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Non-Invasive Blood Flow Measurement Using Optical Sensor

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***Abstract*— Blood flow is the volume of blood that passes through a particular point in the circulatory system. Measuring the blood flow is of prime importance because it not just plays a very crucial role in understanding the functionality of heart but also other organs. It is a reflection of the cardiac activity and greatly helps in monitoring the same. The proposed methodology of blood flow measurement is based upon the acquisition of the photoplethysmography (PPG) signal from the body and by carrying out analysis on the signal the parameters related to heart like the stroke volume, heart rate and blood flow are calculated. The methodology involves design of a reflectance type of an optical sensor from which the photoplethysmography (PPG) signal is acquired. The transfer of the conditioned signal on the computer for further processing is accomplished by using a microcontroller. The signal is then analyzed and processed on MATLAB to determine the blood flow happening across the measurement site. Experimental analysis is then done by carrying out data collection on subjects of different age groups and gender and reliable conclusions are drawn. This method of measurement is advantageous when compared to other methods of blood flow measurement as it is a non-invasive technique and makes use of optical sensor which is rugged and simple in construction making the entire system easy to maintain.**

Keywords- photoplethysmography; cardiac output; blood flow; stroke volume; heart rate

I. INTRODUCTION

One of the important physiological parameter which speaks volumes about the working of heart and needs to be measured and monitored accurately is blood flow. Blood flow helps in transportation of nutrients, hormones, maintains body temperature, and also helps in the early diagnosis of diseases associated with various other body organs. Blood flow measurement techniques can be widely categorized into two types, invasive (surgical) and Non- invasive techniques [1]. Invasive techniques are those which require surgical intervention for measurements to be done whereas in the non-invasive techniques the measurements are done form the outside itself without any kind of surgical intervention. Thermal convection method of measurement is an invasive technique which is based upon the convection principle and measures the velocity of the blood which is later converted to the blood flow by multiplying it with the area of cross section of the artery across which the measurement is being done [2]. The electromagnetic flowmeter which is based upon the Faraday's law of electromagnetic induction also estimates the velocity of blood flow invasively. The other invasive methods include the dye dilution and Fick's method. These involve the injection of a dye/oxygen at a fixed rate. Having known the concentration of dye/oxygen in the blood and the infusion rate the flow is estimated [2]. The non-invasive technique which is by and large the most popular method in medical practices is the Doppler flowmeter. This technique of measurement is based on the Doppler's principle according to which when an ultrasound beam of a particular frequency passes from one medium to another there is a change/shift in the frequency of the beam coming out. This shift is referred to as the Doppler shift or the Doppler frequency which is proportional to the velocity with which the blood is flowing. This velocity is then converted to the blood flow by multiplying it with area of cross section of the artery across which the measurement is being done. The laser Doppler imaging technique of blood flow measurement makes use of the laser source build a laser Doppler image. This method has the advantage of being non-invasive but suffers from disadvantages of limited laser penetration, low resolution and longer measurement time [3]. The laser speckle technique of blood flow measurement has advantages like high resolution over the laser Doppler technique [3]. The other works carried out in this field involve Doppler blood flow velocity measurement using an implantable capacitive micro machined ultrasonic transducer (CMUT) array which involves implantation of CMUT array into the tissue causing tissue disruption which makes it a invasive technique of measurement [4]. The proposed method of blood flow measurement is a non-invasive technique which is based upon the processing of the PPG signal acquired from the designed senor and calculates the blood flow.

The rest of this paper is organized as follows. Section II gives a complete overview of the proposed methodology with study of each of the stages involved. Section III gives the details of experimental results along with the observations made. Finally, section IV concludes the paper with the future scope.

