ORIGINAL ARTICLE

Towards a Simple System for Indicating Temporal Variations in Blood Pressure

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Abstract

Blood pressure is an important physiological parameter to be monitored. For several medical conditions, it is important to quickly know the rise or fall in blood pressure. While researchers are working to evolve a reliable continuous non-invasive arterial pressure (CNAP) monitoring devices based on sophisticated signal processing with various technologies including Peñáz principle & pulse wave velocity (PWV); we present a very simple system to continuously indicate the variations in blood pressure. Using the typical shapes of the pulse wave obtained by infra-red photoplethysmography (PPG) from brachial and radial artery, we estimate the changes in pulse transit time (PTT). This change is effected onto a change in tone of an audio beep. The simple circuit was assembled and tested. The details are presented in the paper.

Keywords— pulse wave velocity, pulse transit time, blood pressure, differential amplifier, photoplethysmogaphy

الملخص

ضغط الدم هو المعلومة الفسيولوجية المهمة التي يتعين رصدها عند تشخيص اي مرض ، فمن المهم سرعة معرفة ارتفاع أو انخفاض ضغط الدم عند العديد من الحالات الطبية.

في حين أن الباحثين يعملون على تطوير أجهزة رصد موثوق بها على أساس إشارات مستمرة و متطورة

لقياس الضغط الشرياني. يحتوي جهاز الرصد المطور في هذا البحث علي مختلف التقنيات بما في ذلك مبدأ بيناز وسرعة موجة النبض

يقدم هذا البحث نظام بسيط جدا لمواصلة رصد الاختلافات في ضغط الدم عن طريق الأشكال النموذجية للموجة النبضية التي تم الحصول عليها عن طريق الأشعة تحت الحمراء (فوتوبثيزموغرافي) من العضد والشريان الكعبري،

ومن ثم نقوم بتقدير التغييرات في وقت عبور النبض . يتم تنفيذ هذا التغير على اختلاف في نغمة صوت صافرة الجهاز . تم تجميع الدائرة البسيطة واختبارها. التفاصيل هي المقدمة في هذه الورقة.

I. INTRODUCTION

Blood pressure is the pressure exerted by the blood on the walls of vessels it flows through. It can be measured in different parts of the body using invasive or non-invasive techniques depending on the availability of access to vessel or underlying medical requirements. Routinely, it refers to the arterial peak (systolic) and lowest (diastolic) pressures exerted in arteries as the heart pumps the blood. As per WHO guidelines, the blood pressure is measured in the brachial artery held at heart level [1]. The gold standard instrument for non-invasive measurement of blood pressure is sphygmomanometer used in ausculatory method. The ausculatory and the other method, called oscillometric method, both involve inflating a cuff tied around the arm to occlude the brachial artery of the subject. Both the methods are widely used for cardiac screening as well as monitoring for various cardiovascular and other health issues. Intermittent obtaining of blood pressure with either of these methods is, in general, sufficient and good indicator for most cardiovascular diseases. The commonest cardiovascular issue, Hypertension or high arterial blood pressure, is routinely screened and monitored by either of these methods.

The blood pressure of an individual keeps on varying in response to various physiological stimuli. This is an adaptive and necessary response of body. However, there are certain medical conditions [2] like critical pregnancies, certain surgeries, cerebrovascular diseases [3], etc.in which blood pressure is required to be monitored rather continuously. Under certain unstable hydration conditions (due to dialysis or pharmaceutical effects) also, regular and continuous non-invasive blood pressure can avoid acute conditions [4]. Even gross indication of continuous variations in blood pressure can also be useful in most cases. The standard non-invasive method of occluding the artery and measuring blood pressure does not lend itself well to repeated or continuous measurements. Although, some situations may warrant invasive monitoring but, wherever possible, non-invasive (without using the cannula or pricking the skin) monitoring would be preferable. It not only drastically reduces the chances of infection but also is convenient for both the patient and the caregiver. Researchers have tried several methods towards continuous non-invasive measurement of blood pressure. Finapres equipment [5] works on Peñáz principle based on exerting an opposing force on the finger cuff to prevent physical disruption of blood pulse. The emerging methods based on Pulse wave velocity (PWV) or pulse transit time (PTT) also promise to become more convenient alternatives to the occlusion methods [6].

