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Survey on Non-Invasive Methods of Heart Rate Measurement

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Abstract - *Heart diseases and stroke are considered among the world's leading causes of death and disability. To overcome the limitations of existing invasive systems of heart rate measurement the non-invasive techniques are required. As per the study and observations, Photoplethysmography (PPG) imaging technology and Thermal Imaging methods are used for capturing signals which contains pulsatile information. These signals can give us many vital parameters related to heart rate. By using these methods different techniques are available in the market with some limitations. In this paper, different PPG techniques and Thermal Imaging method which have been used for estimation of heart rate are studied. Classification of the PPG data collection methods on the basis of some factors, such as source of light, photo detector, skin part*

Key Words: **PPG (Photoplethysmography), Thermal Imaging, HR (Heart rate), ICA (Independent Component Analysis), FFT (Fast Fourier Transform).**

1. INTRODUCTION

Nowadays heart diseases patients are increasing at a tremendous rate, symptoms like obesity. People are suffering from such health disorders due to unhealthy eating habits, Sedentary lifestyle, lack of daily exercise and lack of proper knowledge and awareness about all these health-related factors. Hypertension and diabetes is observed even in early age (i.e. between 25-35 years). Heart disease and stroke can affect anyone without regard to age, race, ethnicity, sex or income level. This is harmful and can cause severe heart disease. Heart diseases increase risk of cardio respiratory failure if doesn't handled properly.

Heart patients have to follow different tests for diagnosis as well as for treatment. The existed techniques such as ECG are expensive, invasive. It can be applied only under clinical observation. Commercial pulse oximetry sensors that attach to the fingertips or earlobes are also inconvenient for patients and the spring-loaded clips can cause pain if worn over a long period of time.

So the development of low-cost non-invasive physiological monitoring solutions those are easy to use, accurate, and can be used in the home or ambulatory settings is one of the main research areas in the field of biomedical engineering. PPG and Thermal imaging techniques are new milestone in the field of biomedical engineering. These optical methods are non-invasive to detect a cardiovascular pulse wave travelling through the body. This technique can be used for detecting HR (Heart Rate). These methods require only two components i.e. light source for illuminating skin part and photo detector for capturing signals from images.

2. METHOD

In heart rate measurement procedure different methods are used. But basically three of them are very important or most used methods. These are as follows:

2.1 ECG (Electrocardiograph).

ECG stands for electrocardiogram. The abbreviations for the word electrocardiogram (derived from the Greek electro for electric, cardio for heart, and graph for "to write") and the German word electrocardiogram. ECG feature extraction has been studied from early time and lots of advanced techniques as well as transformations have been proposed for accurate and fast ECG feature extraction.

The small electrical changes are on the skin RGB. That are caused when the heart muscle depolarizes. During each heartbeat that are detected and amplified by ECG. Each heart muscle cell has a negative charge, called the membrane potential, across its cell membrane. Decreasing this negative charge toward zero and depolarize it, which activates the mechanisms in the cell that cause it to contract [6]. During each heartbeat, a healthy heart will have an orderly progression of a wave of depolarization that is triggered by the cells in the sinoatrial node, spreads out through the atrium, and passes through the atrioventricular node and then spreads all over the ventricles. This is detected as small rises and falls in the voltage between two electrodes placed either side of the heart, which is displayed as a wavy line either on a paper or on screen [7] . This display indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle [8]. Figure 1 shows internal architecture of ECG method.

