV (OpenCV Team, n.d.). OpenCV has wider applicability on various operating systems, which matches the aim of this study to develop a diagnosis system operated by each individual without medical expertise.

Existing studies to develop a diagnosis system on personal computer through nail bed capillary observations do exist (Torii and Shibata, 1997; Takeno et al., 2015). However, the observations on nail bed capillaries requires medical expertise and experience and depend largely on sensory evaluation. These conditions lead to several following challenges:

- Diagnosis varies among observers.
- Numerous noises on images make it difficult to distinguish capillaries from noises.
- Accurate extraction of capillaries characteristics is difficult.

These challenges mean quantitative evaluations on nail bed capillaries have not been established.

Hence, this study aims to extract capillaries features from nail bed capillaries images by utilizing OpenCV. Specifically, the study has investigated a noise reduction method which can retain capillaries features as far as possible by employing adaptive thresholding which allows each pixel to have distinctive threshold.

The organization of this paper is as follows: Chapter 2 introduces existing studies related to the study. In Chapter 3, filters developed originally for the study will be explained before proposed noise reduction method is explained. In chapter 4, experiments using the noise reduction method will be explained. The results of the experiments will be explained in Chapter 5. Chapter 6 summarizes the study and future directions will be explored.

2. Existing studies

Torii and Shibata (1997) have conducted several experiments to extract clear capillary images from the images. Their methods include high-pass filter sharpening, simple binarization, and hollow shape trimming. Their experiment process is as follows: first, high-pass filter sharpening is applied to an image for edge extraction. The filter uses two-dimensional Fourier transform to transform the image into frequency components. The filter removes lower frequency components. Remaining components are transformed back to an image by two-dimensional inverse Fourier transform. The image is then binarized and trimmed into hollow shape.

This process returns 0 to the focus pixel when all the surrounding pixels have color value other than 0. This step is applied to all the pixels in an image. This process extracts contours of capillaries. Information inside the capillaries are removed. Trimmed lines are connected seamlessly at four neighbors. However, the images which underwent this process still retain noises such as halation and murkiness.

Takeno et al. (2015) employ non-linear equations to process images of nail bed capillaries. Their study uses reaction-diffusion equations to binarize nail bed capillary images, instead of ordinary method in which single threshold is set to judge whether a pixel contains capillary information or not. Reaction-diffusion equations are mathematical expressions to formulate changes of space density of certain substance which is subject to two conflicting processes of local chemical reaction and global diffusion. The equations are widely applied in mathematical field and produce numerous results in elucidating the mechanism of self-organization process, in which order arises spontaneously from disorder or macro system arises from micro level components (Tokou et al., 2009).

Takeno et al. (2015) use the FtizHugh-Nagumo equation. The equation uses three-dimensional function for calculating reactions. By applying the equation, areas close to capillaries are whitened and those far from are blackened. This method is developed and refined by Nomura et al. (2008).

Reaction-diffusion equations were in the past applied in several researches for area-wide control of traffic signal networks. However, their applications to image processing was not moving forward since no research had been conducted for image processing.

Reaction-diffusion equations allows extracting better capillaries images compared to simple binarization processing. However, noise reduction by reaction-diffusion equations have erased thickness of capillaries, one of the features necessary for decease detection.

3. Methods

3.1 General

Four male university students participated in the experiments. They were all in the early 20s and in healthy condition. Before participating, they were given verbal explanation regarding all pertinent information and opportunity to ask questions. They all gave consent verbally.

Experiments were conducted from October to December in 2017. A capillary observation device VA201-H (Figure 1, Manufacturer: Toko Co., Ltd.) was used for capturing capillary moving image of the subjects who retained seated position.

The noise reduction method which was developed specifically for the experiments was applied to the captured images to extract clearer capillary images.

Figure 1: Capillaries observation device used in the study

3.2 Proposed noise reduction method

The noise reduction method proposed in this paper is composed of following steps:

(1) Change brightness and saturation.
(2) Color extraction is applied to extract green only.
(3) Apply Gaussian and bilateral filtering.
- Parameters for Gaussian filter:
  Size is 9 x 9 with standard deviation for X axis direction and Y axis direction are normalized to 1.
- Parameters for Bilateral filter:
  Size is 9 x 9 with standard deviations for color and distance are respectively normalized to 70 and 80.

(4) Adaptive thresholding is applied.
(5) Originally developed filters are applied for mask processing.

Green color extraction is adopted since preliminary experiments indicated that green was the best color to locate capillaries.

For smoothing, preliminary experiments were conducted with following filtering procedures: average filtering, weighted-average filtering, Gaussian filtering, bilateral filtering, non-local mean filtering. The combination of Gaussian and bilateral filtering, which yielded the highest accuracy among these filters, are adopted for the proposed methods.

Original filters No.1 and No.2 are developed for this study by the authors. The remaining steps listed above are standard procedures for noise reduction.

3.2.1 Algorithms of originally developed filters No.1

The primary purpose of the filter is to retain size and shape of capillaries since they are important evaluation criteria for the capillary health. Its algorithm is as follows:

- Return 0 if the value of focus pixel (FP) is 0.
- Return 255 if each adjacent pixel of the pixel 3 cells above FP (FPA3) is 255.
- Return 255 if each adjacent pixel of the pixel 3 cells below FP (FPB3) is 255.
- Return 255 if each adjacent pixel of the pixel 3 cells rightward to FP (FPR3) is 255.
- Return 255 if each adjacent pixel of the pixel 3 cells leftward to FP (FPL3) is 255.
- Return 0 if above conditions do not apply.

