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Vascular Pattern Localization via Temporal Signature

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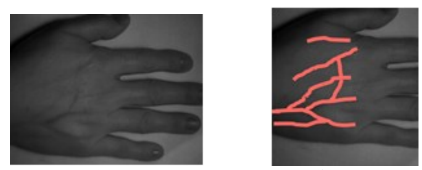
Abstract— **Accurate vascular pattern localization has many applications in the diverse scientific and application domains. For example, vascular patterns not only have been widely used as a biometric-based human identification method that is inexpensive, secure and easy to use, but also have produced more accurate heart-rate estimation using conventional RGB camera by defining regions of interest along the vascular patterns instead of the entire exposed skin area. In addition, extracting temporal activity along vascular patterns can further enable targeted monitoring of other physiological parameters, such as blood flow and blood pulse transition time. This paper presents a method for robust and accurate vascular pattern localization using conventional RGB imaging systems. Our approach overcomes current limitations of systems that use still RGB images for vascular pathway localization - which produce low contrast between areas of vascular patterns and skin tissues and are sensitive to skin color variations - by capturing the temporal differences between these two areas from RGB videos.**

I. Background and Introduction

Vascular patterns are the subcutaneous patterns of blood vessels beneath the skin. Vascular patterns are unique to an individual and are very stable over a long period of time [1]. Recently, vascular pattern biometrics has attracted increasing interest from both research communities and industries due to its ease of use, low cost, accuracy and security [2]. Another area where vascular pattern localization is bringing value is in providing more accurate heart-rate (HR) estimation using conventional RGB camera by defining regions of interest for sensing along vascular patterns instead of sensing across a broad area of exposed skin, especially in the back of the hand [3].

Previous work has shown that infrared imaging provides a noncontact and noninvasive data acquisition method for capturing superficial vascular patterns and does not require injection of any agents into the blood vessels [1, 4-12]. Therefore, it is by far the best known noninvasive technology to acquire vascular pattern images. L. Wang and L. Graham [8] compared near- and far-infrared imaging for capturing vascular patterns and concluded that the near-infrared (NIR) imaging produces good quality images when capturing vein patterns in the back of the hand, palm, and wrist and it is more tolerant to changes in environmental and body condition.

NIR imaging for vascular pattern localization relies on two properties of the infrared radiation: 1) light in 700 to 900 nm spectral window penetrates sufficiently deep into tissues, thus allowing for noninvasive imaging [13]; 2) absorption differences between the reduced hemoglobin and other skin tissues in the NIR spectral band [1]. The absorption difference produces images with high contrast between vascular patterns and skin tissues as shown in Fig. 1(a) and is less sensitive to skin color variations. From Figure 1(a), the vascular pattern can be easily extracted using this high image contrast (e.g., apply a lightness threshold based on image contrast) as shown in Fig. 1(b).

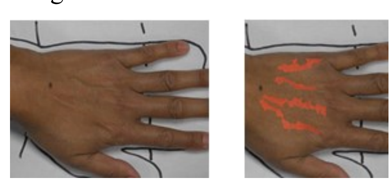


(a) (b)

Figure 1: (a) An NIR image of the hand; (b) Extracted vascular pattern based on the NIR image.

However, NIR-based imaging systems often require special illumination sources and / or specialized NIR cameras in the wavelength range that is suitable for vein pattern localization. These requirements can greatly increase the cost of the imaging system and add implementation challenges.

Conventional RGB imaging applied to vascular pattern localization could overcome these costs and convenience limitations. However, in the visible spectral band, as can be seen in Fig. 1(c), the contrast between vascular patterns and skin tissues is much lower than what NIR imaging systems provide (e.g., compare to the hand image in Fig. 1(a)). Because of the low image contrast, the extracted vascular patterns from the analysis of the still image in Fig. 1(c) can only reveal portions of the main vascular patterns as shown in Fig. 1(d). Another factor that makes it difficult to use still RGB images alone is its sensitivity to skin color, where the contrast between vascular patterns and skin tissues can vary greatly depending on the skin color.



(c) (d)

Figure 1: (c) RGB image of the hand; (d) Extracted vascular pattern based on a single RGB image (threshold based on color).