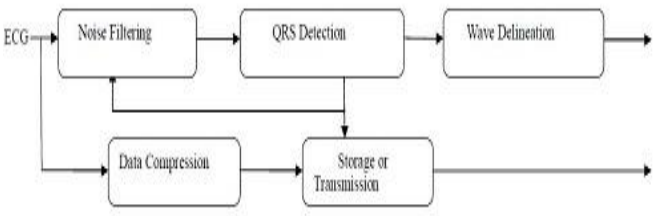

Fig -1: ECG architecture

Zhao et al. [2] proposed a method which support vector machines using wavelet transform. The proposed system two diverse feature extraction methods are applied together to

achieve the feature vector of ECG data. The wavelet transform is used to extract the coefficients of the transform as the features of each ECG segment. To get hold of the temporal

A structure of ECG waveforms autoregressive modelling (AR) is applied. Then at last the support vector machine (SVM) with Gaussian kernel is used to classify different ECG heart rhythm. The performance of the proposed approach reached the overall accuracy of 99.68%.

A novel approach for ECG feature extraction was proposed by Castro et al. in [3]. In the proposed algorithm is based on the wavelet transform, for feature extraction from an electrocardiograph (ECG) signal and recognition of abnormal heartbeats. Since wavelet transforms can be localized both in the frequency and time domains. They developed a method using a set of orthogonal and biorthogonal wavelet filter bank from an optimal mother wavelet. It means of the best correlation with the ECG signal is considered. The foremost step of their approach is to remove noise from the ECG signal by a soft or hard threshold with limitation of 99.99 reconstructs ability and then each PQRST cycle is decomposed into a coefficients vector by the optimal wavelet function.

Advantages:

a) Non-invasive techniques to monitor heart rate

b) This technique can be used for monitoring many cardio logical parameters such as heart rate, respiration rate, heart rate variability, arterial fibrillation, blood pressure, oxygen saturation level etc.

c) Accuracy of results is high.

Limitation:

a) Extra hardware settings are required.

b) Bulkiness.

c) Complex to be used.

d) Incontinent to patient

2.2 PPG Signal

Photoplethysmography (PPG) is an optical measurement technique that can be used to detect blood volume changes in the microvascular bed of tissue. It has widespread clinical application, with the technology utilized in commercially available medical devices, for example in pulse oximetry, vascular diagnostics and digital beat-to-beat blood pressure measurement systems. The basic form of PPG technology requires only a few optoelectronic components: a light source to illuminate the tissue (e.g. skin), and a photo detector to measure the small variations in light intensity associated with changes in perfusion in the catchment volume. PPG is most often employed non-invasively and operates at a red or a near infrared wavelength. The most recognized waveform feature is the peripheral pulse, and it is synchronized to each heartbeat. Despite its simplicity the origins of the different components of the PPG signal are still not fully understood. It is generally accepted, however, that they can provide valuable information about the cardiovascular system [1].

In the year 1937 PPG technique was introduced by Hertzman and published their first paper on PPG describing the use of a reflection mode system to measure blood volume changes in the fingers induced by the Valsalva man oeuvre, exercise and with exposure too cold.

In 1938, Hertzman undertook a validation of the PPG technique by comparing blood volume changes with those measured simultaneously by mechanical plethysmography [2].

In 1938 Matthes and Hauss done preliminary observation on PPG technique. Hertzman and Dillon in 1940 separated the AC and DC components of PPG with filters and electronic amplifiers and monitored vasomotor activity [4]. Hertzman advised that movement of the measurement probe against the skin should be avoided to get good results. These observations led to the development of elaborate positioning of devices. Hertzman identified illumination is also an important design consideration and used a battery powered torch bulb which has relatively wide spectrum. He emphasized that the widespread illumination can mix skin micro vascular blood flow with larger vessel signals. Furthermore, constant light intensity could not be guaranteed [4].

The principle of indirect continuous monitoring of Blood Pressure method was based on idea that if an externally applied pressure in the cuff is equal to the arterial pressure instantaneously, the arterial walls will be unloaded (zero transmutable pressure) and the arteries will not change in size. In this condition, the blood volume will not change. This method was an attempt to realize for the first time by Penaz in the year 1973 using photoelectric technique of detecting blood flow, equipped with a transparent inflatable cuff controlled by a servo control system in the human finger [5].

