A MULTIPLE OBSERVING TIMES APPROACH FOR REAL-TIME CONTACT-FREE HEART RATE MEASUREMENT USING A WEBCAM

BY

VASITPHON PAWANKIATTIKUN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
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SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
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A Thesis Presented

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Submitted to
Sirindhorn International Institute of Technology
Thammasat University
In partial fulfillment of the requirements for the degree of
MASTER OF ENGINEERING (INFORMATION AND COMMUNICATION TECHNOLOGY FOR EMBEDDED SYSTEMS)

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JUNE 2016

Acknowledgements

This research is financially supported by Thailand Advanced Institute of Science and Technology (TAIST), National Science and Technology Development Agency (NSTDA), Tokyo Institute of Technology, and Sirindhorn International Institute of Technology (SIIT), Thammasat University (TU), and the National Research University Project, and Thailand Office of Higher Education Commission.

Abstract

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VASITPHON PAWANKIATTIKUN

Bachelor of Engineering in Electronics and Communication Engineering, Sirindhorn International Institute of Technology Thammasat University, 2013

Master of Engineering (Information and Communication Technology for Embedded Systems), Sirindhorn International Institute of Technology Thammasat University, 2016

There are many instruments for heart rate measurements such as electrocardiogram (ECG or EKG), chest straps, and pulse oximeters. Since these devices are contact-based measurement, they may make the users feel not only uncomfortable but also have some pains. We present a method for a contact-free heart rate measurement on a video sequence using a webcam. The heart rate is measured by detecting the prominent frequency of the skin-color change in a human face. As color features in a video sequence, we utilize both green and hue signals. The frequencies of the two color signals are analyzed in multiple observing times. We select statistically the most reliable Fourier spectrum among all. The proposed method has been implemented using Simulink. Experimental results show that it can perform heart rate measurement accurately in real time.

Keywords: Heart rate, Real-time, Webcam, Simulink, Hue

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List of Acronyms

BPF	Band-pass filter
BPM	Beats per minute
ECG, EKG	Electrocardiogram
FFT	Fast Fourier transform
FPS	Frames per second
GB	Green and blue
HR	Heart rate
HSI	Hue, Saturation, and Intensity
HSV	Hue, Saturation, and Value
MPEG	Moving Picture Experts Group
PC	Personal computer
QQVGA	Quarter-Quarter Video Graphics Array
RB	Red and blue
RGB	Red, green, and blue
RG	Red and green
ROI	Region of interests

List of Notations

j	The imaginary unit
e	Euler's number
σ	Standard deviation
π	The ratio of a circle's circumference to its diameter
$\sum$	The result of an addition

Chapter 1
Introduction

Problem Statement and motivation of this study are introduced in this chapter. Description of related works also included. In addition, this thesis organization and a list of our publication are also inform in this chapter.

1.1 Problem Statement and Motivation

The heart rate is one of the important physiological signals of a human body that varies according to our activities such as physical exercise and emotions. The heart rate (HR) is the number of heart beats in a minute and expressed as beats per minute (BPM). A normal resting heart rate for adults is about 60 to 100 BPM. The easiest way to measure the heart rate is putting two fingers on the wrist or neck and pressing until we can feel the pulse of the heart and count the number of beats manually. The common measurements such as electrocardiogram (ECG or EKG), chest strap worn around the chest, and finger pulse oximeter are contact-measurement that is uncomfortable, inconvenient and can cause some pains to the users. So, this thesis develops video-based method for contact-free heart rate measurement by using a webcam, it can detect the change of skin color on our face and measure heart rate in BPM unit.

1.2 Related Works

In recent years, many research topics are concerned with HR measurement using a video based method that is contact-free [1–8]. When heart is beating, blood will flow through the human body including the face. Skin colors of the face will change a little bit but it cannot be perceived by naked eyes, but the values of the signal from a camera can tell the differences in changing colors on the face. HR measurement can be measured using a video sequence from a webcam or a camera built in a laptop [2–5, 9]. The video-based method is more comfortable and cheaper for HR measurement.

For the video-based method to measuring HR, the motion tracking is used in [6]. The RGB color model which has red (R), green (G), and blue (B) components are all used in [1–4, 7, 8, 10]. The combination of RG, GB and RB also studied in [9]. It has shown that the G signal is the most effective for HR measurement compared with R and B signals [1, 5, 7]. It has been also shown that the hue (H) signal from HSV (or HSI) color model is also effective for HR measurement in [5, 11]. The H signal is robust to light intensity changes from an uncontrolled light source.

The purposed of this study is to develop a method for contact-free heart rate measurements on a video sequence using a webcam. Furthermore, we propose to carry out HR measurement in real-time using Simulink [12].

1.3 Thesis Organization

The thesis is organized as follows. Background of this study is described in Chapter 2 while methodology is introduced in Chapter 3. Chapter 4 is a results and analysis section. The last chapter in this thesis is Chapter 5 which is a conclusion of this study.

1.4 Publication

This study results in the following publication:

- V. Pawankiattikun and T. Kondo, A method for contact-free heart rate measurement on a video sequence using Simulink, Proceedings of The 7th Biomedical Engineering International Conference (BMEiCON 2014), Fukuoka, Japan, November 2014.

- V. Pawankiattikun, C. Lueangwattana, T. Kondo, T. Phatrapornnant, and H. Kaneko, A novel method for contact-free heart rate measurement using Simulink, Proceeding of The 6th International Conference on Information and Communication Technology for Embedded Systems (IC-ICTES 2015), Prachuap Khiri Khan, Thailand, March 2015.

Chapter 2
Background

This chapter gives the background knowledge of this thesis. An explanation about heart rate and instruments are the first sections for this chapter. Fast Fourier transform and Z-score which use in video based method for measure the heart rate are described in this chapter also. In the last section, information about Simulink is informed.

2.1 Heart Rate

Figure 2.1: The image of a method to measure heart rate by our self [13].

Heart rate is one of the important physiological signals of a human body. The heart rate is a speed of heartbeats in a minute and expressed as beat per minute (BPM). When the heart is beating, it supplies oxygenated clean blood from the left ventricle to the blood vessels that transports blood through the human body. In various situations, human body may change the need of oxygen. So, the heart rate will change according to physical exercise, different emotions and so forth. For health-care professionals, they can use heart rate measurement to aid in diagnosis and follow patient in several medical conditions such as heart diseases. Normally heart rate of human is around 60 to 100 beats per minute. In healthy persons, they may have a lower heart rate. the heart rate can be measured by finding the pulse in the human body. When heart beating, it pumps blood into the blood vessels. As the blood pass through blood vessels, the blood vessels expand. So, the easiest way to measure heart rate is putting two fingers on the wrist or neck and pressing until we can feel the pulse of the heart beat and count the number of beats manually. Figure 2.1 shows an example of a method to measure heart rate by our self.

2.1.1 Instruments

Beside we can measure heart rate by our self. Heart rate also can be measured by using instruments such as electrocardiogram (ECG or EKG), Chest Strap, and pulse oximeter.

2.1.1.1 Electrocardiogram

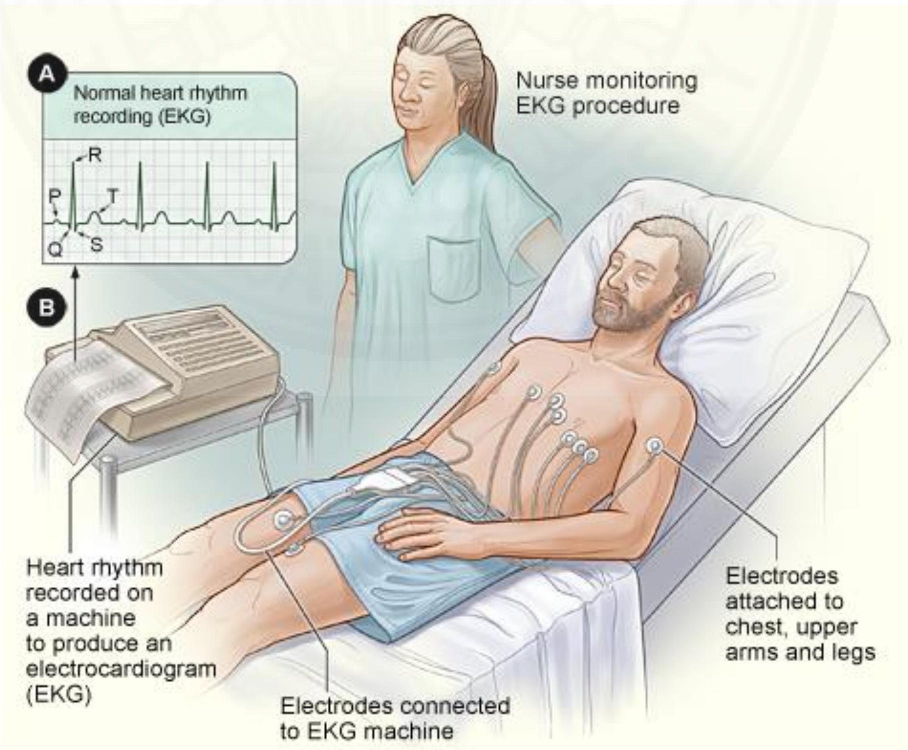

Figure 2.2: The image of standard setup for an electrocardiogram [14].

Figure 2.2 shows a picture of standard setup for an electrocardiogram. The electrocardiogram is recording the electrical activity of our heart over a period of time using electrodes placed on the skin to check its problem. Small metal electrodes are placed on arms, legs and chest. From the electrodes, there are wires that connected to the electrocardiogram machine. Electrodes can detect change of tiny electrical impulses that produces from our heart and shows the heart's electrical activity as line tracings on paper or computer. We can get many medical information from electrocardiogram including heart rate which is the most accurate heart rate measurement.

2.1.1.2 Chest Strap

Figure 2.3: The image of chest strap heart rate monitor [15].

Figure 2.3 shows a picture of chest strap heart rate monitor. It consists of two parts, a transmitter and receiver. The transmitter is attached to a belt that worn around the chest. While the receiver is worn on the wrist like a watch to monitor the heart rate.

As the electrical signal is transmitted through the heart muscle while the heart is beating. The electrical activity can be detected by the transmitter part that placed on the skin around the chest which is the area that the heart is beating for receive the signal. Electromagnetic signal that containing heart rate data is sent from transmitter to the wrist receiver for monitor the heart rate.

2.1.1.3 Pulse Oximeter

Figure 2.4: The image of pulse oximeter [16].

Figure 2.4 shows a picture of pulse oximeter. The pulse oximeter is a one method for monitoring heart rate and it also monitor a human’s oxygen saturation. The pulse oximeter is placed on a thin part of human body such as fingertip. It shrines two wavelengths of light through the fingertip to a photodetector. While heart is beating, it will transport blood through the whole body including fingertip. When blood flow through the body, skin at fingertip will change color according to the heart beating. Pulse oximeter can detect the change of skin color and measure heart rate according to frequency of color change.

Electrocardiogram, chest strap and pulse oximeter are contact-measurement that is uncomfortable, inconvenient and can cause some pains to the users. In this thesis, we develop video-based method for contact-free measurement by using a webcam to detect the color change of skin color on our face. The method is like in pulse oximeter, we use camera as a sensor for detect color change of the face and measure the heart rate in BPM unit.

