



CONTACTLESS HEART BEAT MEASUREMENT SYSTEM USING CAMERA

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ABSTRACT:

This paper describes a method to measure or estimate heart rate of a person using a webcam which focuses on the face of the subject. This approach is implemented in real time by continuously obtaining colour image stream from the webcam and blind source separation to extract principle components that are shared among the RGB colour components of an image. A comparative experiment was conducted with a chest strap heartbeat measurement device and a maximum margin of error of +/- 10 bpm could be achieved. This research is the early stage development of a long range automated heart beat monitoring system.

Keywords: Automated heartbeat monitoring, Principle Component Analysis, Fast Fourier Transform

[1] INTRODUCTION

Heart rate is one of the key cardiovascular parameters that contributes to the knowledge of a person's health level as it gives an indication on the mechanical stress that our heart is undergoing, which would relate to many other health studies. Up to date, the most standard equipment to monitor patient's heart rate is the electrocardiogram (ECG) device that is widely used in hospitals across the globe. However, it requires patients to wear adhesive patches or straps which might cause discomfort and irritation. A more commercial version of heart beat measuring device would be the fingertip pulse oximeter. The first suggestion on obtaining heart beat data from the face is by Pavlidis and associates [1] and later demonstrated through analysis of facial thermal videos [2]. Such discovery could bring advancement and innovation to current variation of health care devices. Although such technique may not be able to provide detailed cardio signals that ECG can provide, a non-obstructive and convenient way of continuous monitoring of heart rate and respiratory rate is made available. Advancement of smart phones nowadays equipped with better cameras and

processing power make it possible that every smart phone user could obtain information about their health in the palm of their hand.

The term for techniques that sense cardiovascular pulse through the variation in transmitted or reflected light is known as photoplethysmography (PPG). An example of devices that use this technique is the fingertip oximeter. Typically, PPG has been implemented using dedicated source such as the infra-red wave or constant visible light source. Few studies on contactless version of PPG have been carried out recently, due to its increasing appeal [3] and had showed that it is possible even with normal ambient light source. Up to date, a number of smart phone apps were developed to measure heart rate through the placement of a fingertip on the rear camera with the aid of flash light. Some examples for the Android mobile platform are “Runtastic Heart Rate” from Runtastic, “Heart Beat Rate” from Bio2Imaging and so on. There are also smart phone apps that use contactless PPG which involves front camera and user’s face, for example “Cardiio” by Cardiio Inc for the Apple iOS platform, and “What’s My Heart Rate” developed by Vitrox for the Android platform.

Apart from PPG, there are also studies that derived heart rate from head motion. Subtle head motion caused by the force induced by blood rush at each heart beat could be used for heart rate analysis. Image processing methods such as optical flow could provide data on the movement of head motion [4]. Eulerian video magnification developed by researchers at MIT lab uses temporal filtering which has the same underlying basis as optical flow to magnify colour and motion changes that is related to heart rate [5].

[2] METHODOLOGY

[2.1] Experiment Setup

All the experiments were conducted indoors with normal fluorescent light as the only source of illumination. A C270 HD Logitech USB webcam with maximum 30 frames per second (fps) and HD 720p resolution is used for the experiments due to its automatic functions such as auto-exposure control and auto-white balance can be disabled to reduce external factors that will affect the end result. An ANT+ certified chest strap from Beurer as shown in Fig. 2, which transmits its result wirelessly to a compatible watch is used in the comparative study in this experiment.

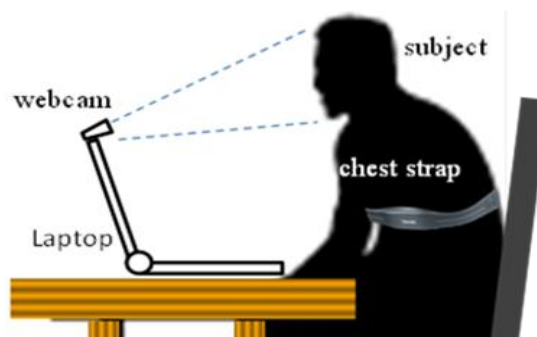


Fig. 1 Experiment setup

The experiments were conducted in 3 stages. The first stage involves only one participant with two different scenarios such as rest and after exercise. This is to pre-test the validity of the method. For the second stage, five participants were invited to take part in this comparative study. Each participant is required to put on the chest strap and the receiver watch is placed close to the monitor so that the readings could be recorded simultaneously. The 3rd stage involves only one participant with different distance between camera and human face represented in terms of different sizes of region of interest (ROI). The ROI original size is 220 x 320 pixels and will be scaled from x0.2 to x1.1 in the increment of 0.1 for 10 different results.

