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Computerized Optical Plethysmography for Data Recording and Processing of Biomedical Signal

Margi Sasono
Centers for Applied Physics Study (PUSFIT)
Departement of Physics Metrology and Electronics
Instrumentation Ahmad Dahlan University
Yogyakarta, Indonesia

Apik Rusdiarna Indrapraja
Calibration and Testing Laboratory
Ahmad Dahlan University
Yogyakarta, Indonesia

***Abstract*— An optical device has been developed for recording and processing of biomedical signal using transmission mode of optical plethysmography technique. The data aquisition process is carried out based on detection of the near-infrared light absorbance in blood vessels of fingertip due to heart's pump activity. The microcontroller was used as main component to provide the operation of electronics module and communication to personal computer through Universial Serial Bus (USB) system. In addition, the USB port was also used as part of power supply device, so that requiring no the external power adaptor. The analogue signal of photosensor (photodiode) was fed to microcontroller for digitalization process and then was transferred to a software for storage, processing and display of the biomedical signal on the personel computer. Performance of the developed device was tested to record the biomedical signal data of three fingertips of healthly volunteers. The testing results have shown that the developed device could successfully perform recording, analysis, and storage of biomedical data. Further, the recorded biomedical signals were processed by the software for filtering (removal noise) and extraction of spectrum signal using Fast Fourier Transform (FFT) function in the developed software. The results of FFT spectrum have shown that the dominan peaks in range 1 - 1.5 Hz according to the normal frequency of human heartbeat. Therefore, this device can potentially be developed as a simple, low power, computerized and portable device for importance of biomedical research and clinical practices.**

Keywords*— *Computerized, Optical Plethysmography, Processing and Recording Data, Biomedical Signal

I. INTRODUCTION

The Optical Plethysmography (OPG) is a non-invasive technique used to optically obtain the arterial blood volume changes in blood vessels close to the skin surface [1]. Currently, pulse oximeter is major application of OPG technique in medical devices.

Pulse oximeters are non-invasive instruments used extensively in hospitals and emergency rooms to acquire patient oxygen saturation (SpO_2) and heart rate (HR). The data of SpO_2 and HR are derived from a series of OPG signal measurement. The principle of measurement is based on the fact that spectra of oxy and deoxy-hemoglobin have different optical absorption at the wavelengths of 660 nm (red light) and 905 to 940 nm (near infrared light) [2]. The measurement based on optical detection has several advantages over other techniques such as the use inexpensive optical sensor (e.g., LED and photodiode), non-invasive, safe, and easy-to-use properties. Therefore, the design of pulse oximeter technology requires only a few opto-electronic component [3].

The modern probes in pulse oximeter utilize low cost semiconductor technology with LED and matched photodetector operating at the red and/or near infrared (NIR) wavelengths [3]. In generally, the probe is placed on a fingertips and can operate in transmittance mode. More recently, advances in opto-electronics and computer have significantly supported to the advancement of OPG instrumentation. Due to demand for low cost, simple, low power, easy-to-use and portable, the OPG technique has been object of an extensive research in the later decades [4]. Therefore, the development of computer based OPG devices for vascular analyzer and portable heart rate detector have been reported [5, 6]. In field signal processing, there are several reports of the developments of computer-based digital OPG signal processing and OPG pulse waveform analysis [9,10].

Currently, many research groups have been focused on the analysis of the OPG pulse waveform obtained from a single pair of infrared LED and photodetector [6]. The analyzing OPG signal waveform can give a valuable physiological information such as blood oxygen saturation, heart rate, and blood flow [2]. Because the OPG pulse is synchronized to each heartbeat, the pulse waveform can be used to assessment of cardiovascular system [11]. Many studies verify the high correlation between the RR intervals obtained from ECG signals and peak-to-peak (PP) intervals obtained from OPG signals [12]. The studies on dysfunction of microcirculation in skin have been also done, since the OPG signal is largely obtained on skin surface [13]. Meanwhile, the analysis of OPG signal waveform can provide information related to the diabetes due to the change of glucose level in blood volume [14]. Future, the detection of diabetes mellitus diseases can be non invasively carried out. In the other hand, the several of research groups was successfully verify that modulation of OPG signal amplitude related to respiration patterns [15,16]. Although the pulse oximetry is commercially available in the market, but the OPG signal waveform analyzer devices have not been widely produced [10]. In particular, the demand for low cost and low power devices are required by the developing world countries, where they have limited resources.