2.2 Fast Fourier Transform

A fast Fourier transform (FFT) is algorithm to compute the discrete Fourier transform (DFT) in faster way. It converts a signal from original domain (time domain) to the frequency domain. In engineering field, it uses FFT in many applications. The results from FFT and DFT are the same, but computational time is the important difference. FFT is much faster than DFT and many FFT algorithms have more accurate result than use DFT directly. Basic formula of DFT express as

$$X_k = \sum_{N=0}^{N-1} x_n e^{-i2\pi k \frac{n}{N}} \tag{2.1}$$

where X : the frequency domain representation of signal time-series signal x. The formula yields one complex number X_k for every k.

k : the k’th frequency component; $k = 0, 1, \dots, N-1$.

N : the total number of samples in signal x.

x : the time series signal (the data); $n = 0, 1, \dots, N-1$.

n : the n’th sample (in the time domain).

j : the imaginary unit.

While heart is beating, skin color on our face will change periodically according to heart beat. So, we can use FFT to observe the signal of skin color change in frequency domain for video-based method of heart rate measurement.

2.3 Z-score

Z-score or standard score is used for evaluate the set of data. Positive value of standard score represent a data above the mean, while negative standard score represents a data below the mean. Z-score is obtained by using different value of individual raw score from population mean and then divided by population standard deviation. The z-score expressed as

$$z = \frac{\boldsymbol{x} - m}{\sigma_x} \tag{2.2}$$

where $\boldsymbol{x}$ are the raw score. The m and σ_x are the mean and the standard deviation. In this thesis, we use z-score to evaluation the spectrum from FFT for heart rate measurement.

2.4 Simulink

Simulink is developed by MathWorks. Figure 2.5 shows an example of Simulink model. Interface of Simulink is a graphical block diagramming tool. There are many toolboxes in Simulink such as image processing toolbox and Digital system toolbox. The Simulink can use function from MATLAB environment also. Simulink is easy to building the model in graphical block environment and suitable for real-time simulating. Moreover, we can connect Simulink model to hardware such as Arduino and Raspberry PI.

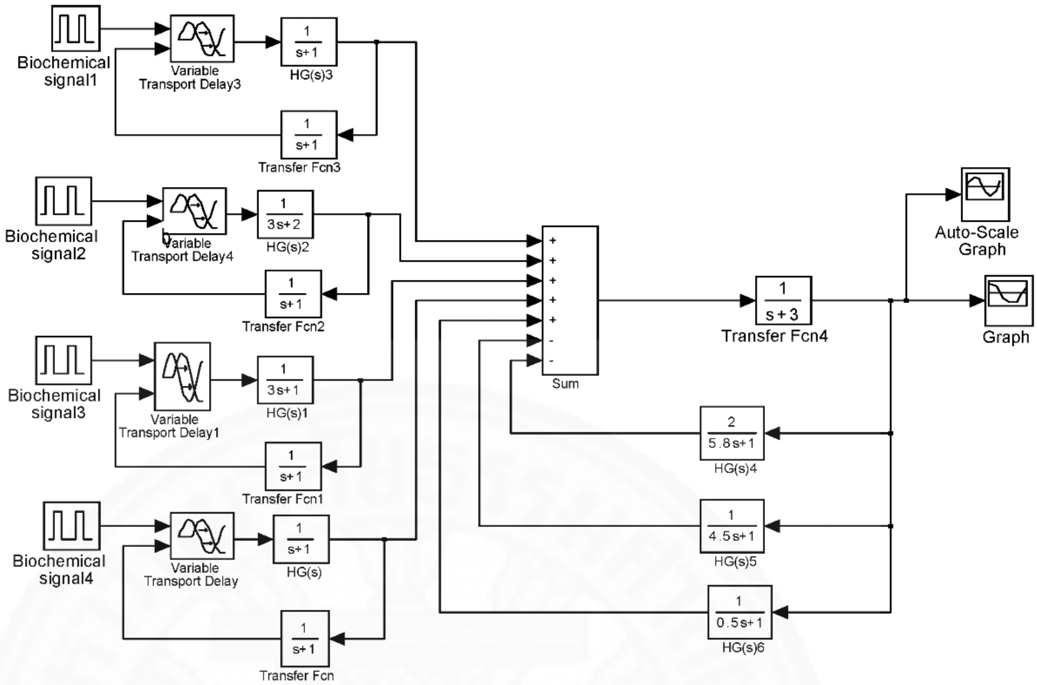

Figure 2.5: The example of Simulink model [17].

Chapter 3
Methodology

A methodology of this study is explained in this chapter. These three parts; experimental setup, procedures in each observation time, and select result from two observations; will be described. In part of procedures in each observation time, it including of green and hue signal, FFT and Z-score, and temporal filter.

3.1 Experimental Setup

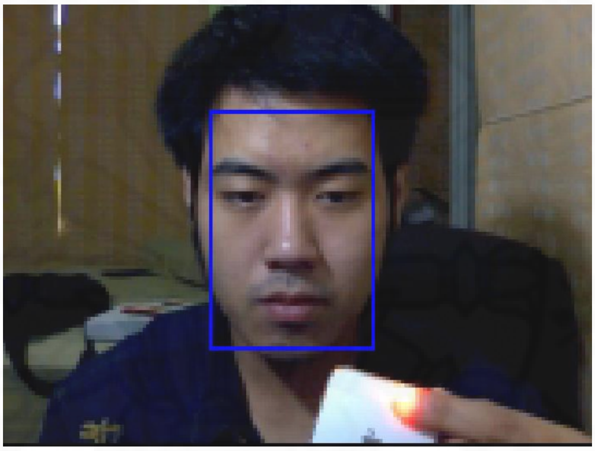

Figure 3.1: A sample frame of an input video sequence for heart rate measurement. The region of interest is indicated by the rectangular box on the face.

In our experiments, we use a webcam, named Microsoft LifeCam VX- 2000, for acquiring video sequences. The frame rate is set at 30 frames per second (fps). The resolution of the video frame is the QQVGA, which is 160 by 120 pixels. The video contains RGB full colors in MPEG format. To avoid the interference from the camera, we turn off the auto exposure function of it. The experiments are conducted indoor with fluorescent light sources and little sun light coming in. We have 10 participants of both genders (five males and five females), of different ages from 23 to 67 years old, with different skin colors. Participants are requested to stay still on a chair in front of the PC with the webcam at distance of about 50cm away from the webcam. Figure 3.1 show the sample frame of an input video sequence during the experiment. The rectangular box shows a region of interest (ROI), which is manually selected. During the measurement, participants need to stay still and locate their face in a region of interest. They are also asked to hold a smartphone to measure their heart rates using the application Cardiio [18] and use it as the ground truth. The proposed methods updates HR measurements every two seconds.

3.1 Procedures in Each Observation Time

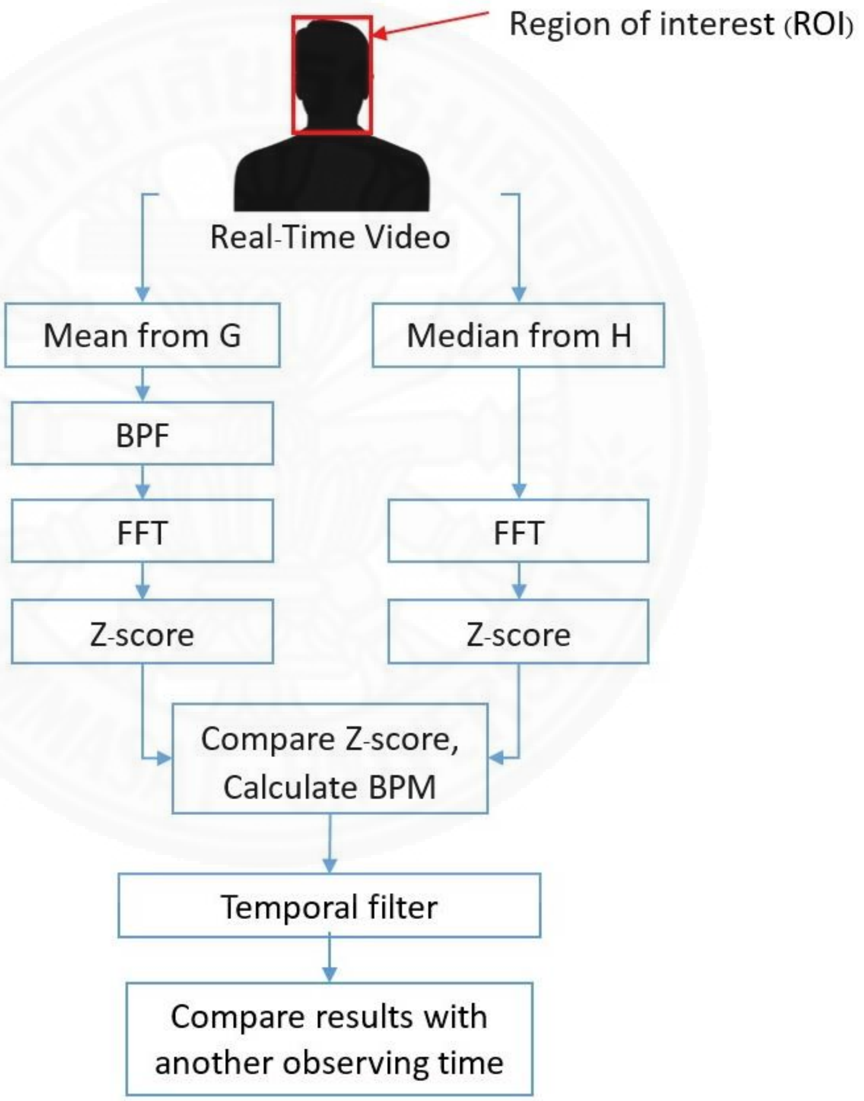

Figure 3.2: A flow chart of the proposed method. Two color signals, green (G) and hue (H), are used separately and the one with a higher z-score is used for calculating beats per minute (BPM).

Figure 3.2 shows a flow chart of the proposed method in each observing time. We extract green (G) and hue (H) signals in the ROI from a real-time video input. Then, we find the mean from the G signal and the median from the H signal at every frame. The Fourier spectrums are obtained from the FFT to observe the data in the frequency domain and then we use the z-score to evaluate the spectrum. Furthermore, we use two most prominent spectrums from FFT for more accurate result. The measurements by the G and H signals are compared by z-score and select the one that has the highest z-score as a more reliable result. A temporal filter is applied for remove error result. Moreover, we compare the results with other observation times to select the most reliable one for achieving both quick response and accurate result.

