Video Amplification for Biomedical Dynamic Image Using the Separation of Chromophore Component

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Abstract

In this paper, we propose a novel method of video amplification based on the separation of chromophore component. A video amplification method, Eulerian video magnification (EVM), was originally proposed by Wu et al.. The method shows the effectiveness to amplify slight change of facial color and can visualize the blood flow in human faces effectively. However, the conventional method was evaluated under stable condition of illumination. It is necessary to enhance the robustness against environmental change for practical use. The proposed method amplifies the variation of the chromophore component which is separated from shading component. We confirm that the proposed method can visualize blood flow in human face without having artifacts caused by shading change. We also apply the video amplification framework to a tongue movie as preliminary work for medical application and confirmed the effectiveness to visualize the blood pulse avoiding any clear artifacts.

1. Introduction

There are a lot of imperceptible, subtle changes out there. Skin color changes slightly due to the blood flow and the heartbeat component on skin surface can be detected remotely by analyzing the dynamic images [1, 2]. Clothes are also slightly moving whole sleeping. It is possible to analyze the status of the respiration by the video analysis [3]. These kinds of remote observation of physiological status hold great potential for healthcare applications, medical diagnosis, and affective computing. For example, the heart rate variability spectrograms (HRVS) are useful for remote monitoring of cognitive stress [4, 5] and driver's awareness [6], since HRVS is related to the status of the autonomic nervous system, which controls involuntary body functions, such as breathing, blood pressure, and heartbeat.

Wu *et al.* showed that Eulerian video magnification (EVM) can amplify slight changes of facial color and can visualize the blood flow in human faces [7]. The visualization of blood flow is beneficial to many healthcare and medical applications. The variation of facial blood flow can yield a clue to estimate affective status [8, 9, 10]. The detection of the difference of blood flow between a left foot and a right foot can provide useful information for the diagnosis of arteriosclerosis [11]. In surgical, the detection of blood vessels is useful to reduce the patient's damage by preventing bleeding. The blood vessels under the surface are sometimes invisible. In that case, surgeons often estimate the position by referring anatomical a priori knowledge or by relying on sense of touch.

The conventional EVM method shows the effectiveness under the stable photographic environment. The subjects are required to be stable in order to avoid the illumination change caused by the motion. The conditions of illuminations are also required to be constant during the capturing time. It is the limitation for the practical use.

In this paper, therefore, we propose new approach of EVM based on the separation of chromophore component in order to enhance the robustness against illumination changes. Tsumura *el al.* [12] proposed a method to separate hemoglobin, melanin, and shading components from a skin image captured with a standard RGB camera. The method can extract hemoglobin component which vary according to the heartbeat and the method can eliminate shading component which is sensitive to illumination change. Therefore, we apply the separation method to EVM since the method can be expected to enhance the robustness against illumination change.

The rest of this paper is organized as follows. In Section 2, we describe the proposed EVM based on the separation of chromophore component. In Section 3, we show the results of EVM to visualize blood flow in human face. In Section 4, we describe the modification of chromophore component separation for medical application and show the results of EVM using a tongue movie as preliminary work for medical application. In Section 5, we present our conclusions.

2. Video Amplification Using the Separation of Chromophore Component

In this section, we describe the video amplification method based on the separation of hemoglobin component.

2.1 Eulerian Video Magnification

The original video amplification method, Eulerian video magnification (EVM) [7], has two kinds of method to amplify subtle changes in video, the enhancement of small motion and that of small color change. We aim at an enhancement of small color change in video. Figure 1 shows the overview of the conventional Eulerian video magnification to amplify subtle color change. First, the method processes the spatially blurred video frames from input video frames to reduce locally random noise. Next, a temporal band-pass filter is applied to the blurred video in order to extract the component of temporal color change. Then, the band-passed video frames are synthesized with original input video frames multiplying gain factor.

