Sensors & Transducers
Published by IFSA Publishing, S. L., 2021
http://www.sensorsportal.com

Visual Intelligence-Based Contactless Bio Signals Measurement and Diagnosis Sensor to Overcome COVID-19

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Received: 21 January 2021 /Accepted: 1 March 2021 /Published: 31 March 2021

Abstract: COVID-19 is mainly transmitted either directly by droplets from infected people or indirectly through contact with vehicles in contaminated environments. Coronavirus, which is highly contagious, is highly likely to result in a secondary infection between the patient and the medical staff during the first diagnosis, and if it is left alone, the likelihood of a tertiary infection is increased. In order to prevent this, a biometric means capable of diagnosing body temperature and heart rate in a non-contact manner is needed in consideration of the characteristics of corona symptoms accompanying high fever and various complications.

In this paper, the body temperature image and pulse image are acquired simultaneously using a general camera to measure the health status of the subject. Using this, it is possible to monitor in real time and to react immediately to the patient's acute disease. This study aims to develop a system capable of simultaneously estimating temperature by measuring heart rate using image sequences and measuring changes in peripheral blood flow. First, the system recognizes the user's face from a sequence of images collected through the camera, then tracks it to continuously extract the color of the same area and measures the user's heart rate using the color change of the corresponding pixel. Second, the system measures changes in peripheral blood flow due to external temperature. The body maintains normal body temperature by regulating peripheral blood flow. In this study, the user's body temperature was estimated by measuring the difference in this delay with the user's body temperature.

As a result of the experiment, we confirmed that there is a close relationship between the external temperature and the stabilization time of blood flow, and based on this, a body temperature inference equation was derived.

In conclusion, this study, a user's face was recognized using a webcam, and a system was developed to infer heart rate and body temperature based on the color data of the recognized user's face.

Keywords: Mobile health, Non-contact, Heart rate, Temperature measurement, Artificial intelligence, Covid-19.

1. Introduction

Coronavirus disease 2019 (COVID-19) was first discovered in Wuhan, China in December 2019 due to the outbreak of pneumonia of unknown origin [1-3]. It rapidly spread from China to other countries around the world, prompting the World Health Organization (WHO) to declare a pandemic in March 2020. In South Korea, a traveller from Wuhan, China was first diagnosed with COVID-19 on January 19, 2020. Since then, the government raised the COVID-19 alert level to “caution” due to the sporadic occurrence of patients caused by foreign inflows, and then to “serious” in February as new cases gradually spread across the country [4-6].

Many transmission epidemiology researches conducted so far has identified acute respiratory infectious diseases and pneumonia are transmitted from person to person, and via droplets. COVID-19 is supposedly transmitted through the droplets originating from infected people or indirectly transmitted through the contact with media in a contaminated environment, as with most respiratory viruses [7]. COVID-19 patients exhibit very mild symptoms at the beginning, but they can release the virus in the asymptomatic phase before transitioning to the symptomatic phase. Therefore, failing to diagnose and impose a quarantine early leads to the widespread community transmission of COVID-19. Airborne transmission is possible as well, but it occurs only in special environments, such as medical institutions where aerosols can be generated [8, 9].

Therefore, the highly infectious coronavirus is likely to cause the secondary infection between the patient and the medical staff during the primary diagnosis, and the likelihood of the tertiary infection increases if it is not properly handled [10, 11]. To prevent the secondary infection, it is deemed necessary to develop bio signal measurement systems capable of detecting the body temperature and heart rate in a contactless manner, considering the characteristics of COVID-19 symptoms involving high fever and various complications. This study introduces a new means to remotely measure bio signals and the body temperature, which can effectively reduce a chance of additional infection during primary diagnosis process of a probable COVID-19 patient.