3.2.1 Green and Hue Signal

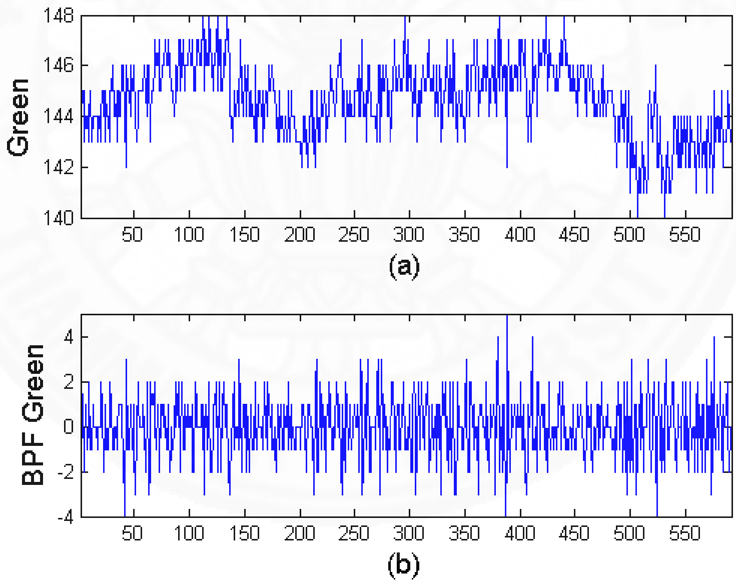

Figure 3.3: Plot of mean value from green signal during heart rate measurement. (a) G signal before apply BPF (b) BPF was applied.

During the experiment, the G and H signals are used in the proposed method. It has been said that the H signals in various human skin colors are similar to each other, for example, even black or white skins [19]. The G signal is extracted from a video sequence directly, while the H signal is computed from R, G, and B signals [20]. Figure 3.3(a) shows plot of mean value from g signal and Figure 3.4 shows plot of median value from h signal during heart rate measurement. We calculate the mean value from the G signal and the median value for the H signal and keep this in different amount of recent data for multi-observing times purposes which are 10 and 20 seconds. In each observing times, we apply a band-pass filter (BPF) with the filter mask [-1, 0, 1] to the G signal data set for attenuating both (extremely) low and high frequencies. Figure 3.3(b) shows mean value of G signal after applied BPF.

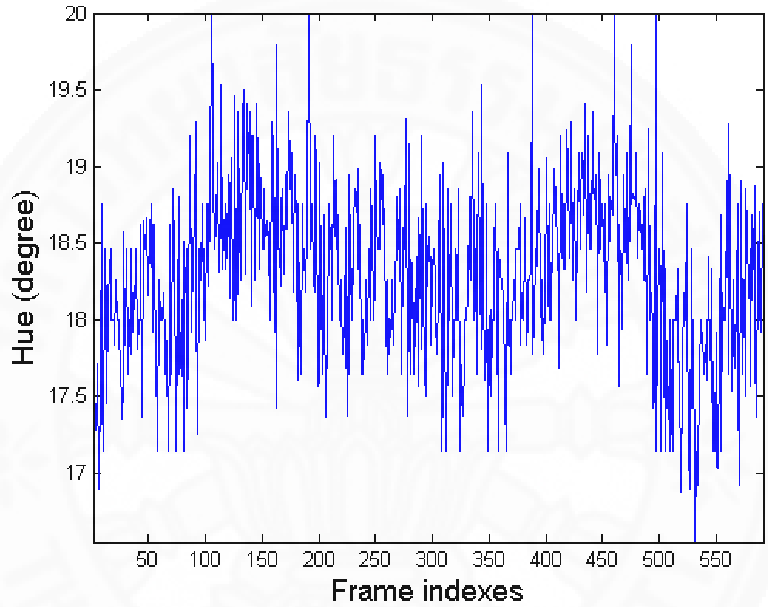

Figure 3.4: Plot of median value from hue signal during heart rate measurement.

3.2.2 Fast Fourier Transform and Z-Score

Figure 3.5 plots Fourier spectrums from green signal and hue signal where the spectrum are plotted in the common log scale. The FFT is applied to the two signals. We set the lower and upper limits of the heart rate (HR) from 39 and 120 beats per minute (BPM) that correspond to the frequencies between 0.65 and 2.0 Hz. The Fourier spectrums within this frequency interval are used for evaluated by z-scores expressed as

$$z = \frac{\boldsymbol{x} - m}{\sigma_x} \quad (3.1)$$

where x are the Fourier spectrums. The m and σ_x are the mean and the standard deviation of x in the selected band. Figure 3.6 plots the z-scores of the spectrums from green signal and hue signal that corresponding to frequencies between 39 and 120 BMP.

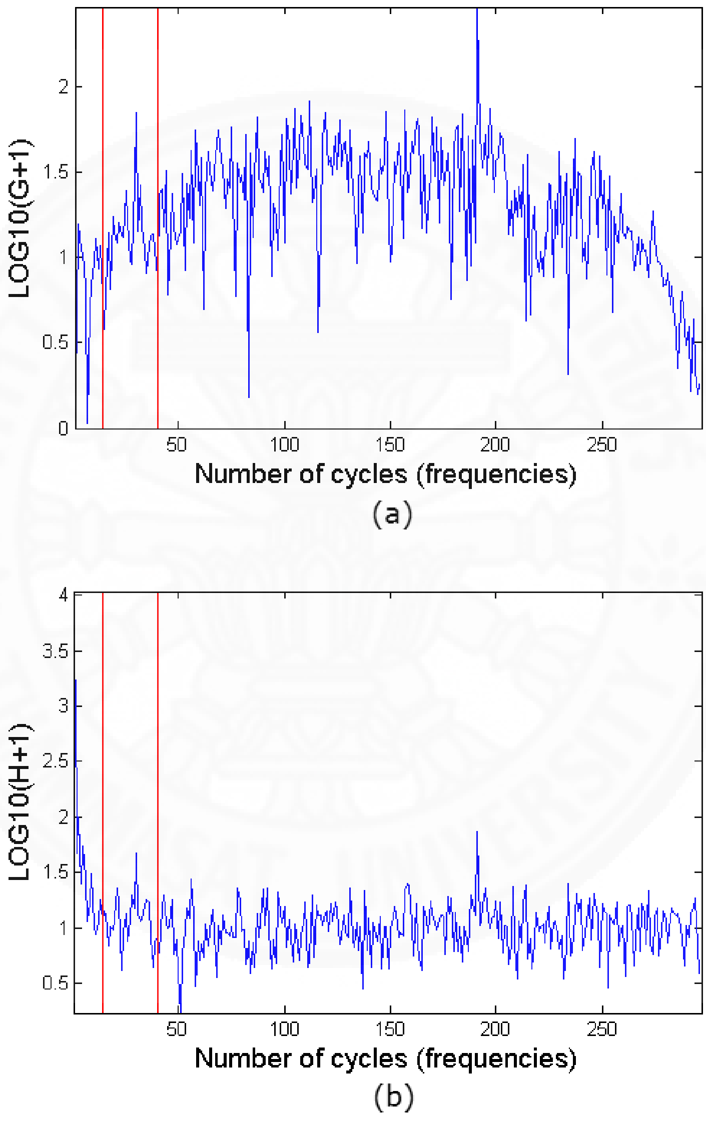

Figure 3.5: The Fourier spectrums between 0.65 and 2.0 Hz from (a) green signal and (b) hue signal where the spectrums are plotted in the common log scale.

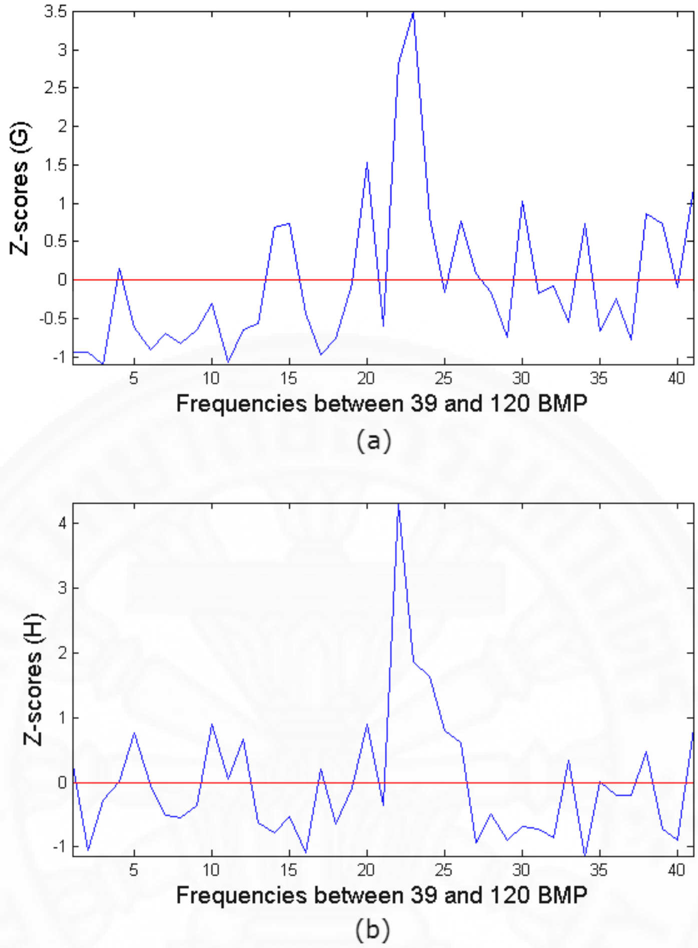

Figure 3.6: The z-score of the spectrums between 0.65 and 2.0 Hz from (a) green signal and (b) hue signal.

3.2.2.1 Two most prominent spectrums

Figure 3.7 shows how we estimate the heart rate in beats per minute (BPM) from the Fourier spectrums. We first find the spectrums with the first and second highest z-scores. As shown in Figure 3.7(b) and 3.7(c), if the two most prominent spectrums are next to each other, for instance, the nth spectrum with the largest z-score and the (n+1)th with the second largest, we calculate the BPM using both of them. When the observing time is 20 seconds, the nth spectrum corresponds to 3n BPM, while (n+1)th results in 3(n+1) BPM. Figure 3.7(b) demonstrates that there is the most distinct spectrum at the frequency that corresponds to 60 BPM. The second most prominent spectrum indicates 63 BPM. There are two choices, 61 and 62 BPM, between them. We then select 61 BPM as the final result because it makes more sense to place a higher priority on the most prominent spectrum than on others. Similarly, when the most distinct spectrum indicates 63 BPM and the 2nd points 60 BPM as shown in Figure 3.7(c), the final selection will be 62 BPM. If the two most prominent spectrums are not next to each other, as exhibited in Figure 3.7(a) and 3.7(d), we simply use the single spectrum with the largest z-score. In this way, coarse estimation of the HR because of the limited observing time (such as 20 seconds) can be refined. The measurements by the G and H signals are compared within the same observing time. The measurement with a higher z-score is selected as a winner.

