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Development of a Reflectance Photo Plethysmograph for the Estimation of Pulse Transit Time

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Abstract*— *Pulse transit time is considered as a vital physiological parameter for assessing several cardiac disorders. It was proven that pulse transit time provides accurate diagnosis in estimation of blood pressure. In this paper, we demonstrate an instrumented hardware for the development of reflectance photoplethysmograph. The designed system uses two reflectance sensors at two different arterial locations for the estimation of pulse transit Time. Developed hardware is used for the calculation or estimation of the pulse transit time from the two photoplethysmograph signals obtained, one from the wrist and the other from the finger respectively, estimated pulse transit time is compared against the gold standard equipment, the results indicate the estimated values are within the limits of medical diagnostic values.

Index Terms—Photoplethysmograph, Pulse transit time, Sensors, Reflectance.

I. INTRODUCTION

The number of persons suffering from cardiovascular diseases is on a rise in this stressful lifestyle. Patients are being monitored such that a potential serious and life-threatening situation can be detected in time of emergency for medical doctors to act. Diagnoses of such ailments are often complicated due to rapid and dynamic variation in the associated parameters of the individual under examination. Patients suffering from, for example heart diseases need to be continuously monitored for their cardiovascular system i.e. heart and blood function.

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To enhance the life quality of these patients, monitoring units should be as mobile, discreet, and autonomic as possible such that patients will not feel a burden by being attached to units making a regular daily life impossible. They should also feature wearable and wireless communication for transmission of data for evaluation by a professional and to send out emergency signals. Mobile and autonomic solutions would be of great benefit for people involved in traumatic accidents and for battlefield soldiers.

In this case rescuers attach monitoring units to the wounded patients such that their condition can be followed during transport to hospital or by doctors ready to receive the patient at the hospital. Monitoring fire fighters, combat soldiers, rescues workers, or just professionals performing tasks that are physically exhausting could help saving lives by warning the professional or the supervisor such that action can be taken before a collapse occurs, hence there is a very robust and demanding situation for the development of wearable medical equipment[12]. Medically, it is important to monitor change in the blood volume, which is estimated using PPG in which light of suitable wavelength (between 600 nm to 1300 nm) is passed through a body part and the resultant scattered or transmitted light is measured with the help of a photo detector. The detected light is directly proportional to the pulsating volume change in the blood [8]. During each cardiac cycle the heart pumps blood to the periphery. Due to pulsatile pumping of heart, the blood volume at any part of body during a period of time varies. These variations can be detected using PPG. PPG can be used to monitor the heart rate, cardiac cycle, breathing, hypovolemia. The implementation of this work helps to overcome the complexity of distance measurement and also reduces the use of ECG for the measurement of Pulse transit time. A unique sensor architecture is employed to estimate pulse wave velocity (PWV), this method is applied to calibrate peripheral pulse transit time measurements to arterial blood pressure. This prototype assumes laminar blood flow from the heart chamber to the fingertip through a rigid pipe, the artery [1, 6] and estimates the difference in pressure between the two sites from the same artery. It was suggested that pulse wave velocity can be estimated using pulse transit time measured from two different arterial locations [1].

Many wearable mobile monitoring systems are available today such as Bionomadix and oximeter PPG sensor shown in Fig 1.1 and fig 1.2.

For patients who need monitoring without affecting their normal life, such systems are required. For traumatic patients, rescuers need not have to attach all the sensors and carry the boxes along with the patient. A small autonomous system would make the rescuers' work simpler, and they could focus on the patient.

Fig1.1 Bio-Nomadix Wireless device

Fig. 1.2 Wearable Pulse Oximeter

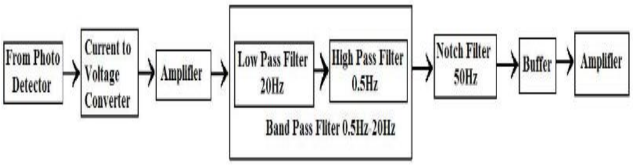

Fig. 2.1 PPG Block diagram

II. MATERIALS AND METHODS

The designed PPG circuits were used to acquire signals from different body locations, in this work we have used the primary location as wrist and finger, and we made sure that the diagnostic information of the PPG is not lost by enclosing the sensors in a black tape. These circuits are interfaced to the computer using a DAQ PCI-6104 and PPG data is acquired in the system. These data are further used in the MATLAB program to calculate the PTT. The pulse transit time obtained is compared with a standard BIOPAC device.