1.1. Clinical Features and History

Among the many complications from the coronavirus, the most prominent is high fever. Many medical institutions first measure the body temperature of a patient to diagnose COVID-19. Since secondary infection may occur during this process, hospitals introduced a contactless temperature measurement method that uses an infrared camera. It is a concept developed before the COVID-19 pandemic, but since the outbreak, this topic has started to draw extensive attention from both academia and industry, making it the most fundamental element for diagnosis and treatment. The most common methods uses thermal imaging cameras, a kind of infrared cameras. They measure the amount of the infrared rays emitted by an object and represent it as a relatively temperature to a reference point. However, if the reference point is inaccurate or is lost, the measured infrared rays cannot be used to determine the absolute temperature. In addition, infrared rays cannot penetrate transparent glass or acrylic materials. The information that infrared cameras receive in presence of a transparent barrier between the object and the camera, such as glass window, is the thermal image of the barrier, not the object. In contrast, conventional cameras can retrieve light information through the barrier. Additionally, it is difficult to widely use thermal imaging cameras due to their high prices compared to conventional thermometers even though the prices have been reduced by the active distribution of the cameras.

To overcome these problems, this study proposed a method to measure bio signals without any physical contact, which reduces the chance of additional infection and also provides convenience to both medical personnel and patients. The health status of the participants was measured by collecting body temperature and pulse images concurrently using image processing. Then the results were used to develop a model that can enable real-time monitoring which provide sufficient time to medical personnel to take immediate action to the acute diseases of the patient.

2. Previous Studies

2.1. Beer-Lambert Law

The Beer-Lambert law represents the correlation between the intensity of the projected light, and that of the light that penetrated through a homogeneous medium when the light is projected at a given wavelength to the medium. This law uses the following equations to evaluate the correlation for the transmitted light from the vasoconstrictive circulation state at the photoplethysmography (PPG) signal measurement point.

$$\frac{I}{I_0} = \exp(-\varepsilon_a C_a V_a - \varepsilon_v C_v V_v - \varepsilon_t C_t V_t), \tag{1}$$

$$\frac{I_t}{I_0} = \exp(-\varepsilon_t C_t V_t) \tag{2}$$

In the above Eq. (1) and Eq. (2), I_0 is the intensity of the light projected from the light source, I is the intensity of the light transmitted through the blood and tissue, and I_t is the intensity of the light transmitted only through the tissue. Eq. (1) represents the relationship between the light source and the light transmitted through the blood and tissue, and Eq. (2) the relationship between the light source and the light transmitted only through the tissue. The ε_a, ε_v, and ε_t are absorption in the artery, vein, and tissue, respectively. Constants C_a, C_v, and C_t are their concentrations, and V_a, V_v, and V_t are their volumes. Eq. (1) is divided by Eq. (2) to obtain Eq. (3).

$$\frac{I}{I_t} = \exp(-\varepsilon C V) \tag{3}$$

In the above equation, V is the total blood volume, and ε is the average absorption coefficient of the total blood. Therefore, $V = V_a + V_v$ and $\varepsilon = (\varepsilon_a V_a + \varepsilon_v V_v) / V$

hold in Eq. (3). C_a and C_v in Eq. (1) represent hematocrits. The value of C_v increases during mental stress, but it varies by only a few percent (%). Consequently, C_v and C_a can be interpreted to be the same as the average concentration of the total blood (C) in the normal circulation state. Therefore, C_a=C_v=C holds. It is known that the arteries and veins in the hands are very sensitive to vasoconstrictor stimuli. In addition, reflex venoconstriction and vasoconstriction do not occur independently. This indicates that changes in alpha-adrenergic sympathetic nerve activation are suitable for detecting changes in the blood vessel state between the arteries and veins at the fingertip. Therefore, assuming $\lambda = V_v/V_a$ (ratio of the venous blood volume to the arterial blood volume), ε can be expressed as follows.

$$\varepsilon = [\frac{1}{(\varepsilon+1)}]\varepsilon_a + [\frac{1}{(\varepsilon+1)}]\varepsilon_v \tag{4}$$