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Therefore, in this paper an optical plethysmography or OPG device has been designed, developed, and tested for the data aquisition and the processing of OPG signal waveform. The demand of low power is provided by USB system, so that requiring no external power adaptor. Meanwhile, in order to low cost in designing of OPG device the programmed microcontroller has been used to acquire the data of OPG signal using its embedded analogue to digital converter (ADC). The data of OPG signal is gathered and stored by a computer program for advanced signal processing. The designed system is simple, portable, low power (due to the device is powered by USB), automated (computerized), and allows the user to do the data acquisition in a clinical setting or biomedical research laboratory.

II. PRINCIPLE OF OPTICAL PLETHYSMOGRAPHY

Figure 1 shows a simple configuration of OPG signal measurement. The light beams illuminating on one side of tissue (e.g., a fingertip or earlobe) will be detected on the opposing side (transmission mode) after traversing the vascular tissues between the light source and the detector. Due to the cardiac cycle, the signal detected is pulsatile waveform. The OPG is based on the differences in light absorbance due to changes in blood volume of vessels during the cardiac cycle. During the cardiac cycle, the heart undergoes contractions (systole) and relaxations (diastole) creating pressure changes in blood vessels. No blood is pumped out when the heart is relaxing and refilling. To ensure continuous blood flow in the capillaries, arteries are functionally to serve as pressure reservoirs. Therefore, the arterial walls change in diameter during the different phases of the cardiac cycle.

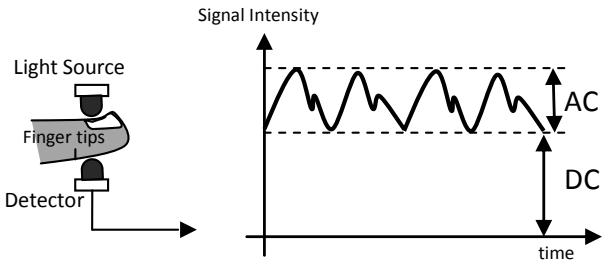

Fig. 1. The simple configuration of the OPG signal measurement on the fingertips

The OPG waveform is composed of the pulsatile (AC) and non pulsatile (DC) components due to the fluctuation of the arterial blood flow. The DC signal is static component that represents the composite absorbances of the non pulsatile portion of arterial blood, as well as of other tissue types such as veins, bone, muscles. The AC component is synchronous with the changes in blood volume each heart beat. Therefore, the amount of light absorbed by the tissues contains two significant aspects. The first is the constant absorbance, or DC component, influenced by the non-vascular tissues and residual arterial and venous blood volumes. The second is a modulated absorbance, or AC component, caused by the variations in arterial blood volume. The changes in arterial blood volume during heart activity are thus reflected as pulsations in arterial blood flow. Together, they affect the amount of light that illuminates the photodiode to produce a pulsatile waveform.

III. METHOD AND MEASUREMENTS

A. Hardware System

As shown in the functional block diagram in Fig. 2, set up of OPG experiment consists of an optical fingertip probe, an electronics module that hosts an analog amplifier, signal conditioning element, and microcontroller, and a software in personal computer (PC) that receives, processes, displays, and storage data from the circuit module. Basically, the probe consists of a near-infrared (NIR) LED transmitter and a sensor photodiode. In these paper, the transmittance - mode of probe is used in the experimental set up. The fingertip of sample (volunteer) was put between the NIR light and photodiode. A pair of transmitter-sensor is clipped on one of the fingertip of the subject in the optical probe. The beam of NIR light to photodiode is interrupted by fingertip, and then the transmitted NIR light is detected by photodiode as OPG signal. A custom and commercial finger probe of pulse oximeter was provided by Nellcor sensor [16], but it is few modified, so that the power of probe is provided by USB port.

