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Study on Physiological Parameter Detection Systems

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Abstract

Heart disease and stroke are considered among the world's leading causes of death and disability. The non-invasive technique for physiological parameter monitoring is required to overcome the limitations of the existing systems. As per the study and observations, photoplenthesmography (PPG) imaging technology can be used for capturing signals which contains pulsatile information. These signals can gives us many vital parameters such as heart rate, respiration rate, oxygen saturation level, heart rate variability, arterial fibrillation etc. These PPG signals contain noise due to motion artifacts. Motion artifact reduction results in better accuracy of final outcomes. In this paper, different PPG techniques and motion artifact reduction methods which have been used for estimation of some of the cardiovascular parameters are studied. Classification of the PPG data collection methods on the basis of some factors such as source of light, photo detector, skin part used, type of PPG used and extracted parameters etc. is carried out.

Keywords

PPG (Photoplenthesmography), HR (Heart Rate), RR (Respiration Rate), SpO2 (oxygen saturation level), MA (Motion Artifact), physiological parameter monitor, pulse, ICA (Independent Component Analysis), ASLMS (Adaptive Step size Least Mean Square), CFSA (cycle-by-cycle Fourier series analysis)etc.

1. Introduction

Nowadays the risk factors such as obesity, hypertension and heart diseases are increasing at a tremendous rate. 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.

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The percentage of hypertension and diabetes in early age (i.e. between 25-35 years) is also increasing. 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 presented techniques such as ECG are expensive, invasive and 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-(photoplenthesmography) imaging technique is new milestone in the field of biomedical engineering. It is a non-invasive optical method to detect a cardiovascular pulse wave travelling through the body. This technique can be used for detecting different cardiovascular parameters such as respiration rate, heart rate, oxygen saturation level, heart variability etc. This method requires only two components i.e. light source for illuminating skin part and photo detector for capturing PPG signals.

The PPG is classified in two different groups by considering the place of photo detector and source of light.

1) Reflection PPG: If both components are at one side of a skin part then is called as reflection PPG.

2) Transmission PPG: If both components are at the opposite sides of a skin part then it is called as transmission PPG.

The PPG technology has been used in monitoring of oxygen saturation i.e. pulse oximetry, heart and respiration rates, blood pressure, cardiac output, assessment of autonomic functions, and detection of peripheral vascular diseases.

2. PPG technique classification based on source of light and photodetector

2.1 PPG using multiLED light source and photo detector sensors

2.1.1 Traditional method

Monitoring of vital body signs such as heart rate and blood oxygenation via photoplethysmography (PPG) originates from early investigations of Hertzman on blood circulation in limb extremities. Early PPG devices contains multiLED light source for illuminating skin part and a photo detector sensors are used to record the signals.

In 1964 Shaw assembled the first absolute reading ear oximeter by using eight wavelengths of light. Pulse oximetry was developed in 1972, by Takuo Aoyagi and Michio Kishi, bioengineers, at Nihon Kohden using the ratio of red to infrared light absorption of pulsating components at the measuring site. The investigations observed by Takuo Aoyagi ware the main step towards the recent oximeters. Next generations of pulse oximeters are using PPG technology for measurement of SpO2 level.

E. Kviesis-Kipge, et al.[1] proposed a system comprising 3-channel digital PPG device with a sampling rate of 1 kHz per channel. 875 nm LED is used as source of light and photodiodes with a daylight filter and peak spectral response wavelength of 880nm is used as photodetector.

Then PPG imaging is used for estimating respiration rate. This system is introduced by Ki H. Chon in AUGUST 2009 [2]. K. H. Shelley utilized short-time Fourier transform (STFT) to extract the respiratory rate from the PPG signal [3]. P. Leonard utilized continuous wavelet transform (CWT) to extract the respiratory rate from the PPG signal [4].

Mika P. Tarvainen proposed the algorithm for detecting heart rate variability from recorded ECG signals during February 2002. Jose Miguel Medeiros developed a tool for measuring heart rate variability using PPG signals in university of ciombra during the year of 2010.

2.1.2 Wristwatch-type PPG Array Sensor Module

Yong Kwi et. al[5] 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.