On the other hand, RGB-*video* imaging enables extraction of the temporal signals which are not available from still images. For example, Wu *et. al*. was able to reveal the subtle motion of blood vessels arising from blood flow in

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the wrist/forearm, which otherwise is difficult or impossible to see with the unaided eye [14].

In this paper, we explore the temporal characteristics of the vascular pathways from captured RGB videos for the purpose of vascular pattern localization. Our study has focused on the back of hands since it is convenient to capture and often used for biometric identification. Our experiments show that the extracted vascular patterns via low cost RGB video cameras using temporal signatures are similar to the patterns extracted using NIR imaging systems. We also demonstrated two applications that use the extracted vascular patterns: 1) biometric-based human identification; 2) improving physiological signal estimation (e.g., HR).

II. EXTRACTING VASCULAR PATTERN

A. Hand Localization and Tracking

From the first few frames of a RGB video sequence, the subject's hand(s) are located in the scene via object localization. In our study, the exposed hand(s) was identified based on skin color as shown in Fig. 2(b). This identification step can be further improved by other features such as the unique shape of the hand(s). In the presence of subject hand motion, the location of the hand(s) in the scene was tracked by using the well-known object tracking method as discussed in [13]. Figure 2(a) is an example of a set of frames from a video of the back of a hand. To reduce computational cost, an ROI shown by the red box in Fig. 2(c) was selected by finding the largest rectangle area in the identified skin area.

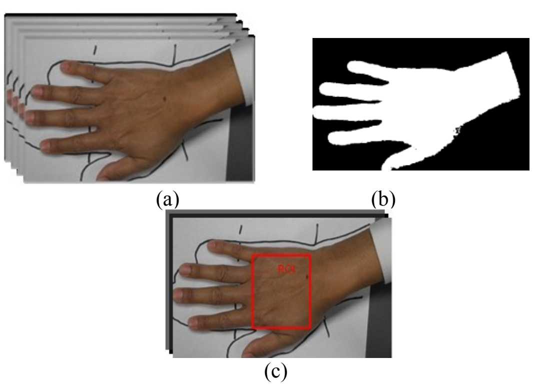


Figure 2: (a) RGB video of the hand; (b) identified hand area based on skin color; (c) identified ROI of this hand video (skin area within the red box).

B. Extracting Temporal Signature

The information contained in a set of values from a particular pixel across the duration of an RGB video can be thought of as three temporal signals, one corresponding to each of the R, G and B channels. To form the temporal signal at each pixel location, the three temporal signals of each channel are concatenated. The concatenation of R, G, and B signals enables us to extract the vascular patterns using color difference between the vascular patterns and skin area as well as the temporal information. Hence, the length of the resulting time series for each pixel is three times as long as the number of frames in the original video.

As mentioned previously, the use of video enables us to utilize the temporal signature of a signal that isn't available from a still image. In this paper, we first use the ***variance*** of the time series signal at each pixel as the representative temporal feature of that time series, though other temporal-related statistics can also be used. Figure 3 shows an image intensity map of the back of a hand produced with pixel values that are proportional to the variance of the concatenated time series at each of the pixel location. Comparing this image to the original RGB hand image from Fig. 1(c), it is obvious that the contrast between vascular patterns and skin areas has been greatly improved by the temporal average and enhancement.

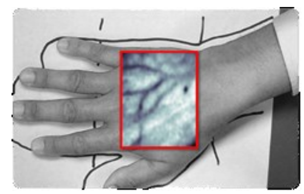
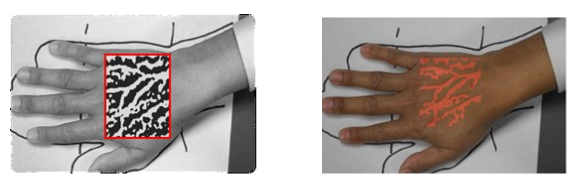


Figure 3: Variance map based on the temporal signature.