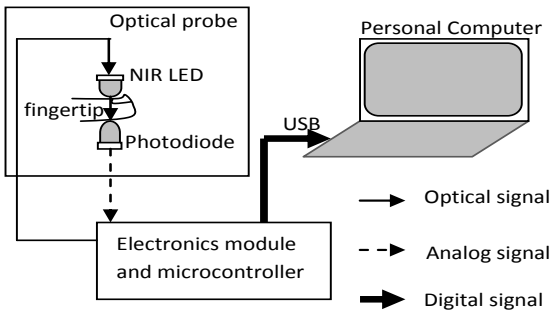

Fig. 2. Functional block diagram of experimental set up for the biomedical signal data acquisition

The LED emits NIR light (optical signal) to the fingertip of the subject and photodiode detects the transmitted light beam of the change of blood volume through the fingertip artery. The detected signal by the photodiode is called as analog of OPG signal and it undergoes further conditioning such as filtering and signal amplification. These signal is fed to electronics circuit module based on a microcontroller for the ADC process (digitalization). Then, the digital of OPG signal is transferred to PC through the USB system. A software is operated on the PC for importance of the controlled experiment set up and the advanced signal processing. In other hand, the USB is also designed to provide the power supply of the device so that the requiring no any external power supply.

Fig. 3(a) shows the photograph of the designed electronics module includes microcontroller, signal conditioning electronics, and USB system. Meanwhile, the whole of the developed device are shown in Fig.3(b). It is consist of the fingertip probe provided by Nellcor and powered by USB, electronics module, and USB connection to a personal computer (PC) unit. The probe contains a NIR LED as light source and a photodiode as photodetector. The subject of fingertip is clipped between them in a the probe system. The operation of the electronics module is based on microcontroller ATmega16 to process the data acquisition. Meanwhile, the communication between the developed device to PC are designed through USB system.

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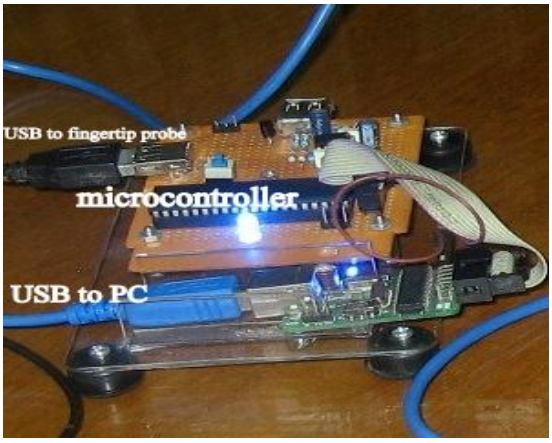
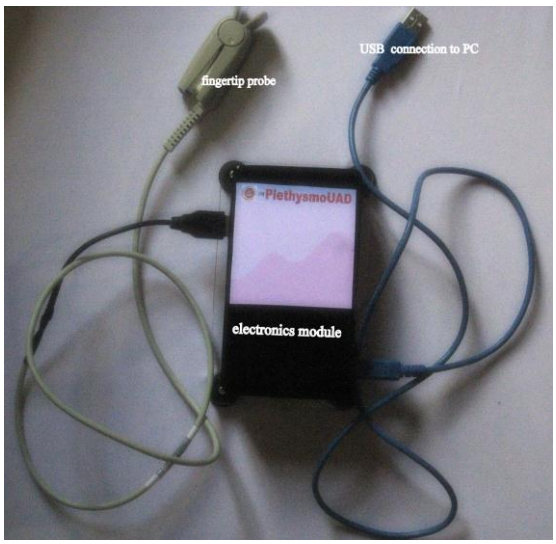


(a)



(b)

Fig.3. Photograph of (a) the designed electronics circuits module (without lid) and (b) whole of the developed device system

B. Software System

As shown in Fig. 4, a screenshot software for single-channel of OPG signal measurement has been developed and written using Delphi Visual Program. The software consist of four part namely for data acquisition, processing, storage, and display for the OPG signal in a PC screenshot monitor. The signal processing parameters such as , DC offset, the filtering data, and spectral of signal were also provided in the developed software. The monitor screenshot in the Fig.4 demonstrates the single-channel OPG software, set in the data acquisition mode. The stored data can be processed using the another software such as MATLAB Software.