We apply the similar framework to enhance small color change. Figure 2 shows the framework of the proposed method. We apply component separation process to extract hemoglobin component and synthesize with original input video frames multiplying gain factor. The fluctuation of hemoglobin component indicates heartbeat behavior and it is free from the side effect caused by shading change which will be described in next section.

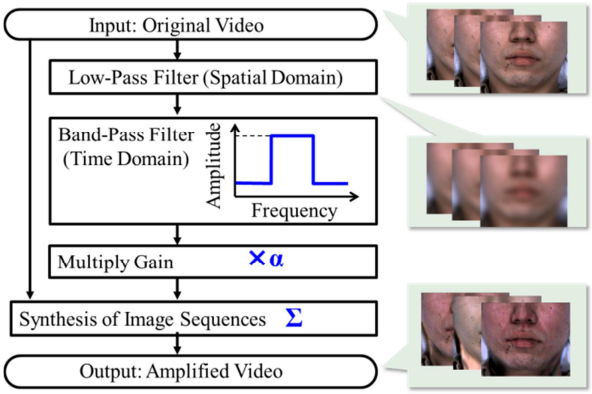


Figure 1 Overview of Conventional Eulerian Video Magnification

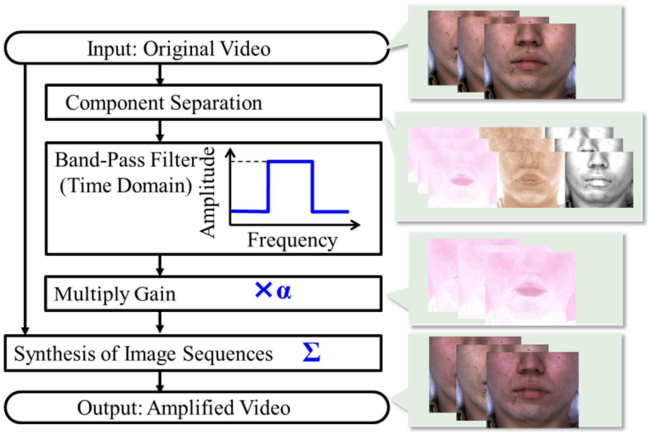


Figure 2 Framework of Video Amplification for Biomedical Dynamic Image

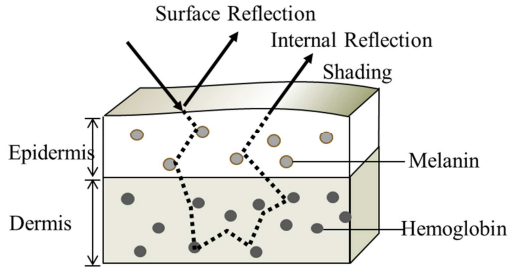


Figure 3 Skin Model of the Hemoglobin Extraction

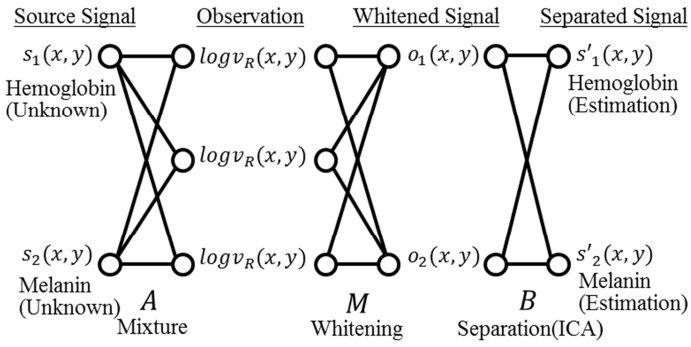


Figure 5 Mixture and Separation of Independent Signals

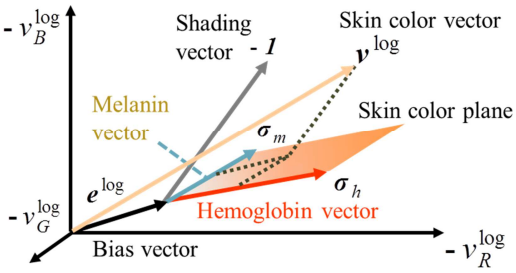
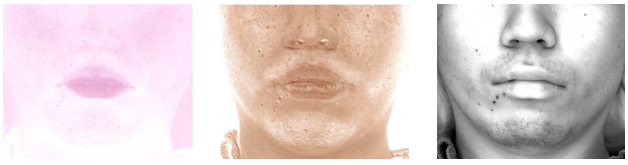