A. Hardware Design

The figure 2.1 illustrates the block diagram of the developed PPG system, the hardware consists of a low pass Butterworth filter and a high pass Butterworth filter (2nd order) with lower cutoff frequency of 20Hz and higher cutoff frequency of 0.5Hz respectively. The signal is pre-amplified with a gain of 1000. Further processing of signal is performed by converting analog signal to digital signal with a notch filter being implemented in the final stage to remove 50Hz power line noise[11].

B. Design Criteria

In this work lot of care is taken to reduce the discomfort of the wearer, the sensor must be thin and unobtrusive. If possible, the sensor can be made in decorative manner such that it is not obvious to the others. Besides that, the sensor should not be obtrusive to the wearer's daily activities. In most cases, noise and signal would be mixed up during acquisition, this was eliminated by attaching the sensor rigidly to the finger, ulnar artery and digital artery were selected for unobtrusive data acquisition. The shielding of the sensor is difficult due to the sensitivity of the sensor to light. To reduce the noise caused by the ambient light, photodiode has to be optically shielded from it. We have used a rigid flexible black tape to protect the sensors from unwanted light which in turn helps in avoiding unwanted voltage[5,8].

C. Circuit Design

Photo Transmitter:

Red LED ELM4000 manufactured by measurement specialists with current and voltage rating of 20mA and 2.3V respectively. IR LED EL23G manufactured by Kodenshi with current rating and voltage rating of 60mA and 1.6V respectively.

Photo Detector:

EPM4001 manufactured by measurement specialists and HP307R2 manufactured by Kodenshi are used to detect Red light and IR light respectively. OPA-07 is used as an OPAMP which is operated with dual power supply +5V to -5V.

D. DAQ interface (tool used)

Measurement Computing PCI-6014 DAQ is a 16-Channel, 16-bit, 200 kS/s DAQ Board with 8 Digital I/O and Two 16-Bit Analog Outputs which is used to interface the PPG signals to the computer along with TracerDAQ software included for acquiring and displaying data and generating signals. The DAQ module samples the signal at the rate of 100sample/sec.

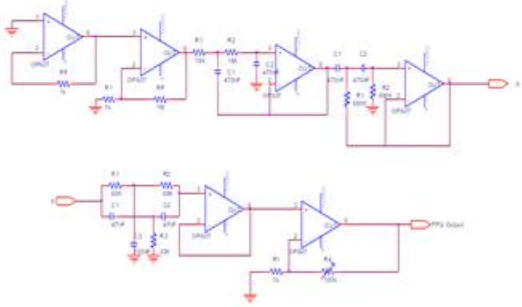

Fig.2.2 Total PPG Circuit

III. RESULTS

It compares the resultant PTT values obtained from R peak derived ECG- finger PPG with respect to wrist PPG – finger PPG. It also shows the results obtained from the hardware developed and the software code written in MATLAB which is implemented on the PPG signals obtained from the developed hardware[4].

A. Hardware development

The hardware developed for the Photoplethysmograph is put together on the breadboard and then tested and transformed to PCB for the essential parameters data collection and the results are as follows:

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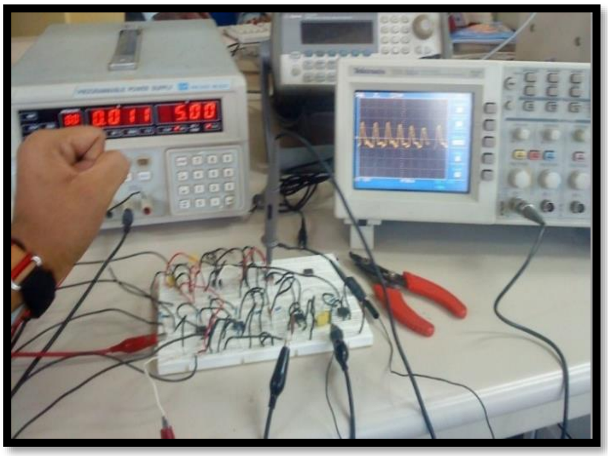