C. Experiment Set-up

The designed and developed OPG device was tested and used to acquire the OPG data of left index fingertip from three subjects. In this testing, the subjects are healthy volunteers in condition. Selected subjects are male 41 year old, female 42 year old, and male 47 year old, respectively. The measurement protocol was used as follows: each subject in sitting condition, left hand was placed on the table, each subject was asked to relax and to take the most comfortable position, and the finger probe was attached to the left index fingertip. In order to keep the finger relatively motionless, the data acquisition process was carried out for short time measurement (10 seconds). The stable measurement is importance to reduce the any noise (artifact) on the obtained signal [9]. Fig. 5 shows the experimental set-up photograph of measurement process.

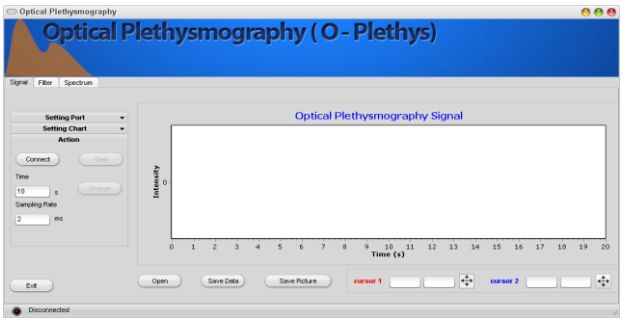


Fig.4. Screenshot software for the data recording and processing of OPG signal

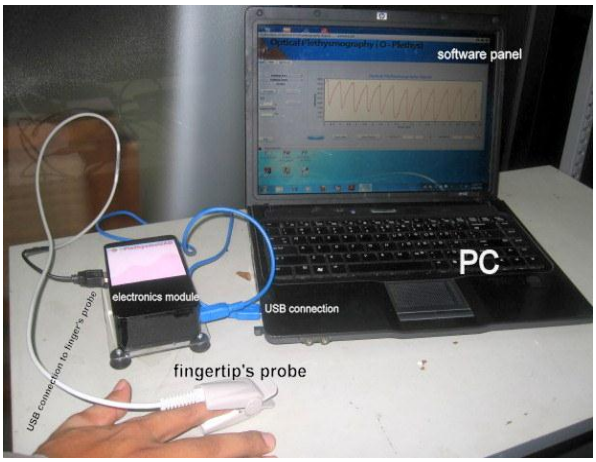


Fig.5. Photograph of the experiment set up for the OPG signal data acquisition of fingertip a healthy volunteer

IV. RESULTS AND DISCUSSION

The display for results of the data acquisition OPG signal are shown in Fig. 6 for (a) male 41 year old (b) female 42 year old, and (c) male 47 year old, respectively. The OPG signal is gathered by the software in time setting for 10 s, 500 Hz sampling rate, and DC offset (removal of DC component). In the Fig.6 shows that the 'AC' component (pulsatile) of the OPG signal is clearly determinated. Prominently, peak to peak (PP) of OPG signal pulse represent a heart's pump activity in human blood system. Moreover, the PP intervals of OPG signal have high correlation with the RR intervals in ECG signal [12]. Unfortunately, third of the obtained OPG signal are still contain the noise (unwanted high frequency). The noises in the OPG signal can be especially derived from the hand or finger movement [17]. In the Fig.6 (a) and (b), the obtained OPG signal are low noises (not so appear). However, in the Fig.6 (c) the signal is highly noise. The source of the highly noise of OPG signal is strongly suspected due to the hand finger tremor since the subject is older male (47 year).