Figure 4 Model of Separation of Skin Components



(a) hemoglobin (b) melanin (c) shading

Figure 6. Separation Result of melanin, hemoglobin and shading components

2.2 Extraction of Hemoglobin Component

The technique to extract hemoglobin chromophore from a single skin color image [12] is briefly reviewed in this subsection.

Figure 3 shows the skin model for the extraction of hemoglobin component. We use two-layered skin model composed of epidermis and dermis. We should note that the chromophores of melanin and hemoglobin are predominantly found in the epidermal and dermal layers, respectively. This model was derived from the previous research on skin optics [13, 14, 15] The reflected light from the skin surface consist of surface reflection and internal reflection. The internal reflection can describe as following using the modified Lambert-Beer law [16], which uses the mean path length of photons in the medium as the depth of the medium.

$$L(x,y,\lambda) = e^{-\rho_m(x,y)\sigma_m(\lambda)l_e(\lambda)-\rho_h(x,y)\sigma_h(\lambda)l_d(\lambda)}E(x,y,\lambda) \quad (1)$$

where $E(x,y,\lambda)$ denotes the spectral irradiance of incident light at point (x,y), $\rho_m(x,y)$, $\rho_h(x,y)$ denote the concentration, $\sigma_m(\lambda)$, $\sigma_h(\lambda)$ denote absorption area melanin and hemoglobin respectively, and $l_e(\lambda)$, $l_d(\lambda)$ denote average light path in the epidermis and dermis layers. By putting polarization filters in front of the illumination and camera, we ignore the surface reflection. Camera signal $v_i(x,y)$, $i = R,G,B$, can be modeled as

$$v_i(x,y) = k\int L(x,y,\lambda)s_i(\lambda)d\lambda = k\int e^{-\rho_m(x,y)\sigma_m(\lambda)l_e(\lambda)-\rho_h(x,y)\sigma_h(\lambda)l_d(\lambda)}E(x,y,\lambda)s_i(\lambda)d\lambda \quad (2)$$

where $s_i(\lambda)$denotes the spectral sensitivity of a camera, k denotes coefficient of camera gain. Spectral reflection of skin is smooth and it is approximately correlated with camera sensitivity. We assume $s_i(\lambda) = \delta(\lambda - \lambda_i)$.

We assume spectral irradiance of incident light $\bar{E}(\lambda)$ is uniform over the observation area, and the shading coefficient p(x,y) accounts for the concavity and convexity of the surface. We derive

$$E(x,y,\lambda) = p(x,y)\bar{E}(\lambda) \quad (3)$$

Camera signal $v_i(x,y)$ can be simply rewrite as

$$v_i(x,y) = ke^{-\rho_m(x,y)\sigma_m(\lambda_i)l_e(\lambda_i)-\rho_h(x,y)\sigma_h(\lambda_i)l_d(\lambda_i)}p(x,y)\bar{E}(\lambda_i) \quad (4)$$

By taking the logarithm of both sides of Equation (4), we derive

$$\boldsymbol{v}^{log}(x,y) = -\boldsymbol{\rho}_m(x,y)\boldsymbol{\sigma}_m - \boldsymbol{\rho}_h(x,y)\boldsymbol{\sigma}_h + p^{log}(x,y)\mathbf{1} + \boldsymbol{e^{log}} \quad (5)$$