In particular, ε is not affected by changes related to the blood volume. Therefore, the differential coefficient of I/It, which corresponds to V in Eq. (3), is expressed as following.

$$\frac{\delta(\frac{I}{I_t})}{\delta V} = -\varepsilon C(\frac{I}{I_t}) \qquad V = \frac{\pi r^4}{8\eta l}\Delta P \tag{5}$$

Summarizing Eq. (5) yields Eq. (6).

$$\Delta V_a = (\varepsilon C)^{-1}\Delta\frac{I_a}{I} \tag{6}$$

The total blood volume consists of the averages and pulsating elements of the arterial and venous blood volumes. When pulsation is observed only in the arterial part, ΔV and corresponding ΔI are again converted into ΔV_a and ΔI_a in Eq. (6). When the attenuation of the transmitted light seems to lower the voltage in the actual PPG signal measurement, the values of ΔI_a and I have (-) and (+) signs, respectively. Therefore, -ΔI_a is replaced with ΔI_a to have (+) for ΔI_a in Eq. (6). Based on this, PPG signals can measure the blood volume change by projecting light toward vein.

2.2. Heart Rate Measurement Using PPG

Previous studies show that the heart rate and respiration rate can be measured using a conventional camera, appropriate lighting, and PPG.

PPG is one of the most commonly measured bio signals along with the electrocardiogram signal. The blood flow velocity, blood oxygen saturation, and pulse rate can be measured using PPG signals. The PPG measurement uses a photosensor that converts light into electric charges. This sensor act as a photoelectric transformation element and photodiodes are mainly used. A photoelectric transformation element converts the incoming incident light into electric charges. These electric charges deliver the intensity of light at each pixel position to the central processing unit through a charge-coupled device and a digital signal processor (DSP) to generate an image. The information of the object is collected from the light reflecting off the object. PPG measurement acquires the signal by irradiating light in a specific wavelength band to the human body and detecting the reflected or transmitted light. The resultant signal represents a pulse wave generated by the heartbeat.

2.3. Utilization of PPG Signals

PPG has been clinically used for diverse physiological diagnoses and the evaluation of the functions and characteristics of the cardiovascular system. The cardiovascular system is a major organ system responsible for circulation, and mainly consists of blood, heart, and vessels. Physiological changes in cardiovascular system may occur due to multiple factors, such as the characteristics of myocardial cells, active state of the heart, mechanical characteristics of vessels and blood, and autonomous nerve system (ANS). Interaction between these multiple components achieve blood circulation in the body. Therefore, PPG, which can be non-invasively measured, has been utilized in various fields even though it indirectly reflects the status of the cardiovascular system.

2.4. Contactless Heart Rate Measurement Using Image Sequences

In previous studies, face was selected as the body part to extract PPG signals from. This is because it is easy to capture the images of a face using a camera and face clearly shows the difference in blood flow depending on the heartbeat. When PPG measurement is performed using an RGB camera, the green channel is more suitable for measuring the heart rate and respiration rate than the red or blue channel. This is because the green channel covers the wavelength that shows a clear difference in light absorption between hemoglobin and oxidized hemoglobin.

In addition, another study demonstrated that it is possible to measure the heart rate and respiration rate in the presence of many people after defining the face area using a face recognition system with a webcam. In the study, three independent factors were extracted from the RGB channels of the camera using blind source separation (BSS), and an independent component analysis (ICA) algorithm was used in this process. BSS is used to extract an accurate signal source under the assumption that an accurate signal cannot be identified because the measured signal is mixed with noise and various signals.

In this study, BSS was used to measure the precise amount of light reflected by oxidized hemoglobin and non-oxidized hemoglobin. While Hemoglobin is under influence of light of all channel and wavelengths, the data residing in the range from

520 to 580 nm is dominantly used in determining the blood vessel status. Based on this, PPG was measured by extracting independent factors that affect the accurate amount of light reflected by hemoglobin. In addition, we attempted to add the process of estimating the temperature of the user through the change in peripheral blood flow due to the external temperature difference.