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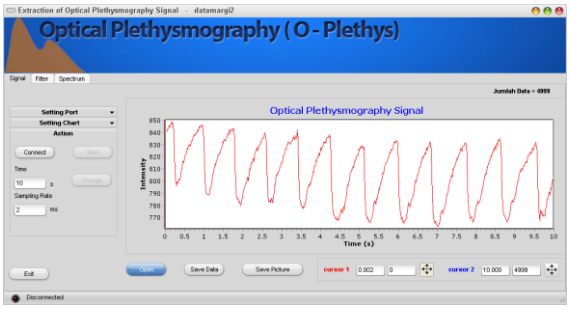
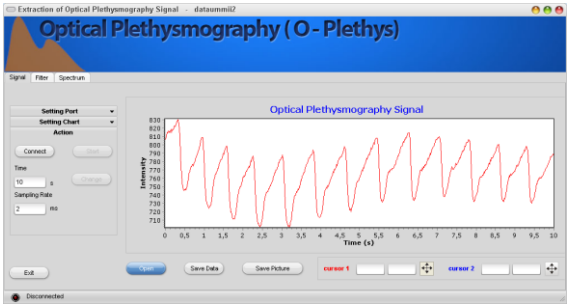


(a)



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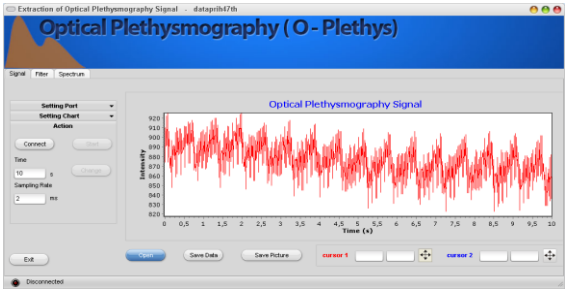
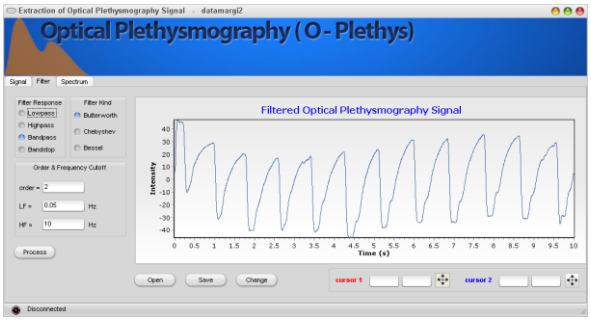


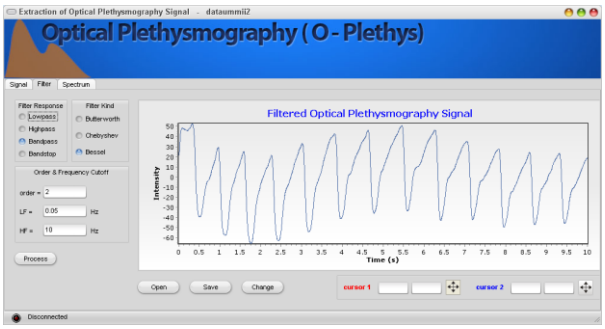
(c)

Fig.6. The results of data acquisition OPG signal are obtained from the testing on fingertip of healthy volunteers of (a) male 41 year old, (b) female 42 year old, and (c) male 47 year old, respectively

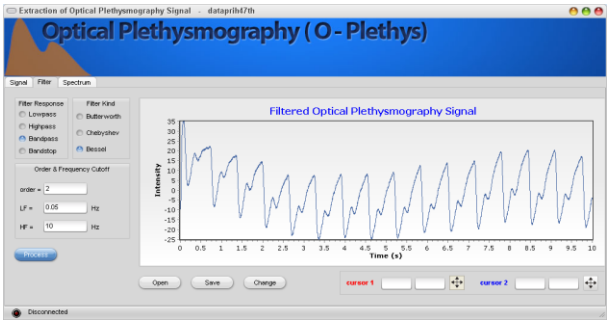
To reduce the noises, a 2rd order band-pass Butterworth filter with a cut-off frequency of 0.05 Hz (low frequency) to 10 Hz (high frequency) embedded in the software was applied to the obtained OPG signals. In addition the removal of either noise of low frequency or high frequency, the another objective of these filter application is to get the heart frequency (heart rate) range from the OPG signal [11]. Fig.7 shows the results of the filtered OPG signal of (a) male 41 year old, (b) female 42 year old, and (c) male 47 year old, respectively. Clearly, the filtered OPG signal is smoother than before filtering (Fig.6). Instead, the highly noise of OPG signal in Fig. 6(c) is dramatically smoother than before filtering.