where

$$\boldsymbol{v}^{log}(x,y) = [logv_R(x,y) \quad logv_G(x,y) \quad logv_B(x,y)]^T,$$
$$\boldsymbol{\sigma}_m = [\sigma_m(\lambda_R)l_e(\lambda_R) \quad \sigma_m(\lambda_G)l_e(\lambda_G) \quad \sigma_m(\lambda_B)l_e(\lambda_B)]^T,$$
$$\boldsymbol{\sigma}_h = [\sigma_h(\lambda_R)l_d(\lambda_R) \quad \sigma_h(\lambda_G)l_d(\lambda_G) \quad \sigma_h(\lambda_B)l_d(\lambda_B)]^T,$$
$$\mathbf{1} = [1 \quad 1 \quad 1]^T,$$
$$p^{log}(x,y) = log\big(p(x,y)\big) + log(k)\big)$$
$$\boldsymbol{e^{log}}(x,y) = [logE_R(\lambda_R) \quad logE_G(\lambda_G) \quad logE_B(\lambda_B)]^T \quad (6)$$

$v_R(x,y)$, $v_G(x,y)$, $v_B(x,y)$ are R, G, B signal at the position of (x,y). $\sigma_m(\lambda_R)$, $\sigma_m(\lambda_G)$, $\sigma_m(\lambda_B)$ and $\sigma_h(\lambda_R), \sigma_h(\lambda_G), \sigma_h(\lambda_B)$ are absorption area of melanin and hemoglobin for RGB wavelength respectively. $l_e(\lambda_R), l_e(\lambda_G), l_e(\lambda_B)$ and $l_d(\lambda_R), l_d(\lambda_G), l_d(\lambda_B)$ are average light path in the epidermis and dermis layers for RGB wavelength respectively. $p(x,y)$ indicates shading coefficient. k denotes coefficient of camera gain. $E_R(\lambda_R), E_G(\lambda_G), E_B(\lambda_B)$ are component of spectral irradiance of incident light for RGB wavelength respectively.

Figure 4 shows the relation between the input RGB signal and each component. The logarithm of the captured RGB signals $\boldsymbol{v^{log}}$ can be represented by the weighted linear combination of the four vectors, melanin vector $\boldsymbol{\sigma}_m$, hemoglobin vector$\boldsymbol{\sigma}_h$, shading vector $\mathbf{1}$ and the bias vector $\boldsymbol{e^{log}}$.

We predefine a skin color plane using training data set. Figure 5 shows the mixing and separation process of melanin and hemoglobin signals for the definition of skin color plane. Let denote $A = [\boldsymbol{a}_1, \boldsymbol{a}_2]$ as the constant 3×2 mixing matrix and $\boldsymbol{s}(x,y) = [s_1(x,y), s_2(x,y)]^T$ as the quantity vector on the image coordinates (x,y). $\boldsymbol{v}^{log}(x,y)$, logarithm of the observational RGB signals, can be written as follows:

$$\boldsymbol{v}^{log}(x,y) = A\boldsymbol{s}(x,y). \quad (7)$$

If the mixing matrix A is known, we can obtain estimation source signal $\boldsymbol{s}'(x,y)$ using separation matrix H as following equation.

$$\boldsymbol{s}'(x,y) = H\boldsymbol{v}^{log}(x,y). \quad (8)$$

where $H = A^{-1}$. However, A is unknown in usual. Hence, we create whitened signal $\boldsymbol{o}(x,y) = [o_1(x,y), o_2(x,y)]^T$ whose elements $o_1(x,y)$ and $o_2(x,y)$ are mutually independent by applying whitening process to source quantity vector $\boldsymbol{s}(x,y) = [s_1(x,y), s_2(x,y)]^T$ and we obtain estimation source signal $\boldsymbol{s}'(x,y) = [s'_1(x,y), s'_2(x,y)]^T$ using independent component analysis (ICA). This process can be rewritten as follows:

$$\boldsymbol{s}'(x,y) = H\boldsymbol{v}^{log}(x,y) = BM\boldsymbol{v}^{log}(x,y), \quad (9)$$

where whitening matrix M and separation matrix by ICA B.

In this case, a number of observational signals are three, RGB, whereas a number of original source signals are two, melanin and hemoglobin. We reduce the dimension of the observation using principal component analysis and define a skin color plane that contains first principal component and second principal component. This process is same as whitening process.