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II. Proposed Approach For Measuring The Blood Flow

The proposed method of blood flow measurement is based upon the acquisition of the photoplethysmography (PPG signal). With each heartbeat, a pulse is generated due to the cardiac activity which radiates towards the peripheral parts and causes changes in the diameters of arteries because of the blood volumetric changes that happen [5]. The block schematic of the proposed methodology of blood flow measurement is as shown in the figure 1. This involves the design of a reflectance type of PPG sensor using LED as the source and OPT 101 as the optical detector. The signal acquired from the sensor is then given to the signal conditioning circuitry to make it suitable for the further processing. The conditioned signal is then acquired on to the computer via the microcontroller. The processing of the signal is carried out on MATLAB and the related parameters are estimated which are then displayed on to the designed GUI.

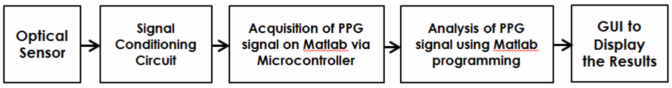

Fig. 1. Block schematic of the proposed methodology

The details of each of the blocks can be studied as different stages. The various stages involved in the proposed methodology are stated below.

A. Stage 1- Sensor Design

The figure 2 shows the optical sensor designed during the course of the work which is used to acquire the photoplethysmography (PPG) signal from the body.

Fig. 2. Optical sensor developed

This is a reflectance type of PPG sensor, which means that the detector detects the light that is reflected by the blood stream. This consists of two LED's of 660nm (Red LED) and 860 nm(IR LED) as sources of light. Each of the sources is built with a separate bank of current limiting resistors to check as to which current limiting resistor gives a definite and acceptable PPG waveform and is freezed upon that value. The detector used is OPT 101 which is an 8 pin monolithic photodiode which converts the light reflected by the blood stream into corresponding voltage. The voltage increases linearly with the increase in the light intensity falling on the detector. The combination of a diode and an on chip transimpedance amplifier eliminates the problems occurring due to leakage current errors, noise pick up. The basic principle of operation of the senor is that when the fingertip is placed on the sensor, the source emits the light into the blood stream and the detector detects the light that is reflected by the blood stream. Whenever the blood flow through that part increases the amount of light reaching the detector reduces and vice versa. These changes results in the signals called PPG signals/pulses from the fingertip. It is this PPG signal that carries a lot of useful diagnostic information which needs to be explored to calculate the blood flow [6].

B. Stage 2- Conditioning of the Acquired PPG signal

The PPG signal so obtained from the sensor requires appropriate conditioning since it is a bio signal which is of low amplitude and is prone to noise and disturbances due to movements. The signal conditioning part consists of filters and amplifiers [7].This conditioning makes the PPG signal makes it suitable for the further processing and analysis. The block schematic of the steps involved in conditioning the signal is as shown in figure 3.

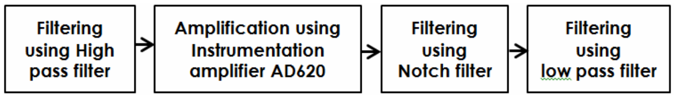

Fig. 3. Steps involved in conditioning the PPG signal

The steps involved are:

- The output from the sensor is first given to the high pass filter to filter out all the low frequencies in the signal.
- From the high pass filter the signal is then passed on the instrumentation amplifier AD620 for further amplification.
- Amplified signal is then given to the Notch filter.
- From the notch filter the signal is directed towards the low pass filter to filter out all the high frequencies in the PPG signal [8].

The signal after it is conditioned is observed on the DSO. The PPG signal observed on the DSO is as shown in figure 4.