2.1.3 Magnetic Earring Sensor

Ming-Zher Poh et. al[6] proposed model containing a magnetic earring sensor and wireless earpiece which calculates cardio logical parameters such as heart rate.

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*:**

1.Non-invasive technique to monitor vital physiological parameters.
2.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.

- ***Limitations:***

1. Extra hardware settings are required.

2.2 PPG using CCD camera as a photodetector and a multi-wavelength RCLED ring as a light source

Sijung Hu et al.[7] developed the new approach for using PPG technology for physiological parameter monitoring in which an improved system with a more sensitive CCD camera and a multi-wavelength RCLED ring light source was used to measure blood perfusion from the human face. [2009]

- ***Advantages*:**

1. Non-invasive technique to monitor vital physiological parameters like pulse rate and blood perfusion.
2. There is no need of any contact of device with skin.

- ***Limitations*:**

1. Extra hardware setting required.

2.3 PPG using webcam as a photo detector and natural sunlight as a source of light

Further studies and experiments introduces a new innovative idea anticipated by Ming-Zher Poh, during year 2010 in which webcam of a computer is used as a photo detector and natural light as a illuminating source. Blind source separation method is also discussed for motion artifact reduction. [8].

- **Advantages:**

1. Non-invasive method for detecting heart rate. It doesn't require any contact with the skin for monitoring heart rate unlike Existing methods i.e. Commercial pulseoximetry sensors.
2. It doesn't require any extra hardware components. Such a technology would also minimize the amount of cabling and clutter associated with neonatal ICU.
3. It can calculate heart rate of more than one subjects at a time.
4. Natural source of light i.e. sun light is used for illuminating the skin.

- **Limitations:**

1. Variations in sunlight intensity can cause decreasing SNR.
2. 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.

2.4 PPG using inbuilt smart phone camera as photo detector and LED flash as a source of light

The recent application using PPG technique is developed by a team led by Ki Chon, professor and head of biomedical engineering at WPI. They have developed a smart phone application that can measure not only heart rate, but also heart rhythm, respiration rate and blood oxygen saturation using the phone's built-in video camera as a photo detector and LED flash as source of light.[9]. The new application yields vital signs as accurate as standard medical monitors now in clinical use. The researchers are also developing an application to detect arterial fibrillation, the most common form of cardiac arrhythmia, and a version for tablets like the iPad2.

- **Advantages:**

1. The system can monitor HR,RR and SpO2 level on a single device and it is Non-invasive and Less costly.
2. No extra H/W settings required.
3. It acts as a "take anywhere" physiological monitor.
4. It can be utilized for personal and clinical use.

- **Limitations:**

1. Low-camera sampling rate of a mobile phone and Motion artifacts can cause error.

3. Approaches for motion artifact reduction from recorded PPG signals

3.1 MA reduction by using traditional approaches

Rajet Krishnan et.al[10] proposed Two-Stage Approach for detection and reduction of motion artifacts in photoplethysmographic data in 2010. Novel and consistent techniques to detect the presence of motion artifact in PPGs given higher order statistical information present in the data is discussed. The data in the time and frequency domains is analyzed and clean and motion-corrupted data is differentiated by identifying metrics. A Neyman–Pearson detection rule is formulated for each of the metrics. Hard fusion and soft fusion is employed by treating each of the metrics as observations from independent sensors. For stage two, a motion artifact reduction method is proposed which is effective even in the presence of severe subject movement. The approach involves an enhanced pre-processing unit consisting of a motion detection unit, period estimation unit, and Fourier series reconstruction unit. The MDU identifies clean data frames versus those corrupted with motion artifacts. The period estimation unit determines the fundamental frequency of a corrupt frame. The Fourier series reconstruction unit reconstructs the final pre-processed signal by utilizing the spectrum variability of the pulse waveform. Pre-processed data are then fed to a magnitude based FD independent component analysis unit. This helps reduce motion artifacts present at the frequencies of the reconstruction components.

J. G. Webster, M. R. Neuman and N.Wang, K. W. Chan and Y. T. Zhang, J. Lee, W. Jung, I. Kang, Y. Kim, and G. Lee proposed that the moving average (MA), adaptive, and multirate filtering techniques for MA reduction.