We predefine a skin color plane using training data set. The logarithm of the captured RGB signals $\boldsymbol{v}^{log}$ is projected onto the skin color plane along with the shading vector $\mathbf{1}$. From the position on the skin plane, we obtain the hemoglobin vector. Figure 6 shows an example of the result of melanin, hemoglobin, and shading components.

3. Evaluation of blood flow in human face

In this section, we show the experimental results of video amplification to visualize blood flow using extracted hemoglobin component in human face.

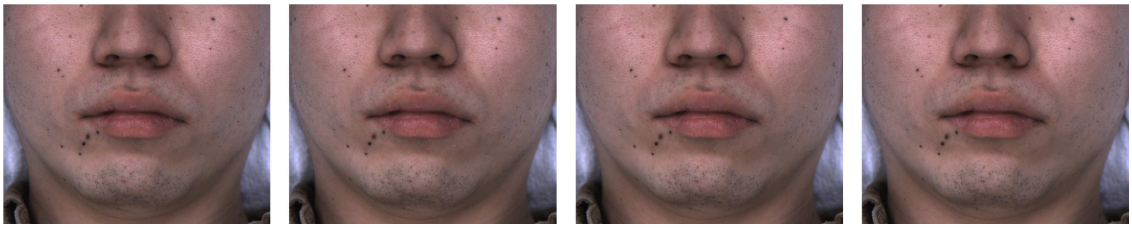
The camera used to collect the video sequences for analysis wasPointgreyGrasshopper3(GS3-U3-23S6C-C). The frame rate was 60[fps], each video frame was 928x760[pixels], 12bit RAW format, no compression. The lens was FUJINON DF6HA-1B, F1.2, focus length 6mm. The subject distance from the camera was 1.0m. The illumination, an artificial solar light (SOLAX XC-100), was used from the distance of 1.0m.

Figure 7 shows the experimental results of video amplification to visualize blood flow in human face. The results of conventional method [7], (b), and the result of the proposed method, (c), was amplified with gain 50 respectively. The original video sequence, (a), does not show pulse signal between four frames. The results of conventional method, (b), amplify the pulse signal in the subject's face. However, the frames have black line along the neck as undesirable artifacts. The result shows that the conventional method mistakenly amplifies the shading component since it simply amplifies the pixel values of blurred image. On the other hand, the results of the proposed method, (c), amplify the pulse signal in the subject's face without having clear artifacts. The results show that the proposed method can successfully eliminate shading component in chromophores separation process and effectively enhance pulse signal by amplifying hemoglobin component.

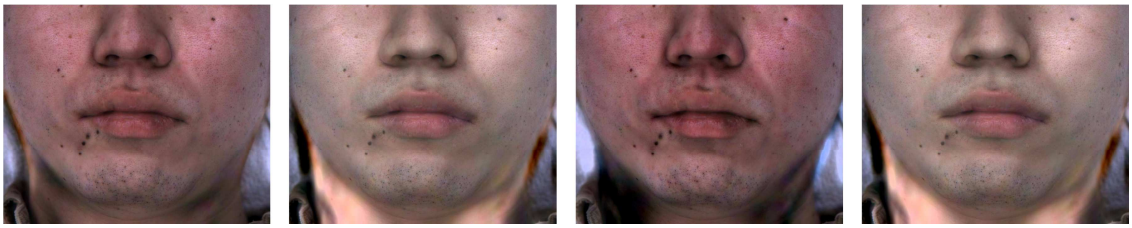
4. Pulse Detection for Medical Application

In this section, we describe the modification of chromophore component separation for medical application and show the results of video amplification using a tongue movie as preliminary work for medical application.