In recent days the desire for reliable, small, simple-to-use and low-cost non-invasive cardiovascular assessment techniques are key factors that have helped in development of PPG technique. Advances in opto-electronics and clinical instrumentation have also significantly contributed to its advancement. The developments in semiconductor technology, i.e. light emitting diodes (LED), photodiodes and phototransistors, have made considerable improvements in the size, sensitivity, portability, reliability and reproducibility of PPG probe design.

PPG Signals are used to retrieve heart rate from human body. PPG means Photoplethysmography signals which are used to get volumetric information about human body. PPG technique classification is based on source of light and photo detector.

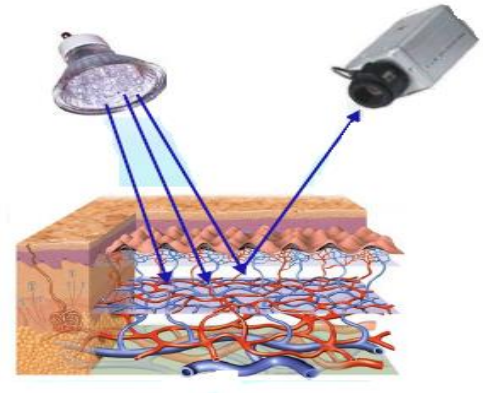

Fig - 2. PPG signals using photo detector and Light source

Following techniques are used PPG signals and calculate heart rate.

1) Wristwatch-type PPG array Sensors Module.

Yong Kwi et al [9] developed the Wristwatch -type PPG array Sensor module which can be used to calculate heart rate by recording signals from radial and ulnar artery of the wrist.

Figure 3 shows working architecture of wristwatch type PPG device to measure heart rate.

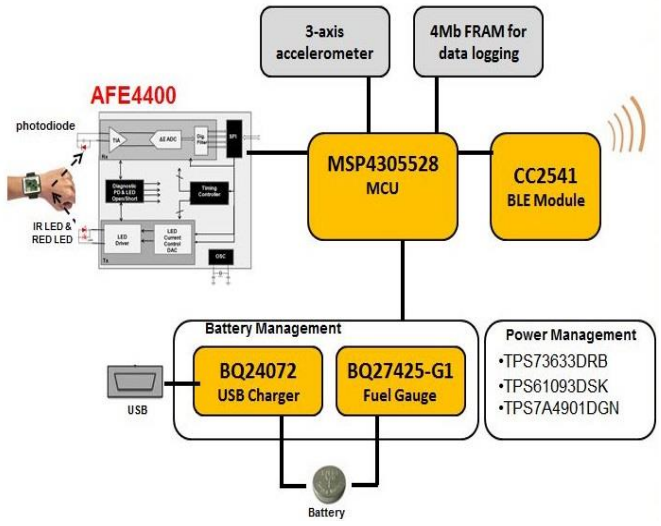

Fig - 3. Wristwatch-type PPG Method architecture

2) Earpiece PPG

Earpiece PPG sensors are also available and provide greater comfort for the user. In this design, a reflective photo sensor is embedded into each ear bud, as shown in Figure. The sensor ear buds are inserted into the ear and positioned against the inner side of the tragus to detect the amount of light reflected from the subcutaneous blood vessels in the region. The PPG sensor ear buds look and work like a regular pair of earphones, requiring no special training for use [12]. Figure 4 shows working architecture of earpiece PPG method.