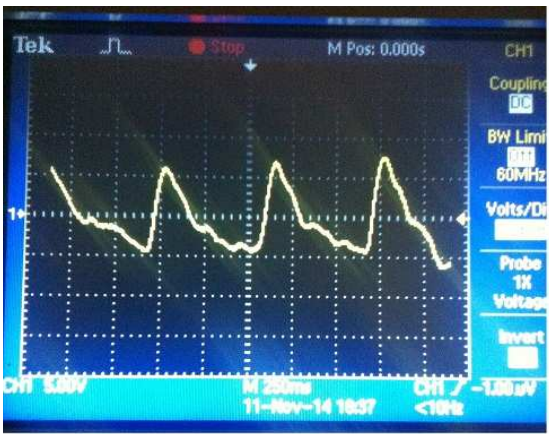

Fig. 4. PPG signal on the DSO

PPG signal for both the sources is obtained by using different current limiting resistors. The value of resistor giving a proper acceptable PPG waveform is finalized. For the red LED the value chosen is 2K ohms and for IR LED the value is around 3.45K ohms. Once these steps are applied to the signal it becomes much more suitable for the further processing and data extraction.

C. Stage 3- Acquisition of the PPG signal on MATLAB

The conditioned PPG signal is acquired on to MATLAB via the micro controller ATmega 8535. ATmega 8535 is a low power, high performance 8- bit microcontroller with RISC architecture. The microcontroller has 8K bytes of In-system programmable flash memory and 512 bytes of EEPROM and SRAM. The operating voltage range of the microcontroller is 4.5 volts to 5.5 volts. It has 32 powerful instructions with 32 registers and has an endurance of 10,000 write/erase cycles. The ATmega 8535 kit designed for the acquisition is as shown has the on chip ADC, USART, sample and hold circuit, timers/counters etc. The microcontroller kit designed for the acquisition is as shown in figure 5.

Fig. 5. AVR ATmega 8535 kit

The steps involved in this stage of acquisition of data on computer are as depicted in the figure 6.

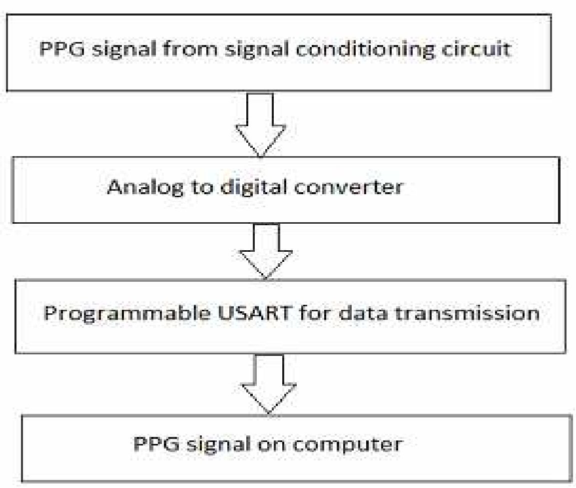

Fig. 6. Flow of steps involved in acquisition

The photoplethysmography signal from the signal conditioning circuit is first given to the analog to digital converter (ADC) via the port A of the microcontroller. The ADC is an 8 channel 10 bit successive approximation ADC. It converts the analog signal into the digital signal. The sample and hold circuit ensures that the input voltage to the ADC is maintained at a constant level. The digitized PPG signal from the ADC is transferred to the computer via the programmable USART from port D of the microcontroller. The PPG signal obtained from the microcontroller is plotted on MATLAB and is as shown in figure 7. The signal can be divided into two phases: Anacrotic phase which is the rising edge of the pulse and talks about the contraction of the heart whereas the falling edge is referred to as the Catacrotic phase which refers to the diastole/relaxation of heart. In the Catacrotic phase, a notch called the dicrotic notch also is seen which is due to the sudden shut down of the aortic valve of heart [9].

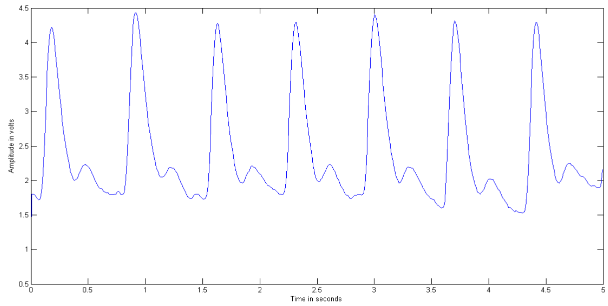

Fig. 7. PPG signal plotted on MATLAB

D. Stage 4- Analyisis of acquired PPG signal on MATLAB

It is this digitized PPG signal that carries useful information which needs to be extracted appropriately. In the work that is carried out, blood flow is the parameter which needs to be derived from the signal. The dependent parameters that are derived from the signal to obtain the blood flow are; stroke volume and heart rate.