The blood pumped by heart rushes into the arteries as a pulse. This mechanical wave of pulse spreads into complete vasculature every cardiac cycle. Stiffening of arteries and reduction of radius of arteries leads to increased blood pressure. Higher blood pressures have been related to increased pulse wave velocity [7]. Standard method of pulse wave velocity measurement consists of measuring the pulse wave recorded by one of the several available methods at carotid artery and at femoral artery (ca-PWV) [8].The PWV is given as the physical distance between the two sites of measurement per unit time elapsed (pulse transit time) between pulse arrival times at two sites. This PWV method of estimating blood pressure and underlying thickening of arteries requires availability of trained technician and a relatively complex hardware. For measuring blood pressures it requires elaborate calibration and does not easily lend itself to automated measurements [7].

For meeting the situations where the objective is only to grossly estimate the temporal variations in blood pressure, we propose a simple technique using conveniently obtained pulse waveforms from the arm of the subject. It avoids precise identification of pulse arrival times and calibration. A simple circuit based on the technique was designed, assembled and tested. The developed system indicates the temporal variations of blood pressure as audio signals. The following paragraphs elaborate this. It can further be developed into an unobtrusive ubiquitous non-invasive blood pressure measurement device.

II. THEORY

As indicated above, increased blood pressure shows as heightened pulse wave velocity. Also, PWV is

$$PWV = \lfloor / PTT \qquad (1)$$

Where $\lfloor$ = physical length of the arterial segment and PTT is the pulse transit time. Formally, PTT is given as difference in pulse arrival times at proximal and distal ends of artery. So, the main goal for indicating blood pressure continuously is to continuously monitor the pulse arrival time at two points of an artery. This is either done manually or requires sophisticated processing. To circumvent this, we can exploit the typical shape of pulse waveforms. Using the basic idea of pulse shapes at different body parts from the literature and based on convenience of wearing and maneuverability of device to heart levels, the brachial artery and the radial artery were chosen as two suitable points. Palm and fingers, although equally convenient, were not selected as the pulse waves at these points show significant reflected waveforms and were considered not suitable.

Typical pulse pressure waveforms obtained at brachial and radial artery are shown in fig 1 below. The times corresponding to point A and B indicate the pulse arrival times at respective locations. The time gap between these two time points indicate the pulse transit time. For measuring this PTT, we need to identify and locate the points on the two waveforms. This would evidently require complex signal processing.

We propose to simply take the difference of the two pulse waveforms with a differential amplifier and subject the output to a dynamic threshold, such that the output is

$$Vo = \begin{cases} V1\text{-}V2 & \text{if } (V1\text{-}V2) > 0.3 * \max.(V1\text{-}V2) \\ 0 & \text{otherwise.} \end{cases} \qquad (2)$$

where, V1 and V2 are the pulse waveforms.

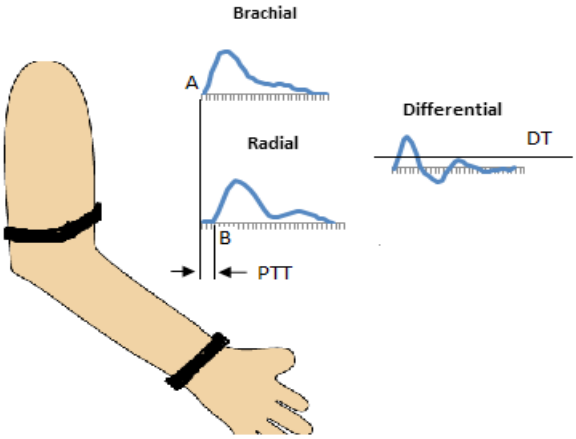


Fig1. Pulse Waveforms

This effectively gives us a clean workable signal which is positive for a time equal to two third of sum of PTT and upstroke time of distal pulse waveform. If tVo' and tVo'' indicate the zero crossing times of the signal Vo, then the time for which the Vo remains positive, TVO is given as,