- **Limitation:**

1. These techniques have limited scope and not suitable for estimation of every physiological parameters.

Table 1: Classification of PPG Techniques.

Sr. No.	Photo Detector	Source of light	Type of PPG	Skin part	Extracted Parameter	MA handling	Extra hardware setting requirement
1	Photo Sensors	Multi LED	Transmission	Finger/ Earlobe	HR,SpO2 level	No	Yes
2	Photodiodes	875 nm LED	Reflection	Popliteal artery, posterior Tibial artery, artery near big toe	Pulse rate	Yes	Yes
3	Photo Transistors	Infrared emitting Diodes	Reflection	Ulnar artery, radial artery	HR	Yes	Yes
4	Photo Transistors	Infrared LED	Reflection	Earlobe	HR	Yes	Yes
5	CCD Camera	RCLED ring	Reflection	Human Face	Pulse rate and Blood Perfusion	No	Yes
6	Webcam	Natural sunlight	Reflection	Human Face	HR	Yes	No
7	Smart Phone Inbuilt Camera	Inbuilt smart phone LED flash	Reflection	Left index Finger	HR,RR and SpO2 level	No	No

J. G. Webster, M. R. Neuman and N.Wang, K. W. Chan and Y. T. Zhang, J. Lee, W. Jung, I. Kang, Y. Kim, and G. Lee proposed that the moving average (MA), adaptive, and multirate filtering techniques for MA reduction.

- **Limitation:**

1.These techniques have limited scope and not suitable for estimation of every physiological parameters.

C. M. Lee and Y. T. Zhang, B. S. Kim and S. K. Yoo, proposed Wavelet transform technique in 2005.

- **Limitation:**

1. Studies indicated that the arterial pulsations are not statistically independent from motion.

3.2 MA reduction using ”ring sensor”

Sokwoo Rhee et. al[11] proposed the sensor, called a “Ring Sensor,” which can be attached to a finger base for monitoring beat-to-beat pulsation.Tthe data is sent to a host computer via a radiofrequency transmitter. Two major design issues are addressed. One is to minimize motion artifact and the other is to minimize the consumption of battery power. An efficient double ring design is developed to lower the influence of external force, acceleration, and ambient light. It also helps to hold the sensor gently and securely on the skin, so that the circulation at the finger may not be disturbed. Total power consumption is analyzed in relation to characteristics of individual components, sampling rate, and CPU clock speed. Optimal operating conditions are obtained for minimizing the power budget. A prototype ring sensor is designed and built based on the power budget analysis and the artifact-resistive attachment method. It is verified through experiments that the ring sensor is resistant to interfering forces and acceleration acting on the ring body.

- **Advantages:**

1.Motion artifact reduction is handled.
2.The consumption of battery power is minimized

- **Limitation:**

1. Extra hardware is required to capture PPG signals.

3.3 MA reduction using CFSA

K. Ashoka Reddy et.al[12] presented a new method of cycle-by-cycle Fourier series analysis (CFSA) to extract artifact-free PPG from PPG signals corrupted by motion artifacts. Since PPG signal is quasi-periodic and nonstationary, a Fourier series is not directly applicable to PPG. This problem is overcome by applying Fourier series on a cycle-by-cycle basis. First, a complete cycle of a PPG is identified, and its time period, e.g., $T1$, is determined. Fourier coefficients with $T = T1$, are stored by assuming that this first cycle endlessly repeats itself. These coefficients are strictly applicable only to the first cycle. Once the Fourier coefficients that are applicable for the first PPG cycle are computed and stored, the next cycle in the PPG signal (with period $T2$) is then identified and subjected to Fourier series expansion. This process is repeated for every cycle. A reverse process is applied to reconstruct PPG signal cycle by cycle from the stored set of coefficients.

- **Advantages:**

1.Helps in MA reduction
2.Supports data compression as well.

- **Limitation:**

1. Extra hardware is required to capture PPG signals with separated red and IR waveforms.

3.4 MA reduction using ICA

Aapo Hyvrinen and Erkki et.al [13] proposed ICA technique for signal separation in their research paper “Independent Component Analysis: Algorithms and Applications”. Byung S. Kim and Sun K. Yoo stated that the combination of independent component analysis and block interleaving with low-pass filtering can reduce the motion artifacts under the condition of general dual-wavelength measurement. Pre-processing PPG signal followed by ICA gives more accurate results [14].