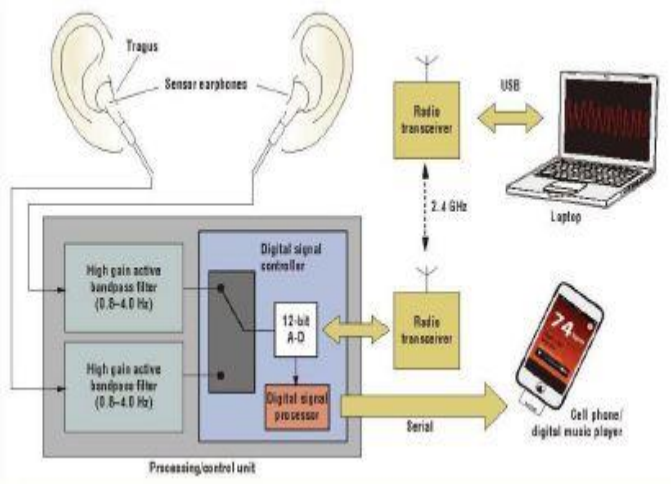

Fig - 4. Earpiece PPG method architecture

3) Magnetic earring Sensor.

A headset with an ear-clip, transmission-type PPG sensor allows continuous, real-time monitoring of heart rate while listening to music during daily activities. In addition, the proposed headset is equipped with a triaxle accelerometer, which enables the measurement of calorie consumption and step-counting. However, over the course of a variety of daily activities (e.g., walking, jogging, and sleeping), the PPG sensor signal may become contaminated with motion artifacts [11]. Yong Kwi et al [10] proposed model containing a magnetic earring sensor and wireless earpiece which calculates cardio logical parameters such as heart rate.

Fig - 5. PPG ring sensor

The miniaturized sensor does not cause pain when it is put on earlobe. Motion reference for adaptive noise cancellation can be obtained from an embedded accelerometer. The tasks such as providing analog signal conditioning and data forwarding are done by the compact wireless earpiece.

Advantages:

a) Non-invasive techniques to monitor vital physiological parameters.

b) This technique can be used for monitoring many cardio logical parameters such as heart rate, respiration rate, heart rate variability, arterial fibrillation, blood pressure, oxygen saturation level etc.

Limitation:

Extra hardware settings are required

4) Thumb PPG.

In 2012 a team of Ki Chon, professor and head of biomedical engineering at WPI developed a smart phone application that can measure heart rate, heart rhythm, respiration rate and blood oxygen saturation using the phone's built in camera as a photo detector and LED flash light as a light source.

Author capture video of thumb with flash light, apply ROI on that video frames. Captured video is processed by using ICA and FFT filtering technique and measure heart rate.

Advantages:

a) The system can monitor HR, RR and SpO2 level on a single device and it is Non-Invasive and less costly.

b) No extra hardware required.

c) It acts as a "take anywhere "physiological monitor.

d) It can be utilized for personal and clinical use.

Limitations:

Low camera sampling rate of mobile phone and

Motion artifacts can cause error.

5) Facial PPG.

1. PPG using CCD camera as a photo detector and a multi-wavelength RCLED ring as a light source.

In 2009 Sijung Hu et al. developed new technique using PPG technology for physiological parameter monitoring in which author used more sensitive CCD Camera as a photo detector and a multi-wavelength RCLED ring light source as light source to measure blood perfusion from human face. [7]

Advantages:

a) Non-invasive system to monitor pulse rate and blood perfusion.

b) Non-Contact device to measure vital physiological parameters.

Limitations:

Extra hardware required for setting a system.

2. PPG using webcam as a photo detector and natural sunlight as a light source

Ming-Zher Poh, introduced a new innovative idea in 2010 in which webcam of computer is used as a photo detector and natural sunlight is used as a light source.

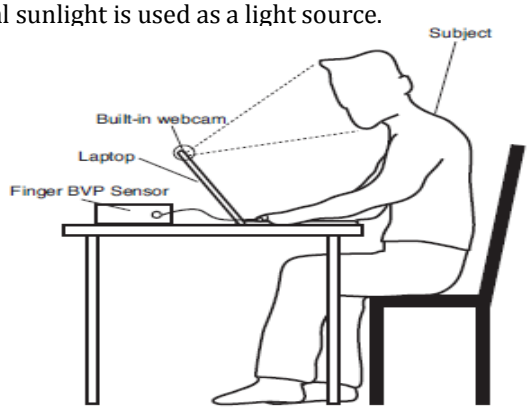

Fig. Experimental setup.