(a)

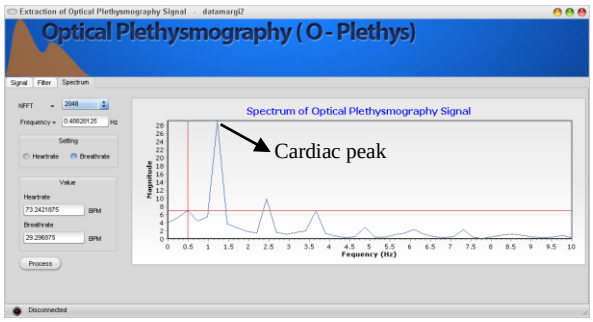


(b)



(c)

Fig.7. The results of filtered OPG signal are obtained from (a) male 41 year old, (b) female 42 year old, and (c) male 47 year old, respectively



(a)

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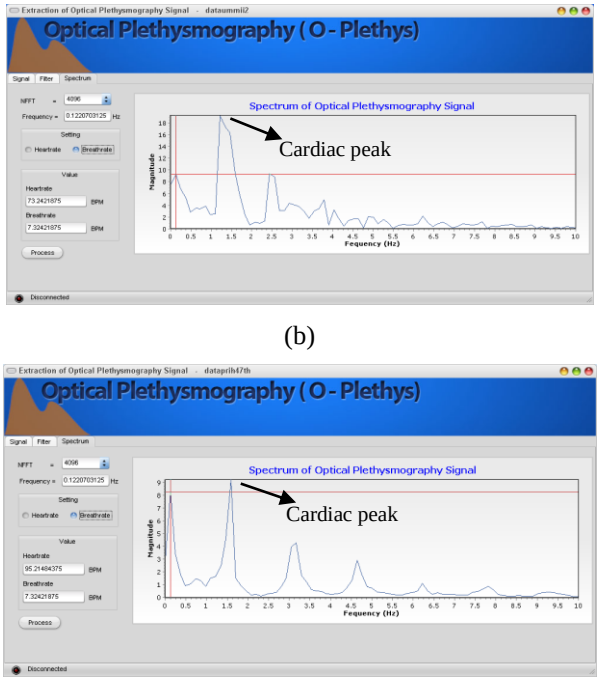

Fig.8. Frequency spectra of the filtered OPG signals are obtained from (a) male 41 year old, (b) female 42 year old, and (c) male 47 year old, respectively

To get the heart frequency (heartbeat) of the OPG signal, the embedded Fast Fourier Transform (FFT) algorithm in the software was applied to the filtered OPG signal. The frequency corresponding to heartbeat can be detected as a dominant peak from the spectral of OPG signal. Fig. 8 shows the results of FFT spectra associated with time domain of the filtered OPG signal in Fig.7. It can seen in Fig.7 that the dominant (magnitude) peaks were achieved consistently in the frequency range of heartbeat (cardiac peaks) where in the healthy adult subjects the frequency heartbeat about 1 – 1.5 Hz [11].

V. CONCLUSION

A simple and computerized system based on optical detection has been proposed as the device for data acquisition and processing of the OPG signal (biomedical signal) on fingertip of healthy volunteers. Due to the use a NIR-LED, microcontroller, and USB-powered the designed device introduces low power and portable. The microcontroller has been used as main component of the developed electronics module. The developed device was also equipped with the software for the data storage and advanced signal processing such as the data filtering and the FFT spectra. The obtained results have shown that the waveform of OPG signal accordance to the pulsatile of heart's pump activity on fingertip blood of healthy volunteers. Peak to peak on the displayed signal is clearly observed as pulse of cardiovascular activity. The results of FFT spectra also showed that the dominant peaks are in the frequency range of the healthy subject heartbeats. Therefore, this device can potentially be proposed and developed as a simple, low power, automated, and portable device for importance the biomedical research and the clinical practice.

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