3.2.2 Algorithms of originally developed filters No.2

This filter is an improved version of the filter No.1 and its algorithm is as follows:

- Return 0 if the value of focus pixel (FP) is 0.
- Return 255 if each adjacent pixel of the pixel 3 cells above FP (FPA3) and of the pixel 6 cells above FP (FPA6) is 255.
- Return 255 if each adjacent pixel of the pixel 3 cells below FP (FPB3) and of the pixel 6 cells below FP (FPB6) is 255.
- Return 255 if each adjacent pixel of the pixel 3 cells rightward to FP (FPR3) and of the pixel 6 cells rightward to FP (FPR6) is 255.
- Return 255 if each adjacent pixel of the pixel 3 cells leftward to FP (FPL3) and of the pixel 6 cells leftward to FP (FPL6) is 255.
- Return 0 if above conditions do not apply.

4. Experiments

The purpose of this study is to extract capillaries features from nail bed capillary images. For capturing the images, a capillary observation device VA201-H is used. For image processing, OpenCV and Python (PythonJapan, n.d.) are used. Specifically, VA201-H is used to record moving images of nail bed capillaries from which still images are captured. The still images are then loaded to a computer, which extracts capillary features from the images by OpenCV image processing. The shapes of the capillaries extracted through binary processing are evaluated for the effectiveness of the proposed method.

Capturing an image of nail bed capillary beneath thick skin or dark skin is extremely difficult. Therefore, in this study, the third finger of non-dominant arm of the subjects participating in the experiments is employed as a target of the study for its relatively thin skin which allows better observation of capillaries. In order to avoid potential camera shake, moving images of nail bed capillary are recorded first. From the moving images, still images ideal for image processing are captured. Permeable liquid is applied to the target finger since the liquid suppresses light reflection, allowing better capturing of capillaries features.

The experiments are applied to four subjects. Their nail bed capillary images before image processing are as follows: subject A is relatively clear and undistorted (Figure 2(a)), subject B is murky but undistorted (Figure 3(a)), subject C is murky and distorted (Figure 4(a)) and subject D is unclear due to thick skin (Figure 5(a)).

5. Results

Compared to the original capillary images (Figures 2(a) to 5(a)), images produced through proposed noise reduction method (Figures 2(b) to 5(b)) showed clearer contour of the capillaries. The method allowed filtering out unnecessary background. Monochrome images led to easier recognition. These results have verified the overall effectiveness of the proposed method.

However, there still remains noises unrelated to capillaries. Also, although distal parts were clearly extracted, proximal parts were not able to be digitized since they were obscure in original images.

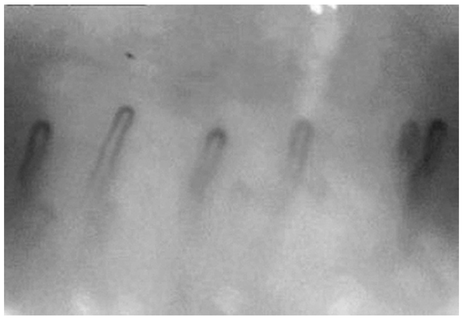
6. Conclusions and future directions

In this study, noise reduction method was proposed on nail bed capillary images. Specifically, nail bed capillary observation device VA-201H and Open CV were employed for observation and noise reduction, such as halation and murkiness

(a) Original image

(b) Image after noise reduction

Figure 2: Subject A

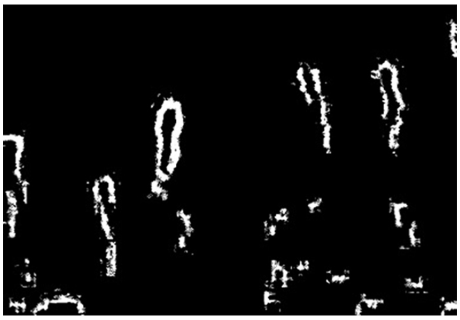


(a) Original image

(b) Image after noise reduction

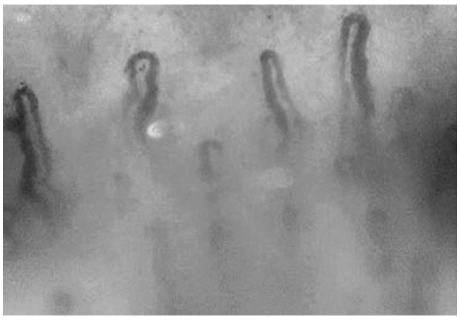
Figure 3: Subject B

(a) Original image



(b) Image after noise reduction

Figure 4: Subject C



(a) Original image

(b) Image after noise reduction

Figure 5: Subject D

from the original images.

The proposed method includes altering brightness and saturation, color extraction, smoothing, adaptive thresholding, originally developed filters, contraction and expansion, and mask processing. Several experiments were conducted with various combination of filters for better noise reduction. The original filters were developed based on presumption that existing filters are not fully capable of reducing noise embedded in capillaries images.

The proposed noise reduction experiments were applied to four subjects. Their nail bed capillary images before image processing are relatively clear and undistorted, murky but undistorted, murky and distorted and unclear due to thick skin.

The experiment results have shown that the two originally developed filters were successful in extracting four types of capillaries shapes. However, some noises remained especially around capillaries. Also, the method mistakenly extracted images unrelated to capillaries.

For future directions of the study, improving the proposed system is the first step. Specifically, originally developed filters can be improved. Also, additional noise reduction and image sharpening experiments will be conducted by setting new parameters for gaussian, bilateral and non-local filters.

The second step would be developing a new system which can observe capillary features and blood stream not only from still images but also from moving images, since blood stream information is pointed out as an evaluation criteria for capillary health (Takeno, 2010).

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