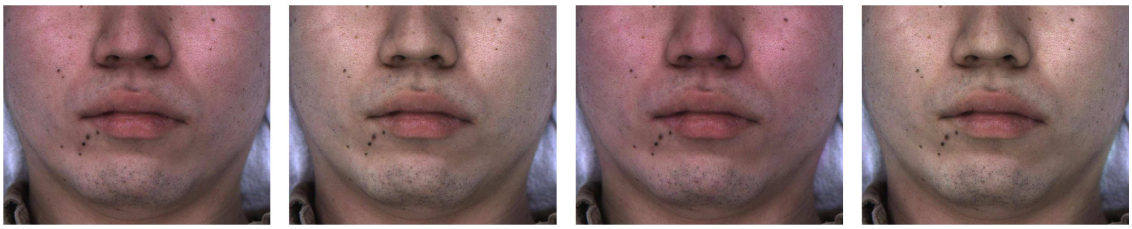
For the pulse detection in facial area which is described in section 2, we extract hemoglobin component utilizing two layered skin model which consist of melanin and hemoglobin. In this section, we also utilize similar approach for the pulse detection from medical video. However, the surfaces of epithelium do not have melanin chromophores. We cannot utilize the skin color plane shown in Figure 4 in order to extract hemoglobin component for medical images. Figure 8 show the temporal behavior of hemoglobin component in facial region and back of tongue respectively, which is extracted using skin color plane in Figure 4.



(a) Original Video (consecutive frames)



(b) Conventional Method: Eulerian Video Magnification [7]



(c) Proposed Method: Video amplification Using the Estimation of Chromophore Component

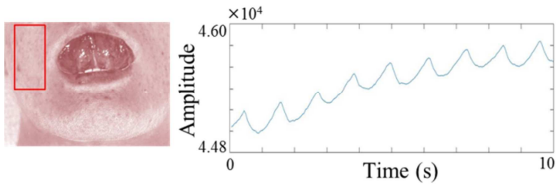
Figure 7. Video Amplification to Visualize Blood Flow in Human Face. (a) Four frames from the original video sequence (face). (b) The same four frames amplified the subject's pulse signal using conventional method [7]. (c) The same four frames amplified the subject's pulse using the proposed method.

The temporal behavior of the back of tongue does not show pulse when we use skin color plane, whereas the method works well in facial area. It is because that separation method described in section 2 is designed for the separation of melanin, hemoglobin and shading components for skin.

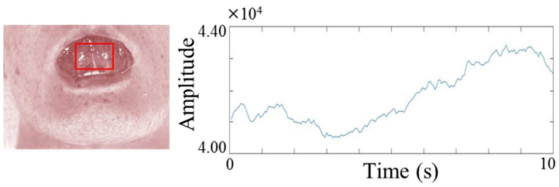
It is known that combination of two illumination wavelength, 415nm and 540nm, is effective for endoscope to visualize blood vessels under surface of epithelium [17][18]. Hence, we make a hypothesis that we can simply represent the existence of blood vessels using the mixture model of two substances. We collect images of back of tongue on vessel and off vessel respectively and defined tongue color plane which contain first and second principal component as described in Figure 9. The basic framework of the separation of chronopher is same as skin component separation. Figure 10 shows an example of the separation of tongue components.

Figure 11 describes the experimental results of the video amplification using a tongue movie. The conventional method [7], (b), amplified the blurred image with gain 50. The proposed method, (c), amplified first independent component on tongue color plane with gain 50. The original video sequence, (a), does not show pulse signal between four frames. The results of conventional method, (b), shows the variation of undesirable dark region in each frame. The result indicates that the conventional method mistakenly amplifies the shading component since it simply amplifies the pixel values of blurred image. On the other hand, the result of the proposed method, (c), shows the periodical color variation on the surface of vessel without having artifacts. It indicates that the proposed method amplify a specific independent component which correlated with blood flow by eliminating shading component.