3. Research Method

This study aims to develop a system that can measure the heart rate using image sequences and estimate the temperature simultaneously by measuring the change in peripheral blood flow. The system can be represented as Fig. 1.

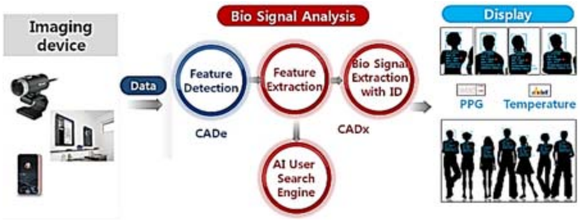

Fig. 1. Schematic of the developed system.

First, the system recognizes the user's face from the image sequences collected through the camera and then extracts feature points from the face. Then, it acquires coordinates for measuring the biometric data of the user based on the extracted feature points. The system continuously extracts the color of the same area by tracking the user's face and measures the heart rate of the user using the color change of the corresponding pixel.

Second, the system measures the change in peripheral blood flow caused by the external temperature. The human body controls the peripheral blood flow to maintain the normal body temperature. In this study, the user's temperature was estimated by measuring the difference in this delay depending on the user's body temperature.

3.1. Heart Rate Measurement

The method of measuring the heart rate using a camera in the detected face area is basically the same as the PPG measurement principle. Briefly, it is shown in Fig. 2 below.

PPG measurement is a method of estimating the heart rate by measuring the blood flow in a vessel using the optical characteristics of tissue. When blood flows to peripheral blood vessels, the flow becomes slow between the diastolic and systolic phases of the heart. In this instance, PPG detects changes in the transparency of the blood vessels.

This can be measured from any peripheral tissue of the body, the face, the fingers, or the earlobe. For conventional PPG measurement, the fingers are used. When the measurement is taken with the face, we expected that the heart rate can be recorded by detecting the variation in speed of blood flow in the vessels of the facial skin.

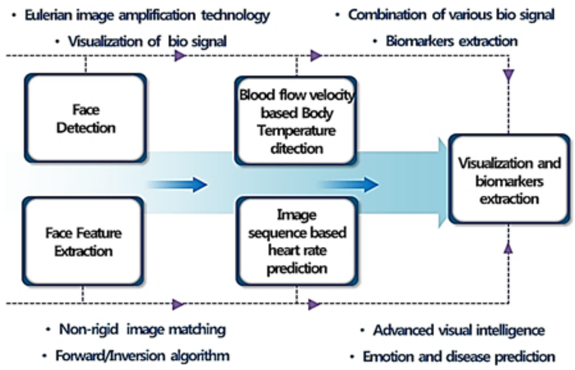

Fig. 2. Process of measuring the heart rate using a camera.

3.2. Temperature Measurement

PPG signals are generated by changes in peripheral blood flow and thus reflect the vessel state in the measurement area. As the cardiovascular system is a closed loop, it is possible to evaluate the state of various vascular systems by analyzing the components of PPG signals. The blood flow can be represented by the Hagen-Poiseuille's law (HPL) as shown in Eq. (7).

$$V = \frac{\pi r^4}{8\eta l}\Delta P, \tag{7}$$

$$R = \frac{8\eta l}{z r^4} \tag{8}$$

In Eq. (7), ΔP is the pressure, η is the viscosity of blood, and l is the length of the tube. Eq. (8) for the resistance in a tube can be obtained using Eq. (7). It indicates that the blood flow and the resistance against it are proportional and inversely proportional to the radius to the fourth power, respectively. Therefore, these two parameters are more affected by the change in the diameter of the tube than by the change in the length, pressure difference, and viscosity of the tube. This principle was applied to derive the change in peripheral blood vessels depending on the temperature. The surface temperature of the measurement area for PPG signal measurement is influenced by the body temperature and the surrounding environment. Local temperature changes will cause the contraction of tissue and peripheral blood vessels, thereby impacting the flow of blood. In a previous study, the correlation between the PPG signal and skin temperature under varying external temperature was revealed through an experiment after attaching a reflective sensor to the forearm. In another study, the correlation between the blood flow and the finger temperature was revealed as Fig. 3. With these findings applied to the capillaries of the face, it is possible to estimate the body temperature using the change in the blood flow of the facial capillaries caused by the temperature change.