$$TVO = tVo' - tVo'' = 2/3\ ((PTT) + (\text{upstroke time})) \qquad (3)$$

Now let the waveforms V1 and V2 shift relatively due to change in blood pressure. The zero crossing Times of Vo shall vary accordingly. For noting the change in blood pressure we notice the change in TVO. The change, Δ TVO from equation (3) above would be

$$\Delta TVO = 2/3\ ((\Delta PTT) + (\Delta.\text{Upstroke time})) \qquad (4)$$

As, the upstroke time of pulse waveform relates to the ventricular compression time, it can be safely approximated to be constant. So, Δ .Upstroke time = 0. Thus, we get Δ TVO proportional to Δ PTT. This fact is exploited for indicating changes in blood pressure. In order to keep the system simple, analog processing was used. The indication is given in terms of an audio tone, the frequency of which varies with the change in TVO times. This scheme is shown in the block diagram (Fig 2) below.

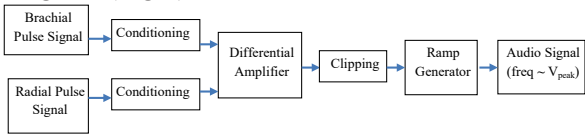


Fig 2. Schematic Diagram of the Technique

III.IMPLEMENTATION AND TESTING

A. Sensor Design

Researchers have used different methods to detect the pulse wave and to analyze the pulse wave velocity [9]. Researchers have also analyzed the contour of pulse wave for different clinical estimates [Predicting Arterial Stiffness From the Digital Volume Pulse Waveform, A knowledge-based approach to arterial stiffness estimation using the digital volume pulse.]. In our design, being primarily interested in arterial pulse waveform, Infra-red PPG was selected for its convenience and suitability based on [6]. Of the two, reflection and transmission modes, reflective sensors are much more unobtrusive and amenable to different body locations. So, two reflective PPG sensors were decided.

We used IR LED (Kingbright KP-1608 with peak λ 940nm and viewing angle 120°) and phototransistor (Vishay VEMT-2020X01, 790 to 970nm with half sensitivity angle = 15degrees) mounted on small circuit board. The LED was placed in the middle and photodetector was mounted at a distance from it. This test-sensor was applied to wrist and arm using a band and the signal obtained. This was repeated for different source –detector distances. Based on test data, two identical sensors were then made with a source – detector distance of 8mm.

B. System Design

The system was implemented on a specially designed circuit board and assembled using hand soldering. The PPG signals obtained from sensors are band-passed between 0.5Hz to 20 Hz. These were then amplified using Operational Amplifier (LM348 with variable gain resistor). The amplified signals were fed to the two ends of differential amplifier (THS 4121, Texas Instruments). The output of the differential amplifier is fed to a peak holding circuit and three resistances are used to get one third of the peak signal. Simple comparator

circuit (using LM348) applies this threshold to the signal. Output of the comparator powers (gates) a RC ramp generator. So, longer the PTT the longer the gating and so, greater the ramp output. The peak of the ramp output, with peak holding, decaying circuit and Voltage controlled oscillator (VCO, MAX 038 of Maxim Integrated), is translated into an audio beep whose frequency changes with PTT. The tone of this audio beep was thus indicative of changes in blood pressure of the individual.

C. Test Set-up

The two sensors were placed at brachial artery and radial artery at wrist respectively and secured with bands. The sensor outputs were given to the designed circuit assembled on a printed circuit board. The output audio beeps were listened to carefully for testing the system. The amplified sensor outputs and the clipped output were tapped out to a custom built acquisition system consisting of three ADCs sampling at 300 Hz in round robin fashion and of microcontroller (AVR evaluation kit) interfaced to PC via serial port. A software program was made to display the waveforms in real time. The Fig 3 below shows the test set up and fig 4 shows a random screenshot of output.