Figure 12 shows the pulse distribution in the tongue region. In red region, the wave of first independent component on tongue color plane shows periodical variation which is correspond to pulse signal, (c). Therefore, there is sharp peak around 1 [Hz] (60 bpm: beat per minute) in frequency analysis by FFT. On the other hand, in green region, the wave of first independent component does not show periodical variation, (d). Hence, the frequency peak around 1 [Hz] (60 bpm) is lower than that of red region. We utilize the property to visualize the distribution of pules signal. The heat map, (b), shows the distribution of pulse signal which is calculated by taking the sum of the magnitude of frequency component from 1 [Hz] (60bpm) to 1.4[Hz] (71bpm).It is useful to observe the detail distribution of pulse component more than video amplification.



(a) Hemoglobin Component in skin area



(b) Hemoglobin Component on the back of tongue

Figure 8. Behavior of Hemoglobin Component (a)Skin area, (b)Back of tongue

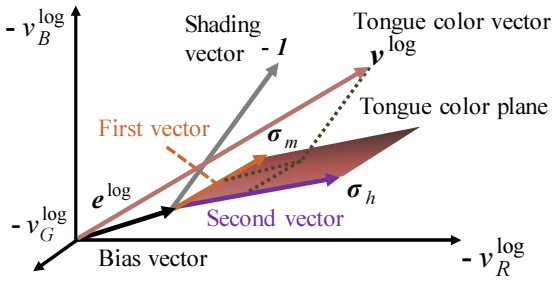
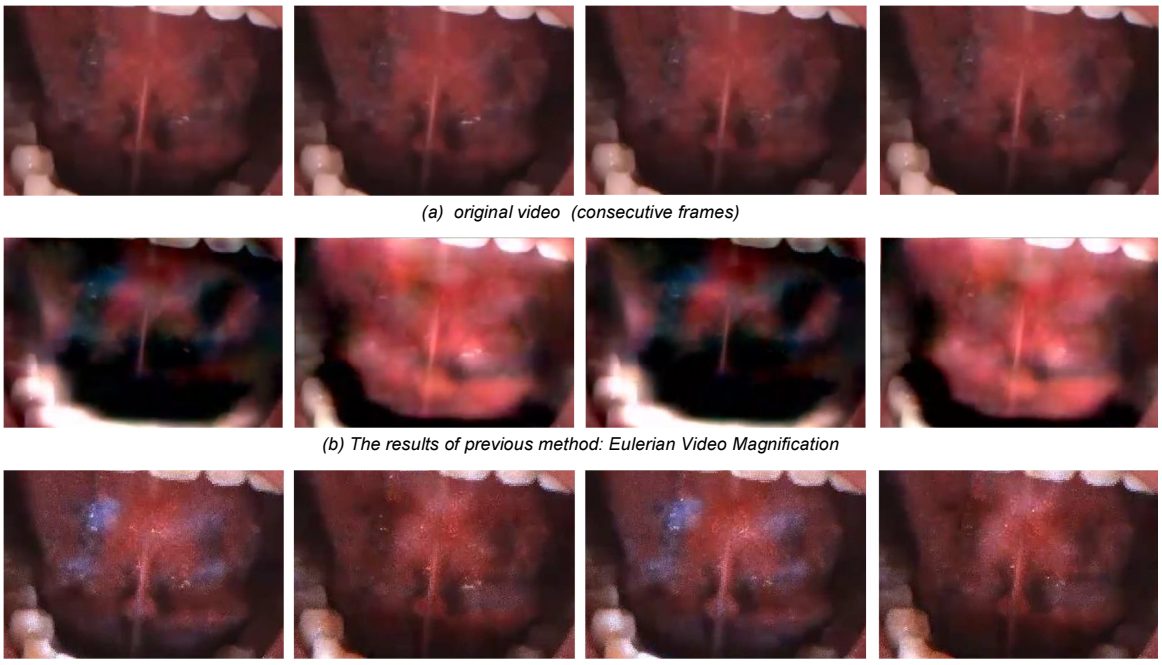


Figure 9. Model to separate components on the back of tongue

(a) First Vector Component (b) Second Vector Component (c) Shading Component

Figure 10. Estimation Result of Components on the Back of Tongue



(a) original video (consecutive frames)