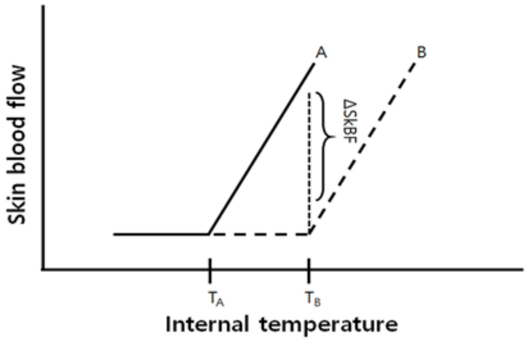

Fig. 3. Skin blood flow according to the external temperature.

The sympathetic nerve control of the skin blood flow involves the noradrenergic vasoconstrictor system and the sympathetic active vasoconstrictor system, and the latter is responsible for 80-90 % of the percutaneous vasoconstrictor caused by the thermal stress of the whole body. In short, the skin blood flow may increase to 6-8 L/min when the body temperature rises.

Thus, this study attempted to measure the body temperature based on the difference in the expansion of the skin capillaries when the body enters a stable environment from an external environment with a large temperature difference. We measured the time required for the temperature of the skin, which was previously disrupted by the environment, to stabilize (stabilization time: ST). The body temperature was calculated through the correlation between the difference of the subject's body temperature between the external temperature and ST (Fig. 4).

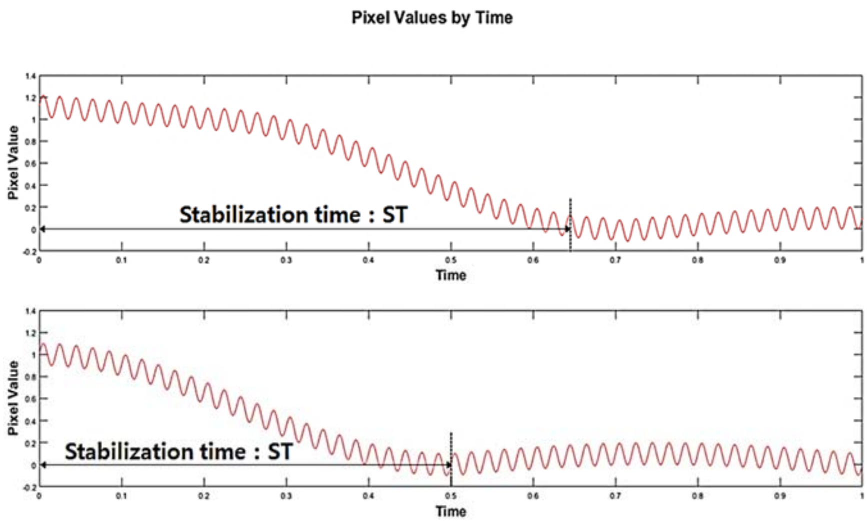

Fig. 4. ST according to the external temperature (top: external temperature of 37°, bottom: external temperature of 33°).

4. Research Results

The validity of the data collected from a camera was evaluated by comparing the variance of blood flow, which was measured through the proposed method, to the value measured through PPG measurement that used Biopac MP150 (Biopac, Goleta, CA, USA).

Biopac MP150, a device for oxygen saturation measurement from Biopac, can measure biosignals using both digital and analog methods.

Fig. 5. Experimental setup of Contactless biosignal measurement system.