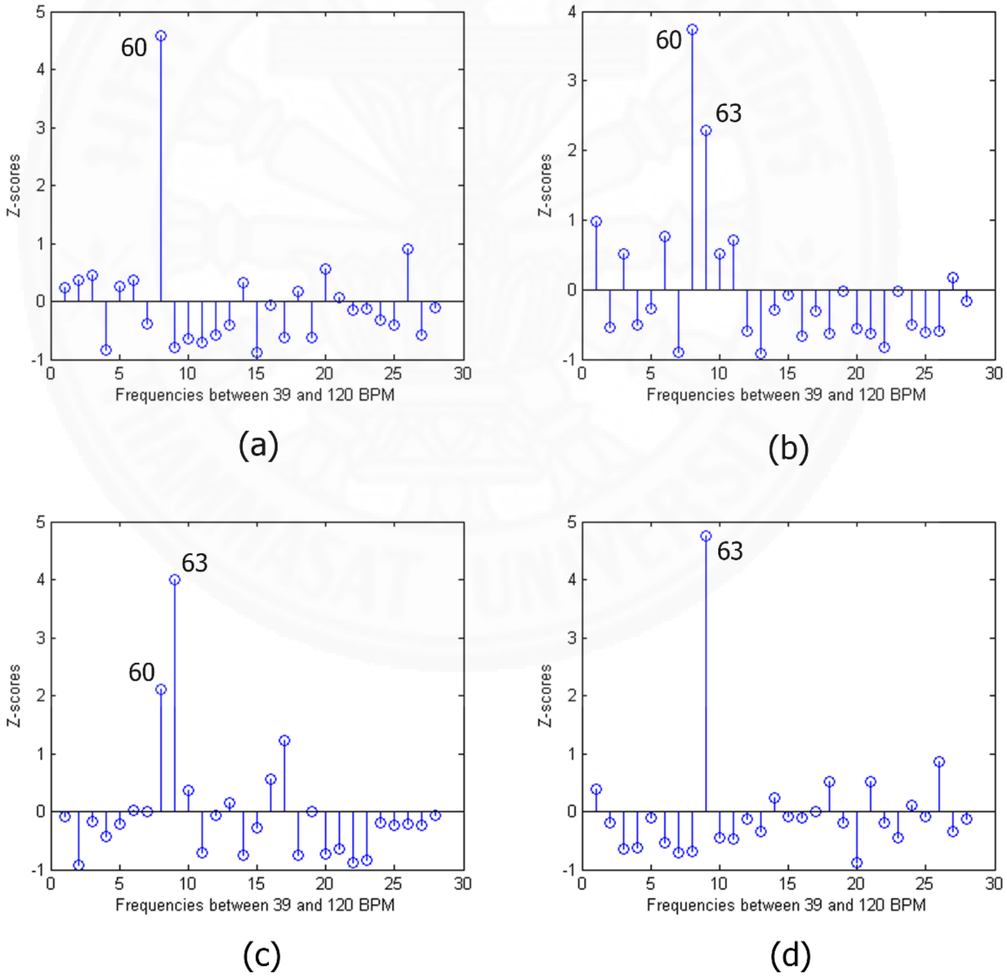

Figure 3.7: Z-scores of the spectrums between 39 and 120 BPM. Input signals are sinusoidal curves of difference frequencies (a) 60, (b) 61, (c) 62, and (d) 63 BPM with random noise.

3.2.3 Temporal Filter

A temporal filter is applied to the 5 most recent measurements where the measurement with the largest z-score among them is selected as output. HR measurement may occasionally include faulty BPMs because of external factors, for instance, varying illuminations and the motions of the face. It is possible to reject those faulty BPMs by monitoring the measurements over time (though a short period) and select one with the highest confidence, i.e., z-score. This is how our temporal filter works to reject unreliable measurements. The filter is particularly effective for improving the accuracy of the HR measurements in a short observing time.

3.3 Select Result from Two Observations

We obtained 2 HR measurements from two different observing times. Figure 3.8 shows how we determine the final HR from the two measurements. We compare the measurements from 10-second and 20-second observations in the stage of Selection. If two measurements are similar to each other that means the results are not different more than 6 BPM (1 index change in 10-second observing time that change 6 BPM), the result from 20-second observation is selected as a winner. If the two measurements are significantly different from each other that means the results are different more than 6 BPM, the result from 10-second observation is selected. This is because the measurement with a longer observation time tends to be more accurate when the HR is stable. The measurement with a shorter observation is more effective when the HR varies because it responds to the change of HR more quickly. In this manner, we attempt to achieve both fast response and high accuracy in HR measurement. The proposed method on Simulink is fast enough to perform HR measurement in real time and it can update the measurement every two seconds. The proposed method is not limited to the measurement times 10 and 20 seconds. A point is that proposed method is designed for obtaining the advantages of short and long observing times.

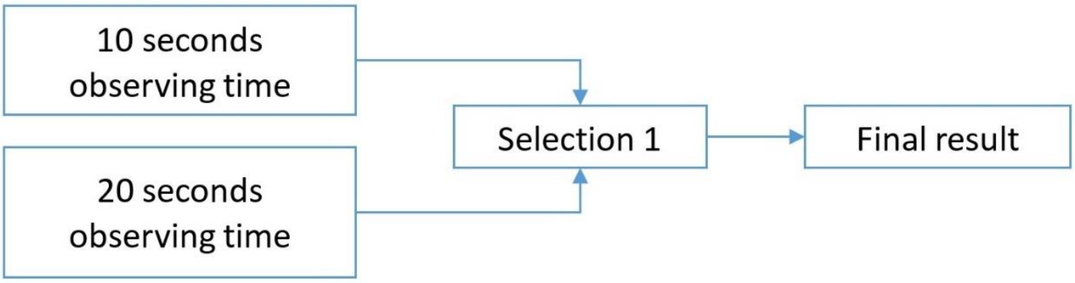

Figure 3.8: The block diagram that shows how the HR measurements from 2 different observing times are evaluated.

Chapter 4
Results and Discussion

The performance of proposed method is demonstrated in this chapter. The first section is ROI evaluation. In features evaluation, there are different observation time feature, temporal filter feature and two most prominent spectrums feature. Additionally, overall evaluation is demonstrated in the last section.

4.1 Region of Interest Evaluation

Table 4.1: Success rates and correlation coefficients from 10 participants among 3 different light condition with forehead as a region of interest.

	Light condition	Green	Hue	Green & Hue
Success rate	Sunlight	50%	20%	70%
	Fluorescent	50%	90%	100%
	Incandescent	60%	90%	90%
Correlation Coefficient	Sunlight	0.8912	0.1482	0.9611
	Fluorescent	-0.2036	0.7486	0.9811
	Incandescent	0.5055	0.9521	0.9521

Tables 4.1, 4.2 and 4.3 show success rates and correlation coefficients from 10 participants among 3 different light conditions with different ROIs in each Table. We manually select ROI in different positions. Forehead is used as a ROI in Table 4.1, cheek is used in Table 4.2, and a whole face is used in Table 4.3. Observation time in this evaluation is 20 seconds length. For success rates, it allows 3 BPM deviation from the ground truth, because 1 index different in 20 second that means 3 index difference in a minute. As shown in the three Tables, success rates and correlation coefficients values can indicate that using both green and hue signals perform better than just using

Table 4.2: Success rates and correlation coefficients from 10 participants among 3 different light condition with cheek as a region of interest.

	Light condition	Green	Hue	Green & Hue
Success rate	Sunlight	40%	60%	80%
	Fluorescent	80%	80%	90%
	Incandescent	90%	90%	90%
Correlation Coefficient	Sunlight	0.7019	-0.3548	0.9732
	Fluorescent	0.8990	0.8928	0.9449
	Incandescent	0..9791	0.9598	0.9598

Table 4.3: Success rates and correlation coefficients from 10 participants among 3 different light condition with face as a region of interest.

	Light condition	Green	Hue	Green & Hue
Success rate	Sunlight	80%	50%	80%
	Fluorescent	90%	90%	100%
	Incandescent	70%	90%	90%
Correlation Coefficient	Sunlight	0.7637	0.5079	0.9619
	Fluorescent	0.8102	0.9025	0.9848
	Incandescent	0.9598	0.7077	0.9863

one of them. In different light conditions, excessive light is not good for HR measurement that make face too bright to measure. It is found that the web cameras are not too sensitive to fluorescent and incandescent light. In different ROIs, forehead, cheek, and face, there is no specific spot best-suit for HR measurement. It depends more on light conditions and individuals.

4.2 Features Evaluation

Figures 4.1, 4.2 and 4.3 show examples of HR measurement results in our experiment. The graphs show the ground truth HR (solid line), 76 BPM, and three HR measurements where two of them are measured in two different observing periods, 10 (+), 20 (×) seconds, respectively. The combination of these two measurements is plotted with a circular symbol (o), which is updated at every two seconds. The ground truth is obtained using fingertip method in the iPhone/iPad application, Cardiio [18]. As shown in Figures 4.1, 4.2, and 4.3, the HR measurements are stabilized after observing periods are past. Therefore, the measurement with a 10 seconds observing time is stabilized quicker than that of 20 seconds observing time. In other words, the observing time determines the response of the HR measurement.

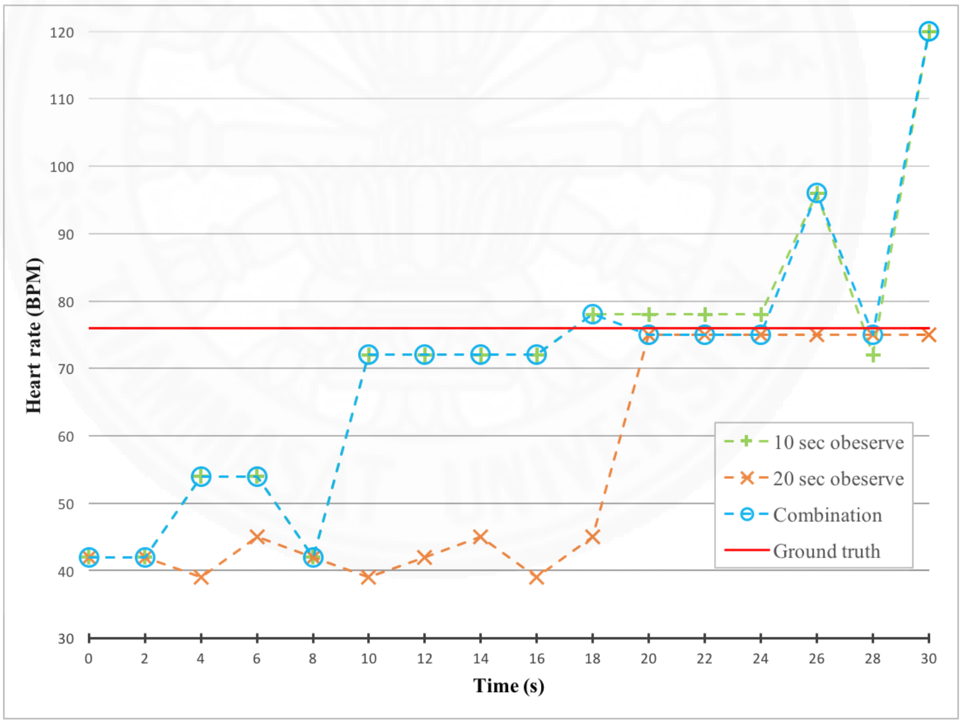

Figure 4.1: Plots of non-temporal filtered HR measurements from two observing times and the combination of the two measurements (being updated at every two seconds). The red line shows the ground truth BPM.