In this system video of face is captured as a source video. Face is considered as a ROI (Region of interest) and extract frame from video. ICA algorithm is used for separating RGB signals from captured video, then applies FFT (Fast Fourier Transform) filtering technique and calculates heart rate.

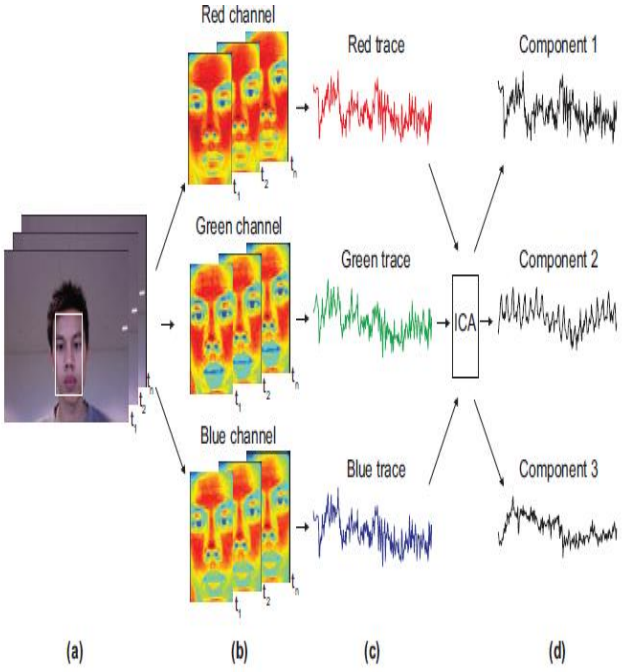

Fig. Cardiac pulse recovery methodology. (a) The region of interest (ROI) is automatically detected using a face tracker. (b) The ROI is decomposed into the RGB channels and spatially averaged to obtain (c) the raw RGB traces. ICA is applied on the normalized RGB traces to recover (d) three independent source signals.

In 2012 J. Krajewski developed a system in which webcam is used as a photo detector and natural light as source light. In additional author told that center of face gives better result than other parts of face region for measuring heart rate.

In 2015 Young-Pho Yu. Proposed a system in which webcam is used as a photo detector and natural light as source light. In additional author compare video lengths and conclude that the medium length video gives better result than short and large length video.

In 2011 Magdalena Lewandowska proposed a system in which author concludes that forehead region of face gives better result than other parts of face in heart rate measurement.

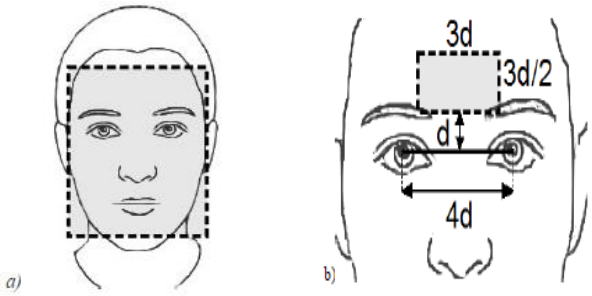

Fig Definition of ROI's for two approaches utilized in the paper, a) the whole face as a ROI, b) selected part of the forehead as a ROI

Advantages:

a) Non-Invasive method for detecting heart rate. It doesn't require any contact with skin for monitoring heart rate unlike Existing methods i.e. commercial pulse oximetry sensors.

b) It doesn't require any extra hardware components such a technology would also minimize the amount of cabling and clutter associated with neonatal ICU.

c) It can calculate heart rate of more than one subjects at a time.

d) Natural source of light i.e. sun light is used for illuminating the skin.