4.1. Heart Rate Measurement Results

The experiment was performed ten times with seven males and three females aged between 23 and 31. In each experiment, the heart rate was measured ten times for a minute, and the average heart rate measured using the image sequences obtained by alternating the lighting conditions was compared with the average heart rate measuring using Biopac. The results are shown in the figure below. The accuracy of average heart rate measurement was found to be 99.1 %.

4.2. Body Temperature Measurement Results

In this study, an experiment was performed with test subjects aged between 23 and 33 while the temperature of the room was fixed at 25°C. ST was measured after each test subject was exposed to an environment with an external temperature between 28°C and 38°C for ten minutes and then introduced to an indoor environment with a fixed temperature of 25°C.

The thickness of the blood vessel wall, the elasticity of the blood vessel wall, and the viscosity of blood were excluded due to their negligible influence over the peripheral blood flow. Based on the temperature difference with the largest influence, a body temperature measurement equation was derived. The results showed that ST increased as the temperature difference between the control and test environment, i.e. the indoor and outdoor respectively. As shown in the Fig. 6, the correlation between the temperature difference and ST was analyzed through the linear regression method to derive a relationship. The derived equation is as follows.

$$\mathrm{T_{ST}} = 1.337(\mathrm{Temp_{out}} - \mathrm{Temp_{\in}}) + 9.710 \quad (9)$$

In Eq. (9), T_{ST} denotes ST. A linear regression model was fitted by including the y-intercept of the graph. As a result, the values of the dotted line in Fig. 6 were obtained. The coefficient of determination was calculated to find relatively suitable fitting. The calculated coefficient of determination was R^2=0.798.

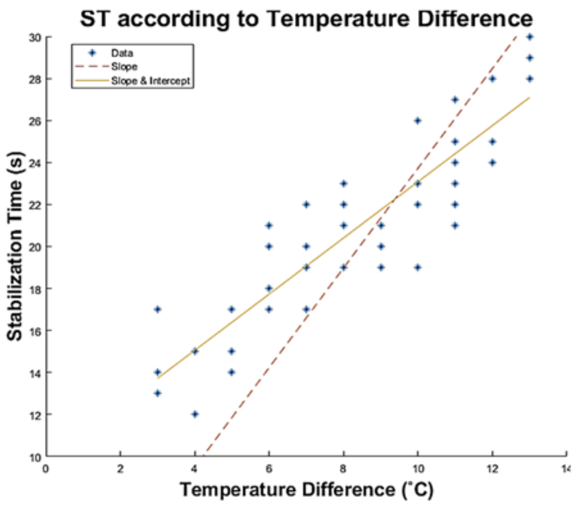

Fig. 6. ST according to the external temperature.

5. Conclusion

As the product of this study, we designed a system to measure the complex biosignals and data of the user using image sequences. The system recognizes the user's face using the image sequences collected through a camera and acquires coordinates for measuring the biometric data of the patient based on the extracted feature points. It extracts the color of the same face area by continuously tracking the user's face and measures the heart rate of the user, using the color change of the corresponding pixel. In addition to simple heart rate measurement, the blood flow in the skin capillaries was measured using the phenomenon that the light absorption wavelengths of oxidized hemoglobin and hemoglobin are different. Based on this, an algorithm and a system for estimating the body temperature were also developed.

When the heart rate measured using image sequences was compared to photoplethysmography (PPG), which is the conventional contact-type measurement method, an accuracy of 99 % was achieved. And the calculated body temperature also exhibited high accuracy compared to the actual temperature measured with a thermometer. The results showed that the biosignals processed using image sequences have comparable reliability to those measured using the conventional biosignal measurement method.

However, the proposed method has a drawback. It estimates the body temperature by measuring the time required for the cooled body to be stabilized. And it can be used only when there is a temperature difference between the external space and the measurement space. As the method does not have control over the environmental temperature, it is necessary to develop and verify additional algorithms that can overcome this limitation.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2017R1D1A1B04031182/NRF2020 R1I1A1A01072101).

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