Fig.3.1 Shows the reflectance PPG signal obtained from the wrist which is obtained from the instrumented hardware developed on breadboard is displayed on the CRO

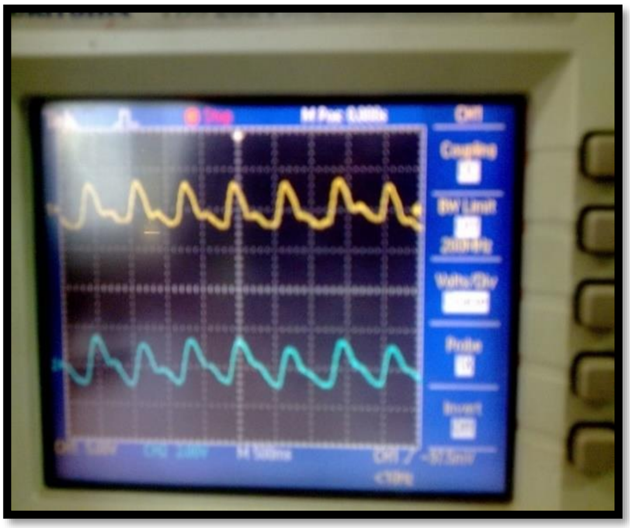

Fig.3.2 Shows the Photoplethysmogram signals obtained from ulnar (yellow) and digital (blue) artery respectively.

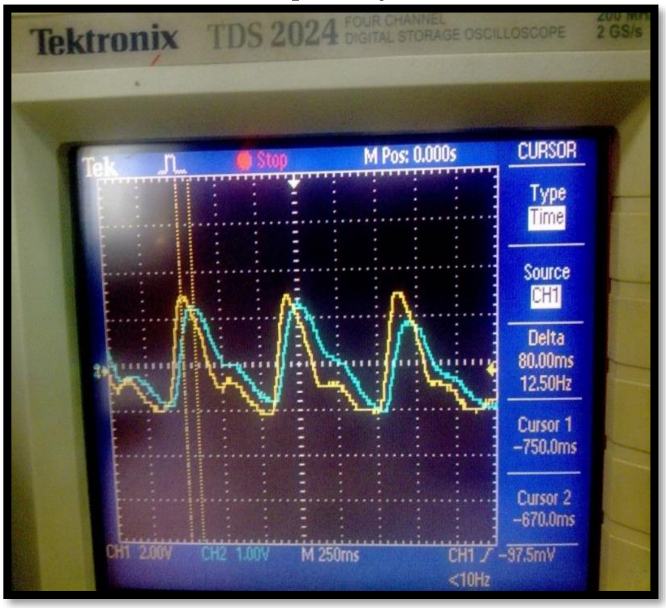

Fig.3.3 shows the overlapping of ulnar(wrist) and digital

(finger) Photoplethysmogram, which shows the time difference value measured as 80ms.

B. Hardware interfacing with DAQ

Fig.3.4: Snapshot of acquiring PPG signals using Daq and the software TraceDAQ

C. PTT calculation using MATLAB

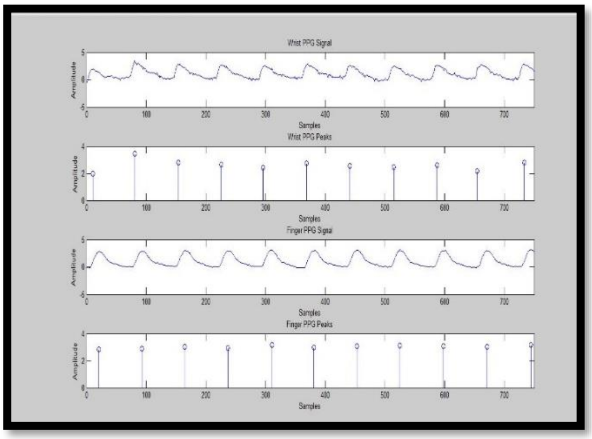

Fig.3.5 Represents the peaks of different PPG signals filtered

Name	Pulse tansit time (Wrist-Finger) ms	Dst(Wrist-Finger) cm	Pulse wave Velocity(Wrist-Finger) m/s
Subject1	80	20	2.5
Subject2	110	22	2.0
Subject3	70	18	02.571
Subject3	90	23	02.555
Subject4	80	18	02.25