Limitations:

a) Variation in sunlight intensity can cause decreasing SNR.

b) This technology uses the webcam available as inbuilt feature with laptop. But the quality of videos can undergo changes due to different resolution of a camera

3. PPG using Smart phone camera as a photo detector and natural light as a light source

In 2012 Sungjun Kwon developed an application for smart phone in which inbuilt smart phone camera used as a photo detector and natural light as a light source.

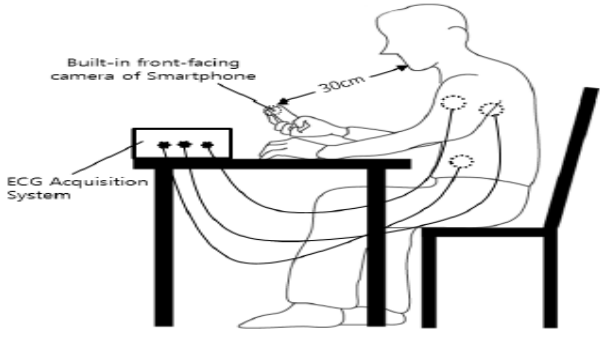

Figure Experimental Setup.

In authors proposed system face video is captured using mobile phone and process that that video using ICA signal separation technique and calculate heart rate.

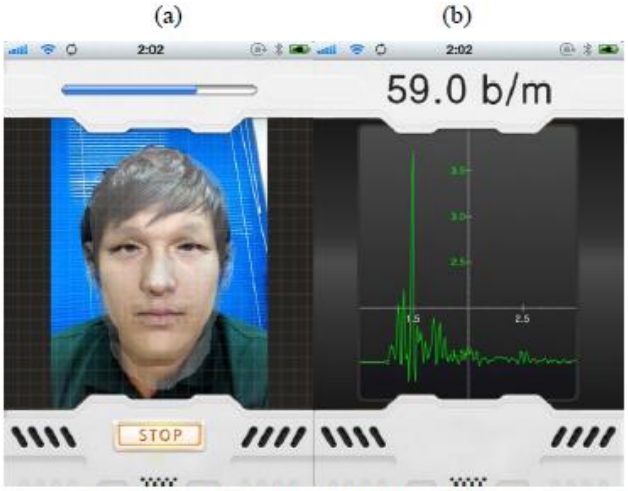

Figure . The screenshots of FaceBEAT. (a) FaceBEAT supports overlaid guide view on the recording. (b) FaceBEAT shows the estimated heart rate and the FFT results to user

In 2014 Haiying Xia developed a system in which smart phone camera is used as a photo detector and natural light is used as a source of light. In additional author capture a video using smart phone camera and send it to server through internet and at server side video is processed and calculate heart rate. The result is send back on smart phone.

Advantages:

a) Non-Invasive and contact less heart rate measurement system.

b) No extra hardware required.

Limitation:

Low camera sampling rate of mobile phone and Motion artifacts can cause error

6) Thermal Imaging

In 2007 Pavlidis and his colleagues proposed a method for heart rate measuring from thermal imaging. In their method heart rate corresponds to the dominant frequency estimated from averaging the power spectra of the pixels in the desired region of interest (ROI) which can be carotid or superficial vessels. Where thermal video of face is captured using thermal camera and calculate the difference between two frames and extract heart rate [10].

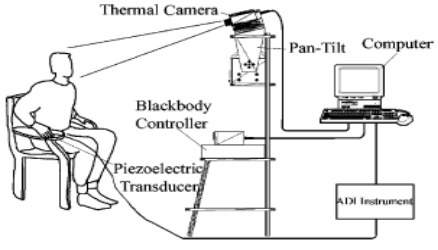

Fig – 6 . Experimental Setup

In their method video is captured by thermal camera. These raw thermal images are considered as an input data. In second step motions are tracked and blood vessels are registered.