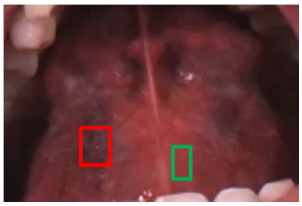
(b) The results of previous method: Eulerian Video Magnification

(c) The results of proposed method: video amplification using pigment component separation

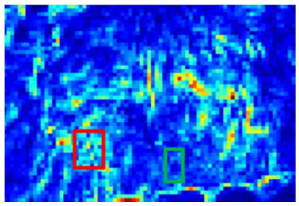
Figure 11 Video Amplification to Visualize Blood Flaw on the back of tongue. (a) Four frames from the original video sequence (back of tongue). (b) The same four frames amplified the pulse signal using conventional method [7]. (c) The same four frames amplified the pulse using the proposed method.

5. Conclusion and Discussion

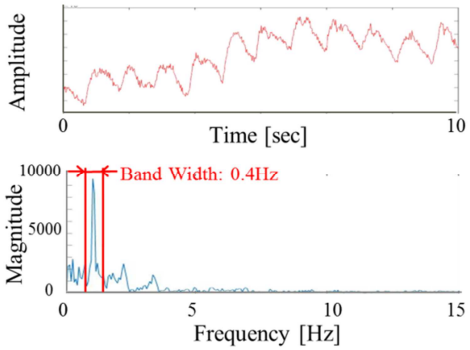
In this paper, we proposed a novel method of video amplification based on the separation of chromophore components. Using the test video data, we confirm that the proposed method can visualize blood flow in human face without having artifacts caused by shading change. We also apply the video amplification framework to a tongue movie as preliminary work for medical application. We defined the tongue color plane by ICA and we used the first competent for video amplification



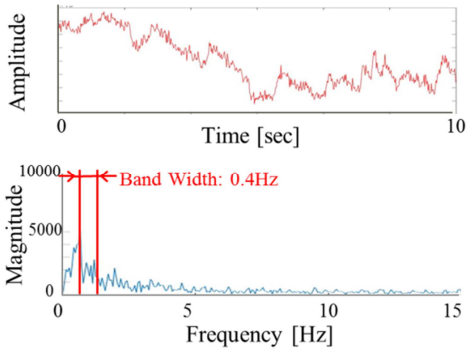
(a)Original Video



(b)Heat Map to Indicate Blood Flow



(c)First Vector Component and its Frequency Analysis (Red Region)



(d)First Vector Component and its Frequency Analysis (Green Region)

Figure 12 The distribution of Pulse Intensity. (a)Original video frame. (b) Heat map of the pulse intensity. (c) First Vector Component and its Frequency Analysis (Red Region). (d) d)First Vector Component and its Frequency Analysis (Green Region)

after we confirmed that the first component shows the periodical behavior caused by blood pulse. We also confirm the effectiveness video amplification using the first component of ICA. It can enhance blood flow avoiding the artifacts caused by shading change. Furthermore, we proposed heat map format to show the detail distribution of blood flow by analyzing magnitude of frequency component of pulse wave.

At last, we mention the current limitations and future works. First, we evaluated small number of samples to examine the effectiveness as a preliminary work. The evaluation with large number of samples is necessary for future work. Second, we also have to think about how to assess the performance. In this paper, we evaluate the effectiveness of the enhancement of blood flow with eyes. We have to think about the method to access the performance quantitatively. Third, we have to study the scientific evidence of two mixture model for medical application. The effectives for the skin model have been evaluated previously [12, 19]. However, the mixture model for medical application is based on the hypnosis from the knowledge of [17,18]. It is important to confirm and evaluate the scientific evidence. It might to lead optimization of illumination spectra. Forth, we also have to confirm the effectiveness for detection of blood vessels at medical front. As a next step, we also have to study usability to switch between the usual observation and the enhancement mode we propose this time. Fifth, the real time processing also remains for future work. Currently the processing is done by Matlab code after taking video sequence. Thinking about implementation as a product, hardware processing such as ASIC is necessary for real time processing.

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