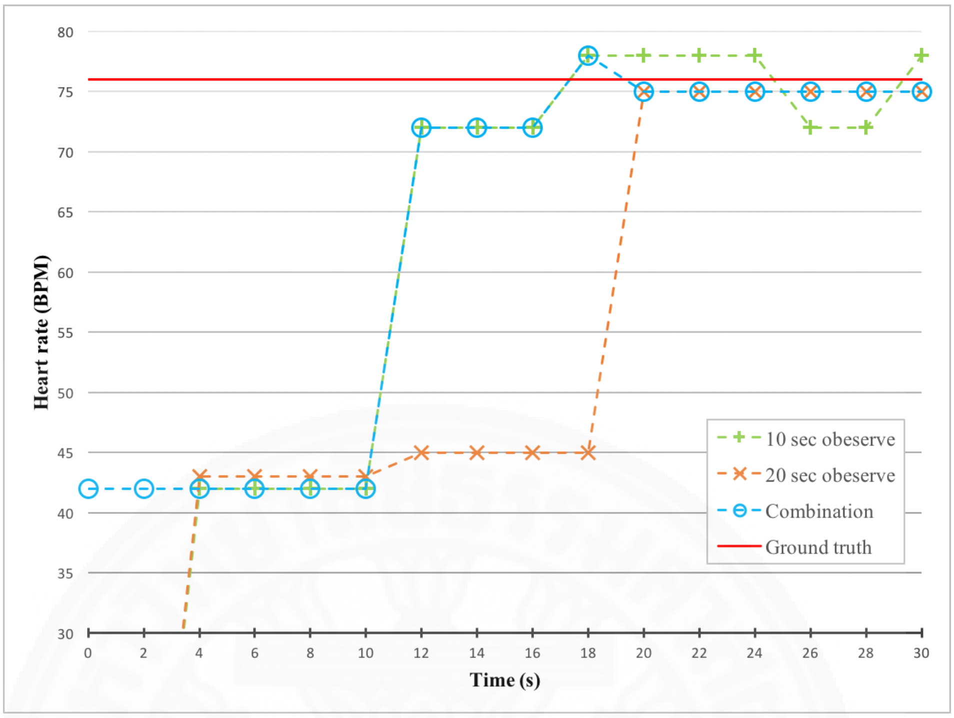

Figure 4.2: Plots of temporal filtered HR measurements from two observing times and the combination of the two measurements (being updated at every two seconds). The red line shows the ground truth BPM.

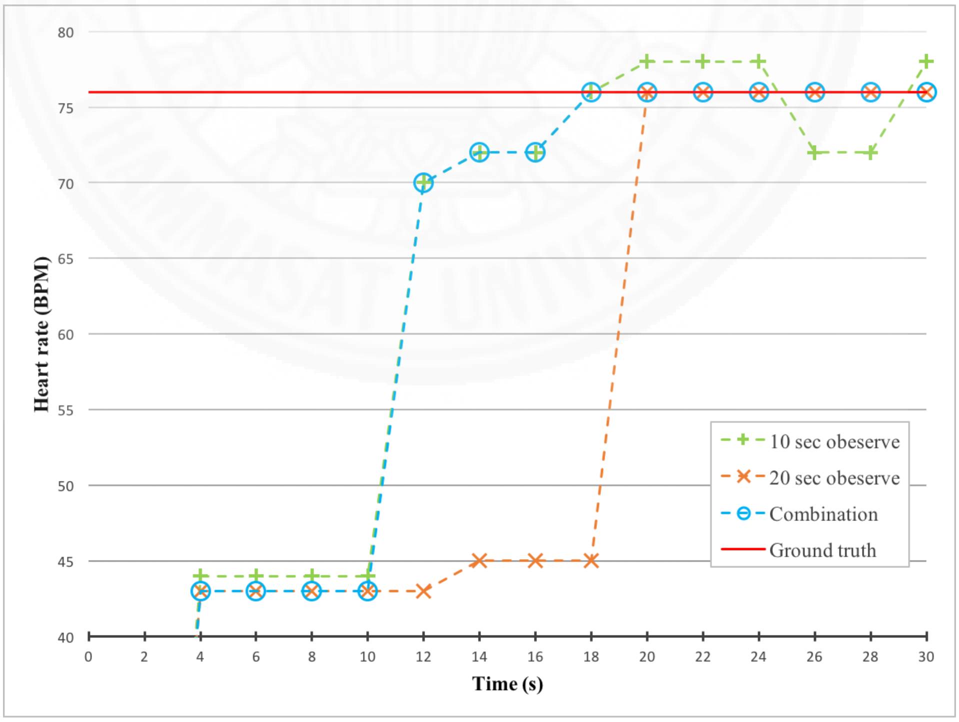

Figure 4.3: Plots of temporal filtered and refined HR measurements from two observing times and the combination of the two measurements (being updated at every two seconds). The red line shows the ground truth BPM.

4.2.1 Different Observation Time Feature

Close observation on Figures 4.1, 4.2, and 4.3 reveal that HR measurements in a short observing time responds to the heart rate quickly but less accurate than the measurements in longer observing times. On the other hand, the HR measurements in a long observing time respond slowly but more accurate after the long observing time is completed. Among the two HR measurements, we choose the result by the propose method, and the most reliable measurement can be selected automatically.

4.2.2 Temporal Filter Feature

In Figure 4.1, a temporal filter is not applied to these measurements yet and only one most prominent spectrum is used for calculating the BPM unit. Figure 4.2 shows the HR measurement results after applying a temporal filter to the raw measurements in Figure 4.2. It is clear that the error results can be remove by the temporal filter. Figure 4.2 shows that the final result (75 BPM) is close to the ground truth (76 BPM).

4.2.3 Two Most Prominent Spectrums Feature

Figure 4.3 shows the HR measurement results after using two most prominent spectrums to calculate the results instead of only the spectrum with the largest z-score in Figure 4.2. It shows that final 7 measurements (76 BPM) are refined and exactly same as the ground truth (76 BPM).

4.2 Overall Evaluation

Table 4.4 shows average errors from the ground truth in different period of observing times from 10 people. The temporal filter is not applied to the measurements yet and just using only one most prominent spectrum. Table 4.5 shows the average errors from the ground truth after applying the temporal filter. The temporal filter helps to improve overall results by removed large erratic measurements. As shown in Tables 4.4 and 4.5, the HR measurements based on 10-second observation are reasonably accurate (3.4, 2.3) in the first time interval (10-20 seconds), while another measurement are not ready for their computation. In the second time interval (20-30 seconds), the HR measurements based on 20-second observation are ready to use and they are more accurate (1.02, 1.02) than those based on 10-second observations (4, 2.27). Table 4.6 shows the average errors in BPM from the ground truth after using two most prominent spectrums to calculate the BPM unit. It helps to improve overall results by increasing the accuracy of the measurements where final results are closer to the ground truth. As shown in Table 4.5 and 4.6, the HR measurements based on 10-second observation are reasonably accurate (2.3, 1.67) in the first time interval (10-20 seconds). In the second time interval (20-30 seconds), the HR measurements based on 20-second are more accurate (1.02, 0.57) than those based on 10-second observations (2.27, 1.77). By using two most prominent spectrums, it helps to improve overall results by increasing the accuracy of the measurements where final results are closer to the ground truth.

Table 4.4: Average error from ground truth BPM of 10 participants in different time interval. The measurements are not applied by a temporal filter and using only one most prominent spectrum.

	Time interval (s)	
Observing Time	**10 - 20**	**20 - 30**
10 Seconds	**3.4**	**4**
20 Seconds	-	**1.02**
Combination	**3.4**	**2.82**

Table 4.5: Average error from ground truth BPM of 10 participants in different time interval. The measurements are applied by a temporal filter but using only one most prominent spectrum.

	Time interval (s)	
Observing Time	**10 - 20**	**20 - 30**
10 Seconds	**2.3**	**2.27**
20 Seconds	-	**1.02**
Combination	**2.3**	**1.02**

Table 4.6: Average error from ground truth BPM of 10 participants in different time interval. The measurements are applied by a temporal filter and using two most prominent spectrums.

	Time interval (s)	
Observing Time	**10 - 20**	**20 - 30**
10 Seconds	**1.67**	**1.77**
20 Seconds	-	**0.57**
Combination	**1.67**	**0.57**

Chapter 5
Conclusions

This study describes a method for heart rate measurement on a video sequence using a webcam. The heart rate is measured by detecting the first and second highest frequencies of both two color signals, green and Hue, on a face in two different observing times, 10 and 20 seconds. Thus, we have 2 HR measurement to assess. The most reliable result can be selected from two different observing time. This work also shows that the two color signals are effective in a complementary manner, contributing to more reliable HR measurement than those based on only one color signal. The employment of multiple-observing times is effective for achieving a fast and accurate HR measurement. This is because the HR measurement in a short observing time responds quickly to the change of HRs, while the one with a long observing time produces more accurate measurements. Although the HR measurement in a short observing time tends to be less accurate, the output from it is reasonably reliable owing to the temporal filter applied to most recent five HR measurements. Since the final HR is the one selected from the two different observing times, it is highly reliable and accurate. Furthermore, the use of two most prominent spectrums helps to increase the accuracy of the results. The use of Simulink is good for constructing, testing, and improving an algorithm for a task. It is also suitable for educational purposes. As future work, we plan to insert face detection and tracking that can automatically detect the face region and also transfer the developed algorithm from Simulink to microcomputer such as Raspberry Pi.

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Appendices

Appendix A
Published Conference Papers

Published conference papers of this study are shown in this chapter. This study results in the following publication.

- V. Pawankiattikun and T. Kondo, A method for contact-free heart rate measurement on a video sequence using Simulink, Proceedings of The 7th Biomedical Engineering International Conference (BMEiCON 2014), Fukuoka, Japan, November 2014.

- V. Pawankiattikun, C. Lueangwattana, T. Kondo, T. Phatrapornnant, and H. Kaneko, A novel method for contact-free heart rate measurement using Simulink, Proceeding of The 6th International Conference on Information and Communication Technology for Embedded Systems (IC-ICTES 2015), Prachuap Khiri Khan, Thailand, March 2015.

A Method for Contact-free Heart Rate Measurement on a Video Sequence Using Simulink

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***Abstract*—This paper presents a method for a contact-free heart rate measurement on a video sequence using Simulink. The heart rate is measured by detecting the prominent frequency of the skin-color change in a human face. As color features in a video sequence, we utilize both green and hue signals. The frequencies of the two color signals are analyzed using multiple observing times. The prominences of the Fourier spectrums of the two color signals at multiple observing times are then evaluated statistically. Finally, the heart rate measurement is conducted based on the most distinct spectrum. Experimental results show that the proposed method can perform heart rate measurement accurately in real time.**

I. Introduction

The heart rate (HR) is the number of heart beats in a minute and expressed as beats per minute (bpm). The heart rate is one of important physiological signals of a human body that varies according to our activities such as physical exercise and emotions. The easiest way to measure the heart rate is putting two fingers on the wrist or neck and pressing until we can feel the pulse of the heart and count the number of beats manually. The common measurements such as electrocardiogram (ECG or EKG), heart rate belt worn around the chest and finger pulse oximeter are contact-measurement that is uncomfortable, inconvenient and can cause pain to user. In recent years, many research topics concerned with HR measurement using a video based method that is contact-free method [1–10]. HR measurement can be measured using a video sequence from a webcam or a camera built in a laptop [2-4, 9, 10]. The video-based method is more comfortable and cheaper for HR measurement.