After blood vessels registration FFT analysis is done. Adaptive function is estimated on that analysis and calculates the cardiac pulses

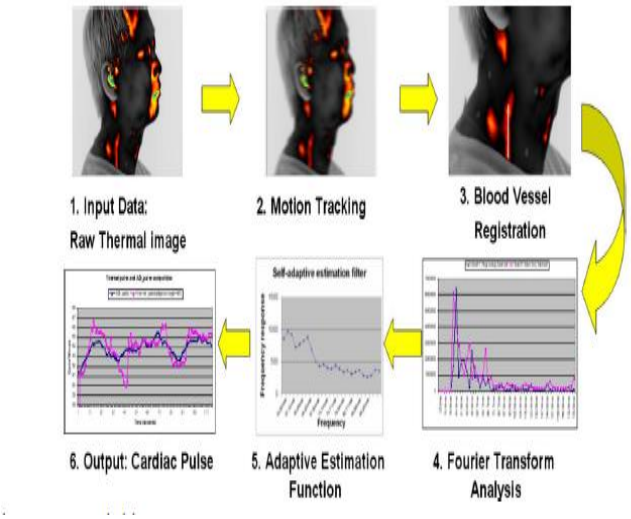

Fig- 7. Pulse Mesurement Methodology

In 2012 Wu et. al. introduced a method for revealing and displaying temporal changes in human face due to blood perfusion in non-IR (visible) videos, these temporal changes are invisible by naked eyes.

This method was successful in revealing variations of the face color caused by blood circulation in ordinary visible videos so that applying this method on IR videos can also reveal thermal temporal changes caused by blood circulation on the face. Although in Wu et al. (2012) only a method was described for displaying the color variations of skin but it is possible to extract the heart rate which corresponds to the color variations displayed.

In this work, it is the first time that spatio-temporal filtering (STF) has been proposed for estimating heart rate from thermal video sequences.

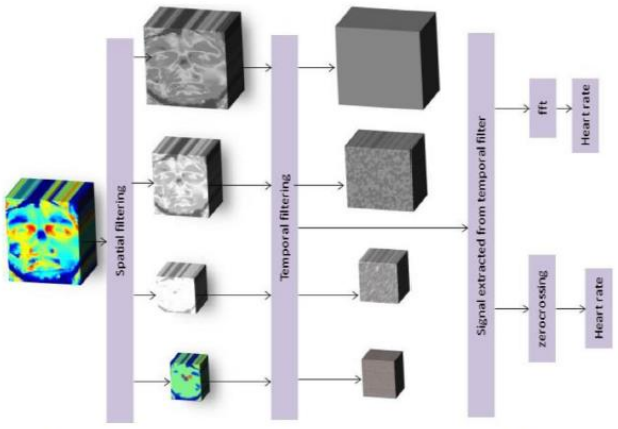

Fig. The block diagram of spatio-temporal filtering algorithm for extracting heart rate.

In 2016 Kian Hamedani developed a system in which thermal imaging video is captured. Consider the ROI on that captured video and processed that ROI and calculate the heart rate

3. CONCLUSIONS

In this paper heart rate measurement methods are studied and compared. For comparing methods different parameters are considered, like accuracy, cost, setup complexity.
So, as per the study and comparison, based on accuracy ECG is gives better result with high cost and considering all parameters Thumb PPG, Face PPG and Thermal Imaging techniques are good for heart rate measurement.

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Table – 1. Comparison of all Methods

	ECG	Wristwatch PPG	Ear-Piece PPG	Magnetic Earring PPG	Thumb PPG	Face PPG	Thermal Imaging
Easy to Handle	No	Yes	Yes	Yes	Yes	Yes	Yes
Accuracy	High	Low	Low	Low	Medium	Medium	Medium
Invasiveness	Yes	Yes	Yes	Yes	Yes	No	No
Cost	High	Medium	Medium	Medium	Low	Low	Medium
Experimental Setup	Complex	Easy	Easy	Easy	Easy	Easy	Complex