Table 1 The table depicts the particulars collected from the different subjects for the estimation of Pulse wave velocity

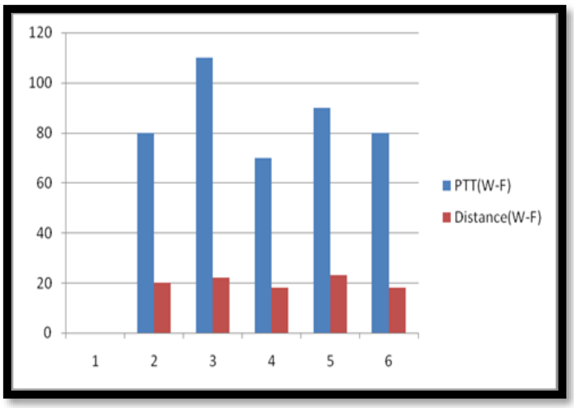

Fig.3.6 Graph plot of Distance from WRIST-FINGER and PTT obtained from Mat lab algorithm

These are the results obtained from the designed PPG wrist and PPG finger circuits interfaced with DAQ and by calculating PTT using MATLAB.

D. PTT calculation by interfacing circuit with BIOPAC

Fig.3.7 Snapshot of BIOPAC showing PTT of PPG wrist and PPG finger with result 107 milliseconds

Table.2. Details of particulars obtained from 5 different subjects

Name	PTT (E-F) ms	PTT (E-W) ms	PTT (W-F) ms	PWV (E-F) m/s	PWV (E-W) m/s	PWV (W-F) m/s
Subject 1	330	250	80	2.57	2.6	2.5
Subject 2	360	270	90	2.5	2.592	2.444
Subject 3	300	230	70	2.666	2.727	2.571
Subject 4	350	260	90	2.714	2.884	2.555
Subject 5	300	230	70	2.666	2.696	2.571

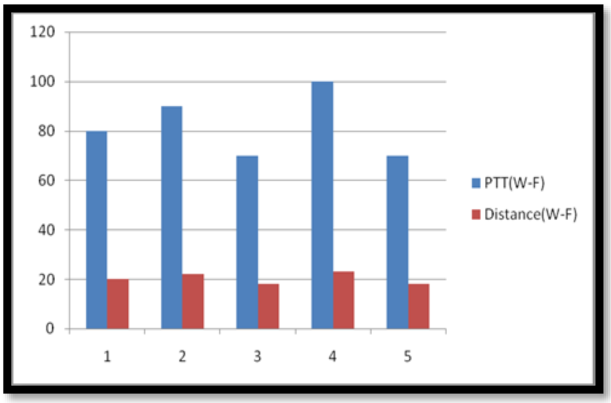

Fig.3.8 Graph shows the Pulse transit time variation with respect to ECG, wrist PPG and PPG finger

IV. CONCLUSION

The outcome clearly show that PTT can be estimated using Photoplethysmograph circuits, one of them being the wrist and other finger circuit which replaces the utilization of Electrocardiograph and prevents the need for error corrections associated with hydrostatic pressure changes when hand movements were performed during daily activities[2]. The Hardware unit developed, and software algorithm implemented to calculate Pulse Transit Time is validated using the standardized BIOPAC instrument, the validation results were satisfactory for the estimation of PTT from wrist to finger. In future, in order to reduce the size and also to make the equipment wearable, we intend to implement hardware by integrating xigbee module for unobtrusive data transmission.motion induced pressure variation changes will be compensated with a Gyroscope and pressure sensor integration, one located in the sensor place on the digital artery housing and a second located at the ulnar artery. There will be variation in pressure with respect to height from heart which will show its effect in calculating pulse transit time so, in order to counter act, the implementation of adaptive hydrostatic pressure. This project will help in assessing the pulse wave velocity and pulse transit time estimation, which will be a valuable marker for pre-clinical assessment of cardio vascular health.

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