The platform used is a Lenovo ideapad Y580 running in Ubuntu 12.04 LTS. The source code is written in C/C++ with supports from OpenCV, an open source imaging library released under BSD license which is free and supports C, C++, Java and Python interfaces. Using the OpenCV face-tracking function, the computer could track a person face position and then define a region of interest (ROI) within the face area as the main source of measurement data.

[2.2] Face Tracking

The method used here for face detection and tracking is done through a built-in method in OpenCV known as “Haar Cascade Classifier” [6]. Object Detection using Haar feature-based cascade classifiers is an effective object detection method proposed by Paul Viola and Michael Jones in their paper, “Rapid Object Detection using a Boosted Cascade of Simple Features” in 2001. This method uses the approach of machine learning where firstly Haar features are extracted from lots of positive image (with face) and negative image (without face) to train the classifier. Haar features are basically single values that are obtained by subtracting sum of pixels under white rectangle from sum of pixels under black rectangle of some kernels that represents edge and lines. During the training of the classifier, selection of the best features is done using the AdaBoost method. Once the classifier is trained, it is ready to be used to detect objects in other images that are not in the pool of samples.



Fig. 2 Beurer PM26 Heart Rate Monitor

While using this method in real-time application, it is observed that the tracking box indicating the location and size of the result fluctuates rapidly, which will in turn introduce lots of noises into the collected data. Thus, to overcome this, a simple stabilizing algorithm is used to limit the change of the position and size of the tracking box. The algorithm would ignore movements that are less than 5 pixels or more than 300 pixels in all directions. To further reduce noises from pixels that are not member of the face, the size of the tracking box is scaled down to fit only within the region of the face.

[2.3] PRINCIPLE COMPONENT ANALYSIS

During cardiac cycle, the changes in the amount of blood in our facial blood vessels cause variations in the path length of the reflected ambient light which occurs in a timed pattern. The RGB color sensors of the webcam pick up a mixture of signals which probably consist of plethysmographic signal and some other fluctuations in light due to subtle head movements or ambient light fluctuation. All these signals might be shared by two or three of the basic RGB data or derivable just from a single channel among the RGB data.

Thus, a method to separate these blind sources is needed to extract the heart rate data, which is accompanied by a prerequisite knowledge on the frequency spectrum range that usual heart rate would fall into. However, it is possible for some other signals or noise to fall into the same range as well.

The blind source separation technique that is used in this experiment is called the Principle Component Analysis (PCA) which is invented in 1901 by Karl Pearson [8]. Principal Component Analysis (PCA) is used to explain the variance-covariance structure of a set of variables through linear combinations of those variables. PCA is often known for dimensionality reduction on a large data set to ease further analysis. The principle rule of PCA is that the number of observed signals cannot exceed the number of principle components. We shall denote the average red, green, blue signals observed from the webcam as x_1 , x_2 , and x_3 , while the three principle components could be denoted as p_1 , p_2 , and p_3 . According to the assumption of PCA, observed signals are the mixture of few sources, thus the relationship could be simply described as:

$$x(t) = \mathbf{A}p(t) \quad (1)$$

\mathbf{A} is the mixture matrix which its inverse, \mathbf{A}^{-1} is the one that we want to approximate. In this experiment, it was observed that p_1 , p_2 , and p_3 take turns to possess better signal-to-noise ratio (SNR) at random times. Thus an alternative algorithm was developed to evaluate and choose the component with the highest SNR within our frequency range of interest to obtain the plethysmographic signal.

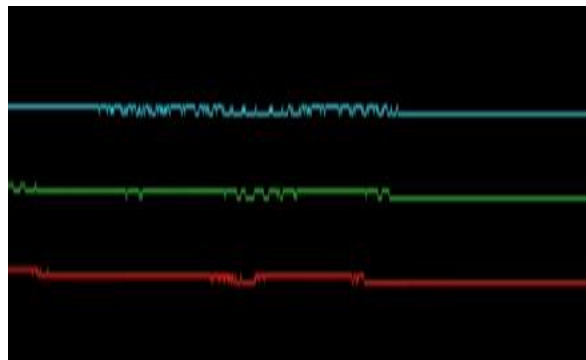


Fig. 3 Average RGB data from the face, each colour of the plot represents their respective colour channel.

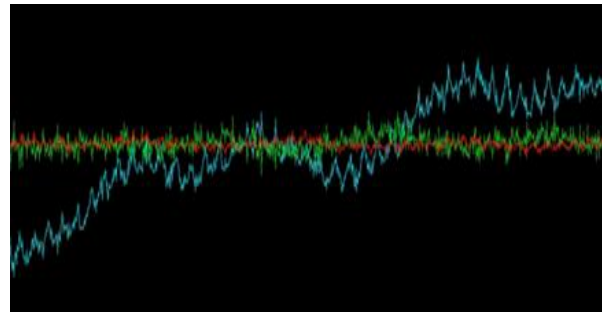


Fig. 4 Result of PCA. 1st component is in blue, followed by 2nd component in green and 3rd component in red.