For the video-based method to measuring HR, the motion tracking is used in [1]. The RGB color model which has red (R), green (G), and blue (B) components are all used in [2–8]. The combination of RG, GB and RB also studied in [9]. It has shown that the G signal is the most effective for HR measurement compare to R and B signal [7, 8, 10]. It has been also shown that the hue (H) signal from HSV (or HSI) color model is also effective for HR measurement in [10]. The H signal is robust to light intensity changes from an uncontrolled light source. Experimental results show that G and H are effective for HR measurement. They have individual characteristics that make the H signal is more effective than the G signal but sometime the G signal is better. Therefore, in this paper, we use H and G signal for HR measurement. Furthermore, we propose to conduct HR measurement in real-time using Simulink with three different observing time. Short observing time has fast response but less accurate. While long observing time is more accurate but need long time to measure. For combined the advantages together, in each observing time is evaluated using the distinctness of their Fourier spectrums and then use temporal smoothing filter to remove error. The method is processing in parallel then select the results from different observing times follow an algorithm. Experimental results show that the proposed method can quickly response measuring heart rate and adaptively select the most accurate result from different observing times.

II. Methods

In our experiments, we use the Microsoft LifeCam VX-2000 camera for acquiring video sequences. The frame rate is set at 30 frames per second (fps). The resolution of the video frame is the QQVGA, which is 160 by 120 pixels. The video contains RGB full colors in MPEG formal. To avoid the interference from the camera, we turn off the auto-exposure function of it. The experiments are conducted indoor with uorescent light sources and little sun light coming in. We have 10 participants of both genders (ve males and ve females), of different ages from 18 to 65 years old, with different skin colors. Participants are seated sat a table in front the PC with the webcam at distance of about 0.5 meter from the webcam. Fig. 1 shows the sample frame of an input video sequence during the experiment. The rectangular box shows a region of interest (ROI), which is manually selected. The participants are asked to stay still in order that their faces are present within the ROI box during the measurement. They are also asked to hold a smartphone to measure their heart rates (HR) using the application Cardiio []. They masure the HR twice and the means of the two measurementss are used as the ground truth. The proposed methods updates HR measurements every two seconds.

Fig. 2 shows a ow chart of the proposed method. We use two color signals, green (G) and hue (H). The G signal is known to be effective for HR measurement in the literature. The H signal is expected to be robust to varying lighting conditions as it is independent of image intensities. The mean of the G signals within the ROI is used for HR measurement. Meanwhile, the median of the H signals within the ROI is used for the meaurement. The G signal is further band-pass filter with the filter coefficients [-1, 0, 1] to suppress both low and high frequency compoments in it. We then apply the fast Fourier transform (FFT) to the two signals to detect a significant spectrum that corresponds to the heart rate. Three pairs of G and H signals with different observing times, 10, 20, and 60 seconds, are fed into the FFT. In the frequency domain, we set the lower and upper limites of v the HR from 40 to 120 beats per minute (BPM) that is equivalent to 0.67 to 2.0 Hz. Within this band, we search for the most distinct Fourier spectrum. The prominence of the spectrum is evaluated statistically using the z-score expressed as

$$z = \frac{x - m}{\sigma_x} \tag{1}$$

where x are the Fourier spectrums. The m and σ_x are the mean and the standard deviation of x in the selected band. We find which frequency has a maximum z-score, and convert it into the BPM unit. The result will update every two seconds in each observing time. Then, temporal filter is applied to the most recent five HR measurements. The filter selects the HR measurement with the largest z-score among them as the latest output. Because, from our experiment we found that, error result may occur in small observing time and five recent is best suit for this experiment. Now, we have the last result in each observing time that run in parallel. the HR measurement in a short observing time responds quickly to the change of HRs, while the one with a long observing time produces more accurate measurements.

Fig. 3 is algorithm for combine the advantage from different observing time. First, compare the result from 10 seconds and 20 seconds observing time, In selection 1, if the different is not more than three, the result from 20 seconds observing time will be selected, if not, the result from 10 seconds observing time will be selected. Because, the one index different in 10 seconds observing time is $\pm$ 6 BPM, and for 20 seconds observing time is $\pm$ 3 BPM. If the result is the same index that mean it does not different more than three. And then, In selection 2, compare the selected result from the selection 1 with the result from 60 seconds observing time again, if the different is not more than two, the result from 60 seconds observing time will be selected, if not, selected result does not change. Because, the one index different in 60 seconds observing time is $\pm$ 1 BPM. Therefore, if the result is the same index that mean it does not different more than two. The final result will be selected after the algorithm. The experiment is real-time, it will calculate and update the final result every two seconds.

III. Results and Discussion

Fig. 4 is one sample graph from 10 participants in our experiment. The graph plot HR measurements from 3 different observing times and combination being updated at every two seconds together with the ground truth BPM. The measurements are not applied a temporal filter. The green line with '$\times$' mark, black line with '$\bullet$' mark, magenta line with '$*$' mark, and blue line with '$\circ$' mark are the result from 10, 20, 60 seconds observing time and Combination (the final result selected from three different observing times) respectively. The red line is the ground truth from Cardiio application on smartphone. From the graph, without temporal filter, the error result may occur during the measurement. Fig. 5 is sample graph from same participants as Fig. 4 but applied a temporal filter to each observing time. The result after applied a temporal filter, it removes the error that occur during the measurement. The green line with '$\times$' mark show the result from the 10 seconds observing time, which the first completed result come out after 10 seconds but the accuracy is still far from ground truth. The black line with '$\bullet$' mark is the result from the 20 seconds observing time, the first completed result come out after 20 seconds, that slower than the 10 seconds observing time but the accuracy is better. And for the magenta line with '$*$' mark, that show the result from 60 seconds observing time which the first completed result will come out after 60 seconds, that is the slowest when compare to the 10 and 20 seconds observing time but the accuracy is the best which equal to the ground truth. From the blue line with '$\circ$' mark that is combination (selected result from the three different observing times), the method will select the most accurate result at that time. Users can make their choice for how much accurate they want and how much time to wait for their own heart rate.

Table I shows average error from ground truth in different period of time from 10 participants together. The measurements are not applied a temporal filter. Table II is the average

TABLE I. Average error from ground truth BPM of 10 participants in different time interval. The measurements are not applied by a temporal filter

	Time interval		
Observing time	10-20	20-60	60-70
10 seconds	4.54%	5.00%	2.85%
20 seconds	36.47%	2.17%	2.00%
60 seconds	45.43%	40.21%	0.80%
Combination	4.63%	4.74%	1.15%

TABLE II. Average error from ground truth BPM of 10 participants in different time interval. The measurements are applied by a temporal filter

	Time interval		
Observing time	10-20	20-60	60-70
10 seconds	3.06%	2.32%	1.82%
20 seconds	41.11%	2.17%	1.80%
60 seconds	45.86%	40.67%	0.70%
Combination	3.16%	2.16%	0.70%

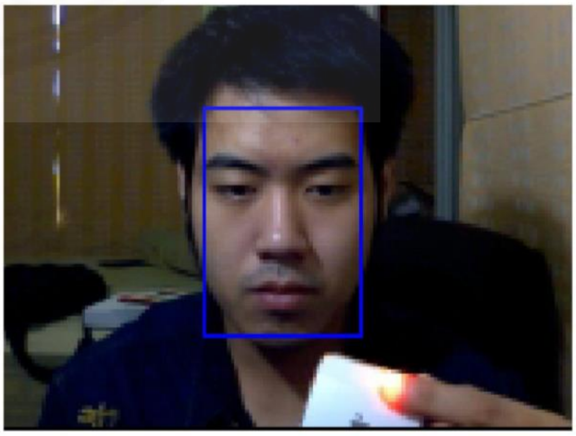

Fig. 1. A sample frame of an input video sequence for heart rate measurement. The region of interest (ROI) is indicated by the rectangular box on the face.

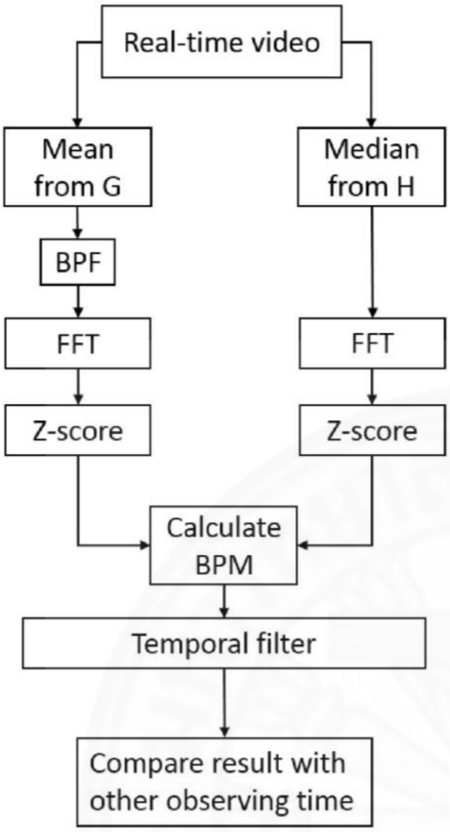

Fig. 2. A flow chart of the proposed method. Two color signals, green (G) and hue (H), are used separately and the one with a higher z-score is used for calculating beats per minute (BPM).

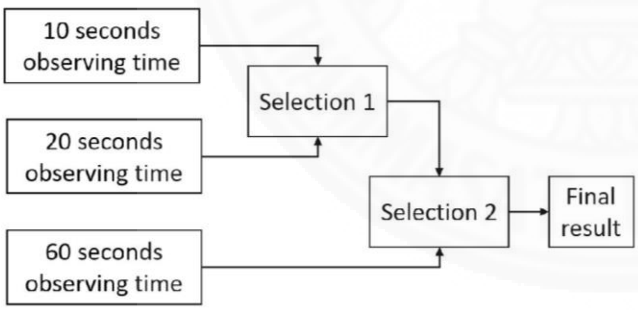

Fig. 3. The block diagram that shows how the HR measurements from 3 different observing times are evaluated.

error from ground truth same as Table I but applied a temporal filter to each observing time. The temporal filter improve in overall result by reduce the error. It very effective for 10 seconds observing time. In 10-20 seconds period, the average error in 10 seconds observing time is 3.06%, while the data for 20 and 60 seconds observing time are not complete for calculate yet and the average error are 41.11% and 45.86% respectively. While the average error of combination method is 3.16% that close to 10 seconds observing time. In 20-60 seconds period, the average error of combination method (2.16%) is close to 20 seconds observing time (2.17%). Because, the

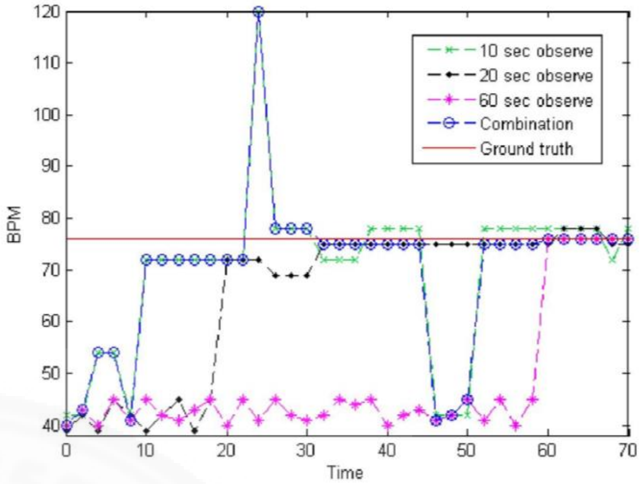

Fig. 4. Plots of HR measurements from 3 different observing times and combination being updated at every two seconds together with the ground truth BPM. The measurements are not applied by a temporal filter.