The stroke volume is the amount of blood that the heart pumps every beat. Precisely this stroke volume can be obtained by calculating the area under the curve of the PPG signal using MATLAB functions. By averaging out the area for a number of pulses obtained for a particular subject the average area under the curve can be obtained. This averaged out area basically increases the accuracy of calculation. The average area so obtained is divided by the aortic impedance which is the patient calibrator Z_{ao} to obtain a quantity approximating the stroke volume. The value of Z_{ao} is found to be 0.140 for adults [1]. The instantaneous heart rate is derived as the inverse of the time lapse between the onset of ejection for every two consecutive pulses. Finally, the blood flow at the site of measurement is computed in liters/min as the instantaneous product of stroke volume and heart rate [1].

The blood flow so calculated tells about the volumetric changes happening across the site of measurement and is an important parameter for early diagnosis of diseases, monitoring functioning of heart.

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III. Experimental Results

A graphical user interface is designed to display the parameters calculated from the analysis stage along with the PPG signal. When the subject places his/her index finger on the designed sensor, and runs the code in MATLAB it displays the GUI where upon clicking the start button, the acquisition of the PPG signal from the subject's finger begins and after the completion of 5 seconds acquisition time the heart rate and blood flow across the measurement site are displayed in beats per minute and liters/min respectively. The GUI displays the PPG signal of the subject on one side and the calculated parameters on the other. It also shows the elapsed time of 5 seconds which is basically the recording time. The figure 8 shows the GUI with the PPG signal of a subject and the calculated parameters.

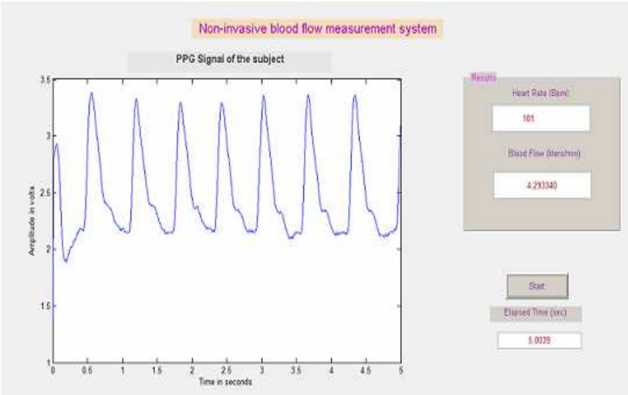

Fig. 8. Designed GUI to display the data

As seen in figure 8, the subject recorded a heart rate of 102 beats/minute and the blood flow of 4.2 liters/min.

The data so acquired speaks volumes about the subject's heart functionality. In order to study the performance of the system, the experiment of estimating blood flow and heart rate was carried out on 40 subjects of different age groups. It was observed form the data collected that the changes in the blood flow happening across the measurement site showed a decreasing trend as the age group increased.

IV. Conclusion And Future Work

The PPG signal acquired has a good amount of diagnostic information which helps assess the functionality of heart and other organs. PPG can be applied in many different clinical settings, including clinical physiological monitoring (blood oxygen saturation, heart rate, blood pressure, cardiac output and respiration), vascular assessment (arterial disease, arterial compliance and ageing, endothelial function, venous assessment, vasospastic conditions, e.g. Raynaud's phenomenon, microvascular blood flow and tissue viability) and autonomic function (vasomotor function and thermoregulation, blood pressure and heart rate variability, orthostatic intolerance, neurology and other cardiovascular variability assessments).

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