[2.4] Fast Fourier Transform

The output of PCA remains as time domain signals. To analyse these components in a quick and convenient manner, the frequency spectrum of these components is computed using the Fast Fourier Transform (FFT). Hanning window were also used in the program flow to further improve the data before the FFT conversion. As suggested by many, normal human heart rate ranges from 60 beat per minute (bpm) to 100bpm.

Since 1 bpm means 1 beat in 60 seconds, it also means 1/60 beat in 1 second which also equals to 1/60 Hertz (Hz). This leads to 60 bpm is equal to 1 Hertz. For our analysis we extended the range into 40bpm to 140bpm (which also means 0.6Hz to 2.3Hz) for a wider range of possibility and to avoid biasness. By observing the FFT plot of each principle components, an outstanding local peak could be seen in the range of 0.6Hz to 2.3Hz for all 3 PCA components, as shown in Fig. 5. This is the f_{peak} that we would use to estimate the heart rate. To calculate heart rate in the unit of bpm, we use:

$$\text{Heart Rate (bpm)} = f_{\text{peak}} \times 60 \quad (2)$$

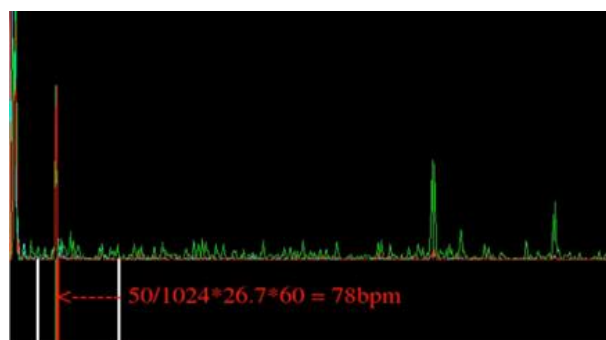


Fig. 5 Normalized FFT plot of the 3 principle components which show common strong local peak at point 50 of the 1024-point FFT graph. The machine measured sampling frequency is 26.7Hz. The equation in the figure yields the result of 78 bpm.

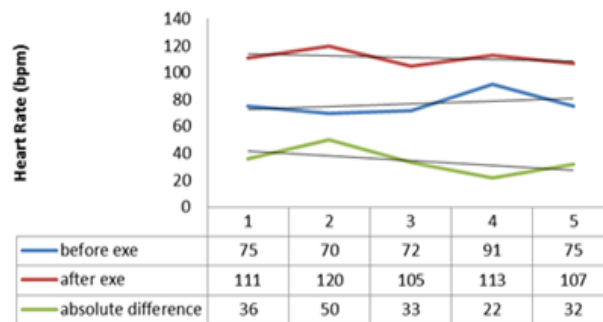
Once the effective q_i is selected, Q_{opt} could be approximated by iteratively adding and choosing local effective terms from Q . Thus, the Q_{opt} will be generated by greedily selecting effective terms. The algorithm presented in the [Figure-3] justifies the use of Q_{opt} in crawling the hidden Web.

[3] Results

[3.1] Comparison between before exercise versus after exercise

The experiment at this stage was tested for 5 random occasions and the result is tabulated as below:

Table 1: Comparison of PPG Data taken at 5 random occasions before and after exercise



From the result at Table 1, we could see that the average heart rate before exercise is 76.6 bpm and the average heart rate after exercise is 111 bpm. The average absolute difference of 34.6 bpm marks a high level of distinguishability between the two scenarios.



Fig. 6 Experiment setup of 2nd stage experiment

[3.2] Comparison between our program with chest strap heart rate monitor

Five different participants were seated in front of the laptop and webcam while wearing the chest strap. A 2 minutes video that records the PPG and Beurer watch (data receiver and display unit of the chest strap) as shown in Fig. 6 is recorded for each of

the participant. By plotting the result that is collected at every 10 second interval, we could obtain the result as shown by the following 5 graphs from Table 2 to Table 6.