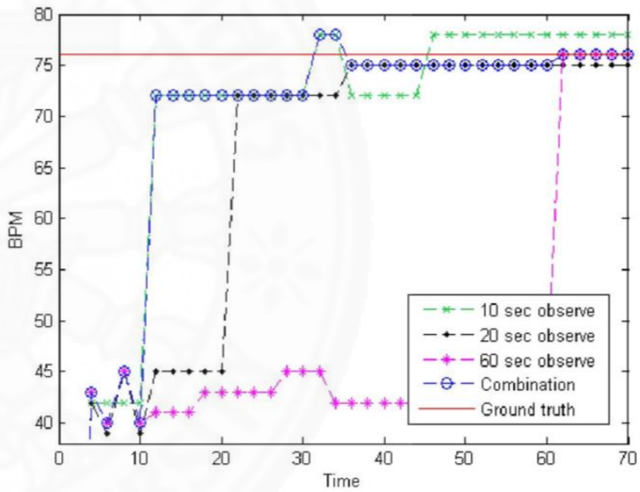

Fig. 5. Plots of HR measurements from 3 different observing times and combination being updated at every two seconds together with the ground truth BPM. The measurements are applied by a temporal filter.

data for 20 seconds observing time are complete and it more accurate, then the combination method is follow the result from 20 seconds observing time. For 60-70 seconds period, the average error of combination method (0.70%) also follows the best accurate one, which is result from 60 seconds observing time (0.70%). Therefore, in every period of time the proposed method will select the most accurate result from three different observing times.

IV. Conclusion and Future Work

This paper describes a method for heart rate measurement on a video sequence using Simulink. The heart rate (HR) is measured by detecting the most prominent frequency of the two color signals, green (G) and Hue (H), on a face from three different observing times. Thus, we have altogether six Fourier spectrums to assess. The prominences of the spectrums are

A Novel Method for Contact-free Heart Rate Measurement Using Simulink

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***Abstract*—This paper presents a method for a contact-free heart rate measurement on a video sequence using Simulink. The heart rate is measured by detecting the prominent frequency of the skin-color change in a human face. As color features in a video sequence, we utilize both green and hue signals. The frequencies of the two color signals are analyzed using multiple observing times. The prominences of the Fourier spectrums of the two color signals at multiple observing times are then evaluated statistically. Finally, the heart rate measurement is conducted based on the first and second most distinct spectrums and the most reliable result can be selected from multiple observing times. Experimental results show that the proposed method can perform heart rate measurement accurately in real time.**

Keywords*—*heart rate; real-time; Simulink; webcam; RGB; hue

I. INTRODUCTION

The heart rate (HR) is the number of heart beats in a minute and expressed as beats per minute (BPM). The heart rate is one of important physiological signals of a human body that varies according to our activities such as physical exercise and emotions. The easiest way to measure the heart rate is putting two fingers on the wrist or neck and pressing until we can feel the pulse of the heart and count the number of beats manually. The common measurements such as electrocardiogram (ECG or EKG), heart rate belt worn around the chest and finger pulse oximeter are contact-measurement that is uncomfortable, inconvenient and can cause pain to user. In recent years, many research topics concerned with HR measurement using a video based method that is contact-free method [1–10]. HR measurement can be measured using a video sequence from a webcam or a camera built in a laptop [2-4, 9, 10]. The video-based method is more comfortable and cheaper for HR measurement.

For the video-based method to measuring HR, the motion tracking is used in [1]. The RGB color model which has red (R), green (G), and blue (B) components are all used in [2–8]. The combination of RG, GB and RB also studied in [9]. It has shown that the G signal is the most effective for HR measurement compare to R and B signal [7, 8, 10]. It has been also shown that the hue (H) signal from HSV (or HSI) color model is also effective for HR measurement in [10, 11]. The H signal is robust to light intensity changes from an uncontrolled light source. Experimental results show that G and H are effective for HR measurement. They have individual characteristics that make the H signal is more effective than the G signal but sometime the G signal is better. Therefore, in this paper, we use H and G signal for HR measurement. Furthermore, we propose to conduct HR measurement in real-time using Simulink [12]. The proposed method measure the HR in two different observing time. Short observing time has fast response but less accurate. While long observing time is more accurate but need long time to measure. For combined the advantages together, in each observing time is evaluated using the distinctness of their Fourier spectrums and then use temporal filter to remove error. The results are calculated by the first and second most distinct spectrums. The method is processing in parallel then select the most reliable measurement from different observing times follow an algorithm. Experimental results show that the proposed method can quickly response measuring heart rate and adaptively select the most accurate result from different observing times.

II. METHODS

In our experiments, we use the Microsoft LifeCam VX-2000 camera for acquiring video sequences. The frame rate is set at 30 frames per second (fps). The resolution of the video frame is the QQVGA, which is 160 by 120 pixels. The video contains RGB full colors in MPEG format. To avoid the interference from the camera, we turn off the auto-exposure function of it. The experiments are conducted indoor with fluorescent light sources and little sun light coming in. We have 10 participants of both genders (five males and five females), of different ages from 23 to 67 years old, with different skin colors. Participants are requested to stay still on a chair in front of the PC with the webcam at distance of about 50cm away from the webcam. Fig. 1 shows the sample frame of an input video sequence during the experiment. The rectangular box shows a region of interest (ROI), which is manually selected. The participants are asked to stay still in order that their faces

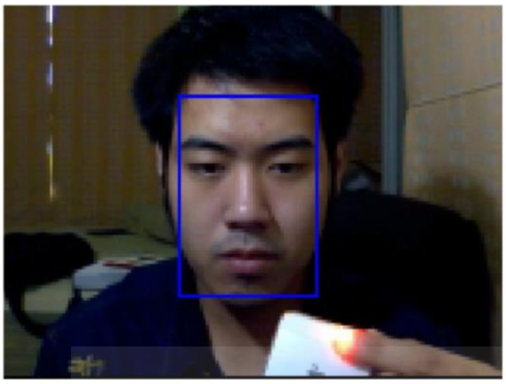

Fig. 1. A sample frame of an input video sequence for heart rate measurement. The region of interest (ROI) is indicated by the rectangular box on the face.

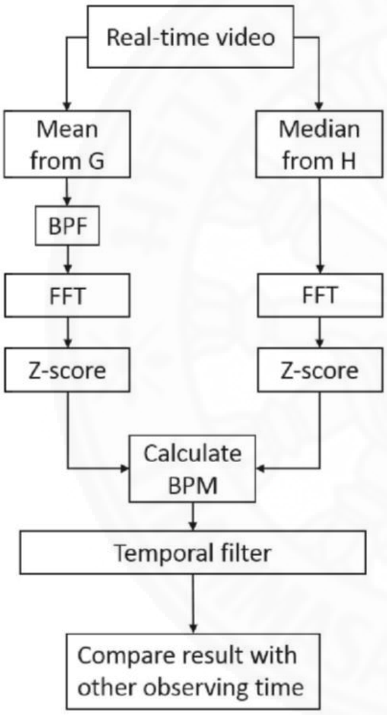

Fig. 2. A flow chart of the proposed method. Two color signals, green (G) and hue (H), are used separately and the one with a higher z-score is used for calculating beats per minute (BPM).

are present within the ROI box during the measurement. They are also asked to hold a smartphone to measure their heart rates (HR) using the application Cardiio [13] and use it as a ground truth. The proposed methods updates HR measurements every two seconds.

Fig. 2 shows a flow chart of the proposed method in each observing time. During the experiment, the G and H signal are use in the method. It has been said that the H signal in human skin color are all the same color, for example, black and whites skin [14]. The G signal extract from a video sequence directly while H signal is computed from R, G, and B signals. Then,

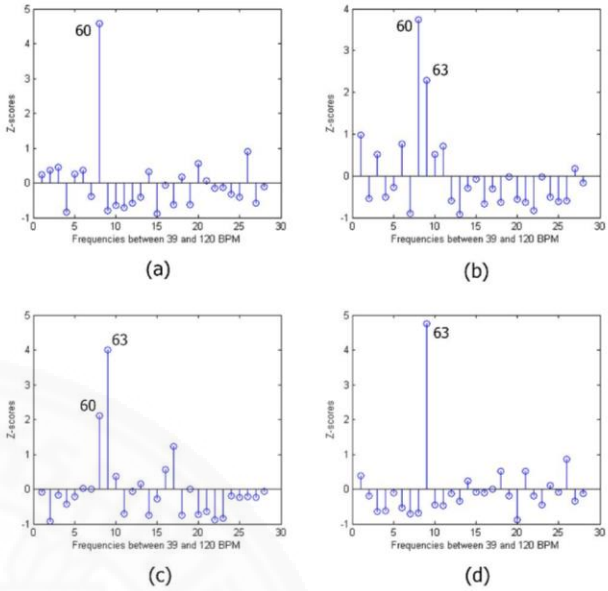

Fig. 3. Z-scores of the spectrums between 39 and 120 BPM. Input signals are sinusoidal curves of difference frequencies (a) 60, (b) 61, (c) 62, and (d) 63 BPM with random noise.

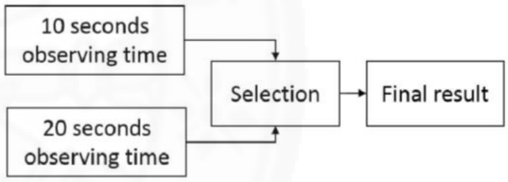

Fig. 4. The block diagram that shows how the HR measurements from 2 different observing times are evaluated.

calculate the mean value from G signal and median value for H signal and keep this in different amount of recent data for multi-observing time purpose which is 10 and 20 seconds. In each observing times, we apply a band-pass filter (BPF) with the filter mask [-1, 0, 1] to the G signal data set and then apply the fast Fourier transform (FFT) to the two signals. We set the lower and upper limits of the HR from 40 and 120 beats per minute (BPM) that is frequency range between 0.67 and 2.0 Hz. The Fourier spectrums within this frequency interval are used for evaluated by z-scores expressed as

$$\mathbf{z} = \frac{\mathbf{x} - m}{\sigma_x} \quad (1)$$

where $\mathbf{x}$ are the Fourier spectrums. The m and σ_x are the mean and the standard deviation of $\mathbf{x}$ in the selected band.