C. Vascular Pattern Localization

Thresholding is a simple way to extract the vascular patterns from the variance map shown in Fig. 4. However, applying a conventional static threshold is not optimal since the variance contrast can vary with factors that include different depths of the vascular pathways and non-uniform illumination of the hand. A better approach is to use an adaptive threshold algorithm that accommodates the differences in different parts of the variance map. Note that on the thresholded image shown in Fig. 4(a), there exist some small components that do not correspond to the vascular pathways. Therefore, further processing is required for their removal. In our study, morphological filtering is applied to the thresholded image to remove the small spurious features while preserving the connectivity of the extracted vascular patterns. The final extracted vascular pattern based on the variance map is shown in Fig. 4(b).



(a) (b)

Figure 4: (a) Adaptive thresholded image based on temporal variance; (b) Vascular pathways extracted from the hand RGB videos.

Comparing the extracted vascular patterns in Fig. 4(b) to the ground truth shown in Fig. 1(b), it is clearly seen that our algorithm can successfully extract the vascular pattern even from low-contrast RGB video, while the pattern extracted with approaches based on a single RGB image (shown in Fig. 1(d)) can only reveal a portion of the main vascular branches.

D. Discussion

The example video was taken at a rate of 30 fps by a high-resolution (HD) RGB camera with 720×1280 pixels. To speed up the process, a ROI was selected from the identified hand region as indicated by the red box in Fig. 2(b). We'd like to point out that the selection of camera resolution will depend on the application. For example, for biometric identification, small branches of vascular pathways might be of great importance to identify different subjects, thus high resolution cameras are desired. For improving HR estimation, since major branches are sufficient, low resolution camera can often meet the need.

Although the examples shown here used a minute-long video, we have examined the robustness of our proposed method using different video lengths. In our study, we have shown that a video length of 5~10 seconds was able to capture 80~90% of the vascular patterns. The length of the video will depend on any given application. For biometric identification, up to 20~30 seconds of video might be needed to capture fine vascular pathways to ensure the accuracy for human identification. For improving physiological signal estimation, the length can be shortened for real-time monitoring since major vascular pathways can be sufficient. Of course, this length will also depend on the frame rate and heart rate / heart rate variability of the subject.

Although we used the variance of the time-series to enhance the vascular pathways in RGB videos, many other temporal characteristics can also be considered as features to distinguish the vascular patterns from skin tissues. Another alternative is to use classification/clustering approaches based on temporal features such as *k*-means clustering that exploits similarity measures of time series signals between vascular pathways and skin tissues or SVM classification using temporal features [16]. For example, the average and the variance (or a combination of both, which would result in a vectorial feature representation) of the time series signal or the frequency responses (amplitudes) of the time series signal can be combined as features into a classifier.

III. APPLICATIONS

A. Biometric Human Identification via Vascular Pattern

The first application tests the use of the extracted vascular pattern for biometrics-based human identification. Although significant amount of previous work has been done in the field of vascular pattern biometrics, most of the existing art relies on using hand images taken in the NIR wavelength band with specific illuminators, rather than with more common RGB cameras under "ambient light". By applying the proposed vascular pattern extraction algorithm, we demonstrated the potential for developing a vascular pattern biometrics system via RGB video.

The demonstration shows an example of repeatability for a given subject over a range of magnification, over time and illumination variation. We also show inter-subject differences. In Figs. 5(a) and (b), two videos of one hand of the first subject were taken at two different magnifications. While the extracted vascular pattern from the video in Fig. 5(a) has more leaf-like shape, the main branches in the two patterns match quite well with each other, especially the 4 branching points outlined by the red circles. For the hand of the second subject shown in Figs. 5(c) and (d), two videos were taken at two different times (eight months apart), with different camera models and under different illumination conditions. The extracted main vascular pathways (highlighted by red lines) look very similar to each other. In comparison, the extracted vascular patterns shown in Figs. 5(a) and (b) are quite different from the ones shown in Figs. 5(c) and (d). The intra-subject similarity and inter-subject difference demonstrate that our proposed vascular pattern localization algorithm can be robust to varying imaging conditions (including magnification, camera model, illumination, etc.). Furthermore, the extracted vascular pathways can potentially be used to recognize the same subject (identity verification) and distinguish different subjects (biometrics). The experiment has been repeated for 4 different subjects with similar visual conclusions. To further validate the proposed method, we plan to compare the results with vascular patterns extracted using an NIR camera based on more quantitative measures.