Ming-Zher Poh proposed the novel approach which can be applied to PPG color video recordings of the human face and is based on automatic face tracking along with blind source separation of the colour channels into independent components [May 2010].

- **Advantages:**

1. This is the first demonstration of a low-cost accurate video-based method for contact free heart rate measurements that is automated, motion-tolerant.
2. Capable of performing concomitant measurements on more than one person at a time.

Ming-Zher Poh proposed ICA technique for obtaining better results of heart rate variability, HR and RR from the recorded PPG videos using inbuilt webcam of laptop and natural sunlight as illuminating light source with some additional methods in their prior work.[15]

- **Advantage:**

1.This is the first demonstration of a simple, low-cost method for noncontact HRV measurements.
2.More accurate results are obtained by analyzing different component and selecting the component whose power spectrum contained the highest peak.

- **Limitation:**

1. Motion artifact is not handled properly.

3.5 AS-LMS method for MA reduction

M. Raghu Ram proposed a simple and efficient approach based on adaptive step-size least mean squares (AS-LMS) adaptive filter for reducing MA in corrupted PPG signals in their IEEE transaction paper[16]. The performance of pulse oximeters is highly influenced by motion artifacts in PPG signals. Some of the scientists in this field proposed a simple, new and efficient approach based on adaptive step-size least mean squares (ASLMS) adaptive filter for reducing MA in corrupted PPG signals. The novelty of the method lies in the fact that a synthetic noise reference signal for an adaptive filtering process, representing MA noise, is generated internally from the MA-corrupted PPG signal itself instead of using any additional hardware such as accelerometer or source-detector pair for acquiring noise reference signal. Thus, the generated noise reference signal is then applied to the AS-LMS adaptive filter for artifact removal. An adaptive filtering algorithm for MA reduction is implemented, making use of existing two wavelength probe of CPO without looking for any additional hardware. The frequency spectrum of noise due to MA (0.1 Hz or more) has every chance of overlapping with that of a useful PPG signal (0.5-4.0 Hz) and results in in-band noise.

Adaptive filters are very effective in in-band noise cancellation by self adjusting the filter coefficients based on some specific adaptive algorithms. In addition to the suitable adaptive algorithm, the reference signal plays a vital role in adaptive filters. In fact, the adaptive filters require a reference signal that is strongly correlated either with the artifact but uncorrelated with the signal or with the signal but uncorrelated with the artifact.

Step 1: Synthetic noise reference signal generation:

NR(n) is generated from the corrupted PPG signal individually using three different methods, namely, FFT, ICA and SVD. ICA is a quite-powerful signal processing technique, which expresses a set of random variables as linear combination of statistically independent component variables. The noise reference signal is generated using ICA method. Kurtosis is used as a measure of randomness. A high value of kurtosis alone would serve as a reliable measure for the selection of synthetic noise reference signal.

Step 2: Thus, the generated noise reference signal is then applied to the AS-LMS adaptive filter for artifact removal.

- **Advantage:**

1.No extra hardware is required for detecting noise.

2.A synthetic noise reference signal for an adaptive filtering process, representing MA noise, is generated internally from the MA-corrupted PPG signal itself.

4. Conclusion

In above paper, different methods for recording PPG signals including traditional approaches, wrist watch type sensor, CCD camera, webcam and smart phone camera are discussed. The latest generation of smart phones is increasingly viewed as handheld computers rather than as phones. Smart phones have different sensors available to capture information from the outside world, process the data in real-time, and transfer information remotely using wireless communications. Most of the newer generation of smart phones also incorporates other features such as on-board personal management tools, high quality cameras and recording devices. These factors make smart phones an ideal option as a ”take-anywhere” physiological monitor without the need for additional hardware, and their potential has been explored for many medical telemonitoring applications.

As well as, different approaches for MA reduction which includes traditional techniques, ring sensors, ICA, ICA with pre-processing, two stage approach, BSS, AS-LMS filter etc. are studied. As per the observations and study, ICA with pre-processing gives better results than alone ICA. BSS and AS-LMS filter are also approved for giving better MA reduction.

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