Fig. 3 shows how we estimate the heart rate in beats per minute (BPM) from the Fourier spectrums. We first find the spectrums with the first and second largest z-scores. As shown in Figs. 3(b) and 3(c), if the two most prominent spectrums are next to each other, for instance, the nth spectrum with the largest z-score and the (n+1)th with the second largest, we calculate the BPM using both of them. When the observing time is 20 seconds, the nth spectrum corresponds to 3n BPM,

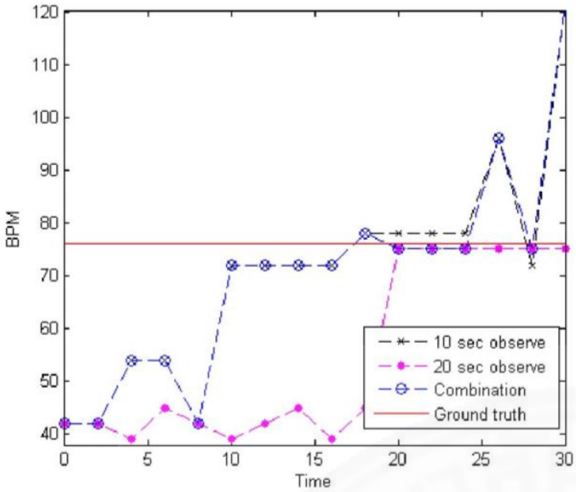

Fig. 5. Plots of HR measurements from two different observing times and combination being updated at every two seconds together with the ground truth BPM. The measurements are not applied by a temporal filter and using only one most prominent spectrum.

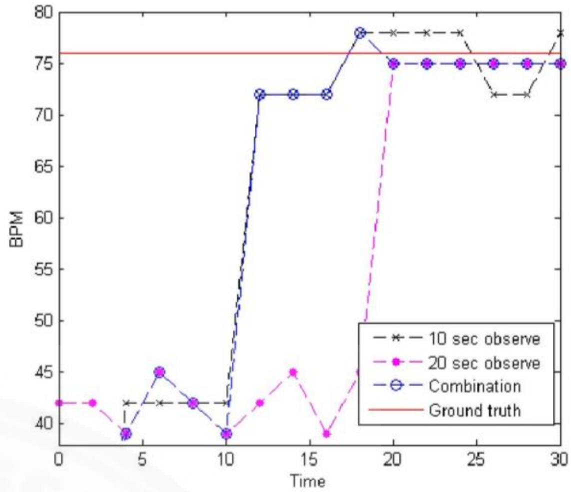

Fig. 6. Plots of HR measurements from two different observing times and combination being updated at every two seconds together with the ground truth BPM. The measurements are applied by a temporal filter but using only one most prominent spectrum.

while (n+1)th results in 3(n+1) BPM. Fig. 3(b) demonstrates that there is the most distinct spectrum at the frequency that corresponds to 60 BPM. The second most prominent spectrum indicates 63 BPM. There are two choices, 61 and 62 BPM, between them. We then select 61 BPM as the final result because it makes more sense to place a higher priority on the most prominent spectrum than on others. Similarly, when the most distinct spectrum indicates 63 BPM and the 2nd points 60 BPM as shown in Fig. 3(c), the final selection will be 62 BPM. If the two most prominent spectrums are not next to each other, as exhibited in Figs. 3(a) and (d), we simply use the single spectrum with the largest z-score. In this way, coarse estimation of the HR because of the limited observing time (such as 20 seconds) can be refined. The measurements by the G and H signals are compared within the same observing time. The measurement with a higher z-score is selected as a winner. Furthermore, a temporal filter is applied to the 5 most recent measurements where the measurement with the largest z-score among them is selected as output. HR measurement may occasionally include faulty BPMs because of external factors, for instance, varying illuminations and the motions of the face. It is possible to reject those faulty BPMs by monitoring the measurements over time (though a short period) and select one with a high confidence, i.e.,z-score. This is how our temporal filter works. The filter is particularly effective for improving the accuracy of the HR measurements in a short observing time. In this way, we obtain 2 HR measurements from two different observing times.

Fig. 4 shows how we determine the final HR from the two measurements. We compare the measurements from 10-second and 20-second observations in the stage of Selection. If two measurements are similar to each other, the result from 20-second observation is selected as a winner. If the two measurements are significantly different from each other, the result from 10-second observation is selected. This is because the measurement with a longer observation time tends to be more accurate when the HR is stable. The measurement with a shorter observation is more effective when the HR varies because it responds to the change of HR more quickly. In this manner, we attempt to achieve both fast response and high accuracy in HR measurement. The proposed method based on Simulink is fast enough to perform HR measurement in real time and it can update the measurement every two seconds. The proposed method is not limited to the measurement times 10 and 20 seconds. A point is that proposed method is designed for obtaining the advantages of short and long observing times.

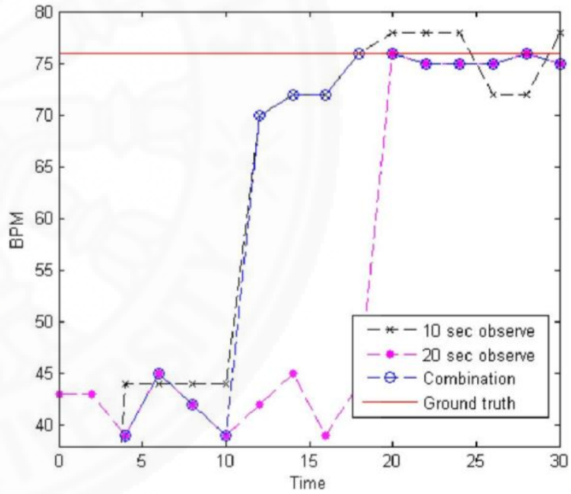

Fig. 7. Plots of HR measurements from two different observing times and combination being updated at every two seconds together with the ground truth BPM. The measurements are applied by a temporal filter and using two most prominent spectrums.

TABLE I. AVERAGE ERROR FROM GROUND TRUTH BPM OF 10 PARTICIPANTS IN DIFFERENT TIME INTERVAL. THE MEASUREMENTS ARE NOT APPLIED BY A TEMPORAL FILTER AND USING ONLY ONE MOST PROMINENT SPECTRUM.

	Time interval	
Observing time	10-20	20-30
10 seconds	3.4	4
20 seconds	-	1.02
Combination	3.4	2.82

TABLE II. AVERAGE ERROR FROM GROUND TRUTH BPM OF 10 PARTICIPANTS IN DIFFERENT TIME INTERVAL. THE MEASUREMENTS ARE APPLIED BY A TEMPORAL FILTER BUT USING ONLY ONE MOST PROMINENT SPECTRUM.

	Time interval	
Observing time	10-20	20-30
10 seconds	2.3	2.27
20 seconds	-	1.02
Combination	2.3	1.02

TABLE III. AVERAGE ERROR FROM GROUND TRUTH BPM OF 10 PARTICIPANTS IN DIFFERENT TIME INTERVAL. THE MEASUREMENTS ARE APPLIED BY A TEMPORAL FILTER AND USING TWO MOST PROMINENT SPECTRUMS.

	Time interval	
Observing time	10-20	20-30
10 seconds	1.67	1.77
20 seconds	-	0.57
Combination	1.67	0.57

III. RESULTS AND DISCUSSION

Fig. 5 shows an example of HR measurement results in our experiment. The graphs show the ground truth HR (solid line), 76 BPM, and three HR measurements where two of them are measured in two different observing periods, 10 ($\times$), 20 ($\bullet$) seconds, respectively. The combination of these two measurements is plotted with a circular symbol ($\circ$) in Fig. 5, which is updated at every two seconds. A temporal filter is not applied to these measurements yet and just using only one most prominent spectrum for calculating the BPM unit. The ground truth is obtained using finger tip method in the iPhone/iPad application, Cardiio [13]. As shown in Fig. 5, the HR measurements are stabilized after observing periods are past. Therefore, the measurement with a 10 seconds observing time is stabilized quicker than 20 seconds observing times. In other words, the observing time determines the response of the HR measurement.

Fig. 6 shows the HR measurement results after applying a temporal filter to the raw measurements in Fig. 5. It is clear that the error results can be remove by temporal filter. Close observation on Fig. 6 reveals that HR measurements in a short observing time responds to the heart rate quickly but less accurate than the measurements in longer observing times. On the other hand, the HR measurements in a long observing time respond slowly but more accurate after the long observing time is completed. Among the two HR measurements, we choose the result by the propose method, and the most reliable measurement can be selected automatically. Fig. 6 shows that the final result (75 BPM) is close to the ground truth (76 BPM). Fig. 7 shows the HR measurement results after using two most prominent spectrums to calculate the results instead of only the spectrum with the largest z-score in Fig. 6. It show that some final results (76 BPM) are more refined and closer to the ground truth (76 BPM).

Table I shows average errors from the ground truth in different period of observing times from 10 people. The temporal filter is not applied to the measurements yet and just using only one most prominent spectrum. Table II shows the average errors from the ground truth after applying the temporal filter. The temporal filter helps to improve overall results by removed large erratic measurements. As shown in Tables I and II, the HR measurements based on 10-second observation are reasonably accurate (3.4, 2.3) in the first time interval (10-20 seconds), while another measurements are not ready for their computation. In the second time interval (20-30 seconds), the HR measurements based on 20-second observation are ready to use and they are more accurate (1.02, 1.02) than those based on 10-second observations (4, 2.27). Table III shows the average errors in BPM from the ground truth after using two most prominent spectrums to calculate the BPM unit. It helps to improve overall results by increasing the accuracy of the measurements where final results are closer to the ground truth. As shown in Table II and III, the HR measurements based on 10-second observation are reasonably accurate (2.3, 1.67) in the first time interval (10-20 seconds). In the second time interval (20-30 seconds), the HR measurements based on 20-second are more accurate (1.02, 0.57) than those based on 10-second observations (2.27, 1.77)

IV. CONCLUSION AND FUTURE WORK

This paper describes a method for heart rate measurement on a video sequence using Simulink [12]. The heart rate (HR) is measured by detecting the first and second peak frequency of the two color signals, green (G) and Hue (H), on a face in two different observing times, 10 and 20 seconds. Thus, we have 2 HR measurement to assess. The most reliable result can be selected from two different observing time. Our previous work shows that the two color signals are effective in a complementary manner, contributing to more reliable HR measurement than those based on only one color signal [10, 11]. The employment of multiple-observing times is effective for achieving a fast and accurate HR measurement. This is because the HR measurement in a short observing time responds quickly to the change of HRs, while the one with a long observing time produces more accurate measurements. Although the HR measurement in a short observing time tends to be less accurate, the output from it is reasonably reliable owing to the temporal filter applied to most recent five HR measurements. Since the final HR is the one selected from the two different observing times, it is highly reliable and accurate. Furthermore, the using of two most prominent spectrums help to increase the accuracy of the results. The use of Simulink is good for constructing, testing, and improving an algorithm for a task. It is also suitable for educational purposes. As future work, we plan to insert face detection and tracking that can automatically detect the face region and also transfer the developed algorithm from Simulink to microcomputer such as Raspberry Pi.

ACKNOWLEDGMENT

This research is financially supported by Thailand Advanced Institute of Science and Technology (TAIST), National Science and Technology Development Agency (NSTDA), Tokyo Institute of Technology and Sirindhorn International Institute of Technology (SIIT), Thammasat University (TU) under the TAIST Tokyo Tech Program and the National Research University Project, Thailand Office of Higher Education Commission.

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