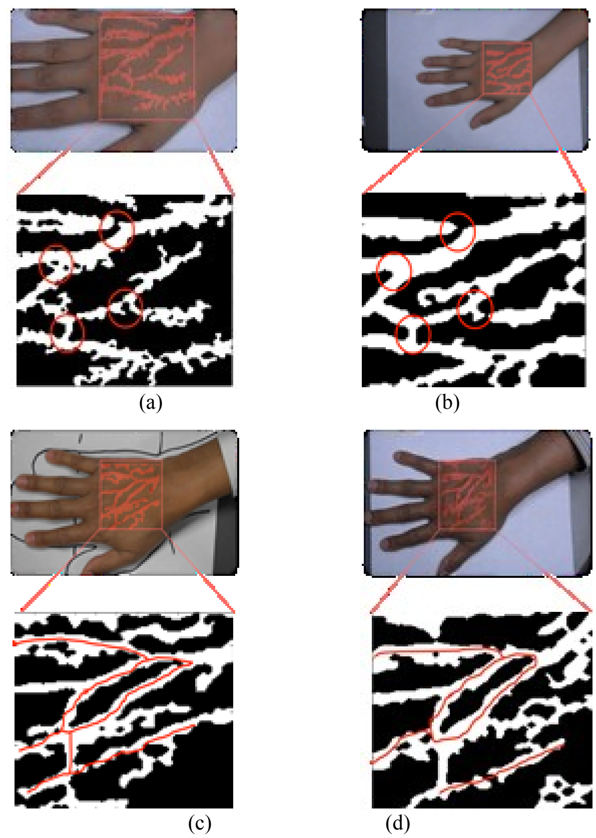
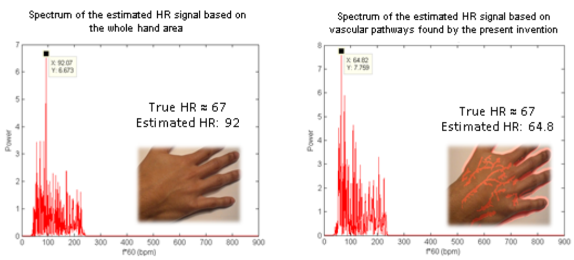


Figure 5: (a) and (b), (c) and (d) videos and extracted vascular patterns for subjects 1 and 2 respectively.

B. Improved Heart Rate Estimation with Extracted Vascular Pattern

The second application we demonstrated is aimed at improving physiological signal (e.g., HR) estimation with extracted vascular patterns. While HR estimation from face images is quite accurate via Independent Component Analysis (ICA) [17] or constrained-ICA [18], Fig. 6(a) shows that extending the method to the whole hand can be problematic due to integration of pixels from large non-pulsating regions. For example, Fig. 6(a) shows the estimated HR of 92 beats per minute (bpm) when using the whole hand as ROI, while the ground truth provided by a finger pulse oximeter was recorded between 65 and 69 bpm (mean value = 67 bpm). However, when we limited the ROI to the extracted vascular pathways, the HR is estimated at 65 bpm, which is much closer to the ground truth than using the whole hand as ROI. This demonstrates that using the extracted vascular patterns can produce more accurate estimations of HR than using entire exposed skin areas, matching well with the conclusion in [3]. We have also compared the results using cICA, which gave the same conclusion.



(a) (b)

Figure 6: (a) Spectrum of the estimated HR signals based on whole hand (top) and (b) extracted vascular pathways only (bottom).

IV. Conclusion

The paper introduces a method for vascular pattern localization from RGB video frames. The proposed method provides a low cost option for capturing vascular pattern without using specialized NIR imaging systems. The method utilizes the temporal signature of the vascular pathways extracted from a video sequence to separate vascular patterns from skin tissues. Its performance was demonstrated through two applications. Other time series classification/clustering methods will be investigated in the future. We'd also like to test the capability of our proposed method to detect finer vascular patterns as it is noted that the vascular patterns in the back of hands are usually much thicker and shallower than those in the palm.

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