Table 2: Result of 1st participant at every 10 sec interval of a 2 minutes video

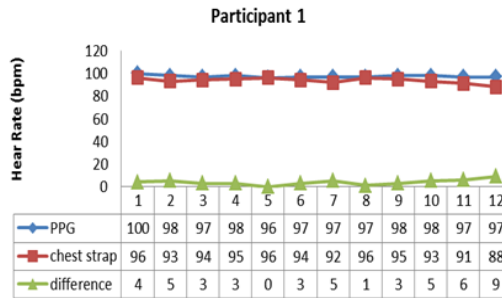


Table 3: Result of 2nd participant at every 10 sec interval of a 2 minutes video

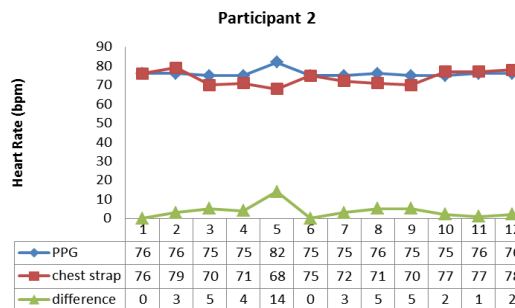


Table 4: Result of 3rd participant at every 10 sec interval of a 2 minutes video

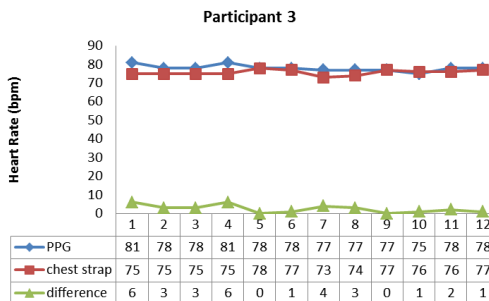


Table 5: Result of 4th participant at every 10 sec interval of a 2 minutes video

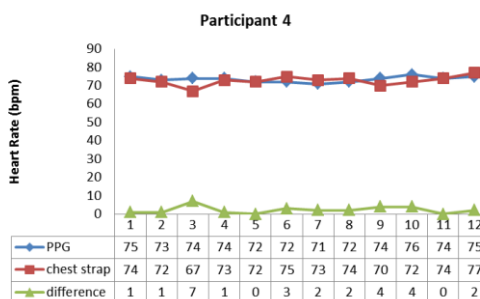
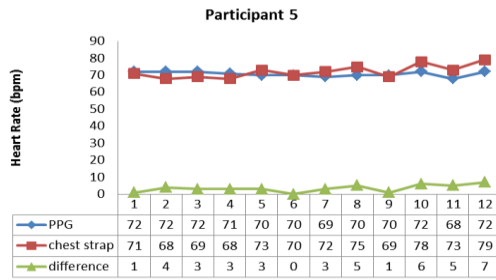
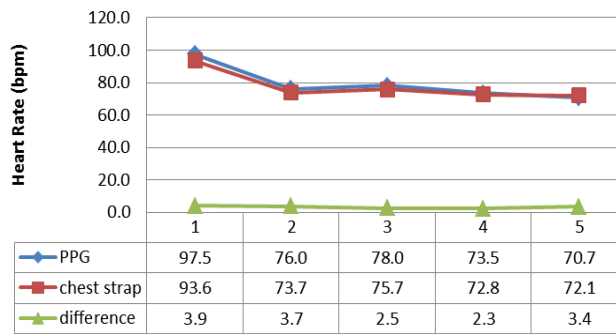


Table 6: Result of 5th participant at every 10 sec interval of a 2 minutes video



From Table 7, we could see that our webcam based PPG heart rate measurement technique produced result which is very close to the measurement of a chest strap heart rate sensor. An average absolute error of 3.2 bpm was achieved in this experiment.

Table 7: Comparison of average PPG data and average chest strap data for 5 different participants.



[3.3] Heart Beat versus Distance

Plot of HeartBeat (bpm) vs ROI Scale

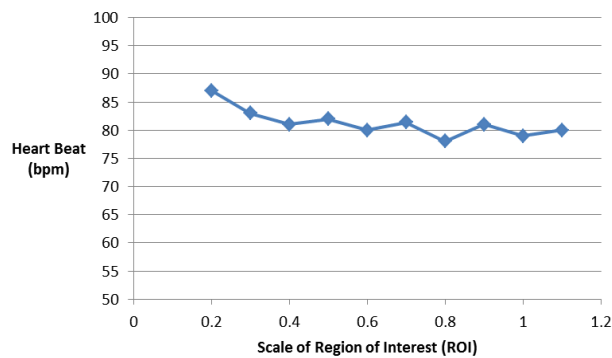


Fig. 6: Comparison of Heart Beat measured over 10 different distances

From Fig. 6, we could see from scale of x0.3 to x1.1, the heart beat measured does not vary so much and average around 81 bpm. However, at scale of x0.2 the heart beat is 88 bpm which is quite far off from the rest of the data. Thus, there is a limit to how much we can use digital zoom for long distance measurement and optical zoom is needed for more accurate results for extreme distance.

[4] Conclusion

This paper has presented a real-time implementation of a method to extract cardiac pulse rate from live stream of the human face through a webcam under indoor room ambient. This approach has the potential to expand to a larger scale with the current advancement rate of cameras and computer hardware, i.e. multiple subjects at once, go along side with a face tracking algorithm and so on. Its application could expand beyond the area of health care into emotion and mood study, home assistant robots, automated health assistant and so on. The development of an automated optical zoom monitoring system is of future work.

Acknowledgments

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Author[s] brief Introduction



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