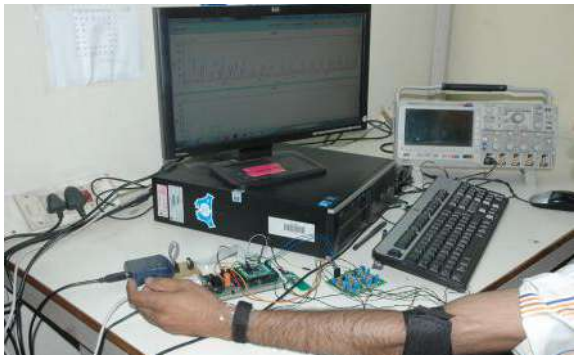


Fig 3. Test Set-up

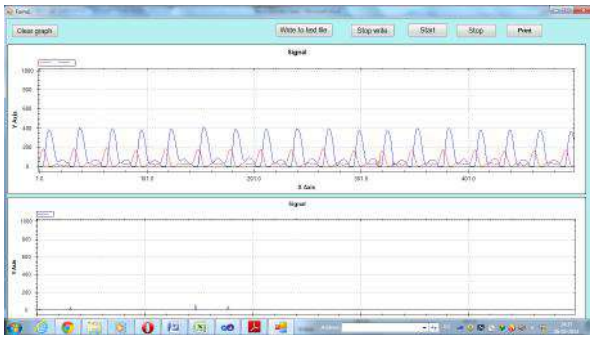


Fig 4 Random Screenshot

The system was applied to a normal healthy volunteer and audio tone listened. His systolic, diastolic and mean blood pressure was also recorded using automatic blood pressure monitor (Omron HEM-7120). The volunteer was then shown a random video clip from the collection of movies in library and the above process repeated. After sufficient rest, he was asked to undertake strenuous exercise and all measurements were repeated. The process was repeated randomly for the same individual without disturbing the sensors attached. This was done for each of ten normal healthy volunteers recruited for the purpose. The results are tabulated in table 1 below.

IV.RESULTS AND DISCUSSIONS

The experiment was run for seventy instances of change in blood pressure. Observations by listening to the audio tone have correlated well with the change in systolic blood pressure as measured using standard NIBP instrument. The Fisher's exact test on the results show a p=0.0064 (and total 'unusual tables' probability = 0.952). thus, the results are significantly related. This experiment is an initial result of feasibility and suitability of proposed novel system for indicating changes in blood pressure of the subject. The system has well indicated the changes in systolic blood pressure of an individual. Various possibilities of error and bias of the observer have not been really addressed. So, validation of the system with extensive experiments and on a larger population is imperative. The simplicity of the system comes from the selection of pulse waveforms and the method to estimate changes in PTT. Its suitability in patients with various cardiovascular issues remains to be explored. Nevertheless, it can be further developed and customized to precise measurements of blood pressure for most cases. Further, the application of sensors is prone to lot of errors requires extensive experimentation for standardization. In this experiment we have applied sensors by looking at the real time waveforms and reapplying (or adjusting the pressure) if optimal waveform matched with previously stored waveform is not obtained. In practice, robust method of locating the pulse and applying the sensors need to be worked out.

TABLE I. SUMMARY OF OBSERVATIONS

		No of instances of change in Systolic BP (mm of Hg)				Total
		≤ 20	No Change	≤ 20	>20	
After watching movie	Actual	1	6	3	0	10
	Observed by tone	0	5	5	0	10
After exercise	Actual	0	1	3	6	10
	Observed by tone	0	0	3	7	10

V. CONCLUSION

We have designed a simple circuit that outputs an audio beep indicating changes in blood pressure. It uses the PPG signals obtained from brachial and radial artery of the single arm. By virtue of the typical signal shapes, passing the signals through a differential amplifier gives a waveform indicating current pulse transit time and therefore, the blood pressure. The circuit was assembled and tested. While exact measurements would require rigorous processing and calibration, the presented system was found suitable for gross indication of changes in blood pressure.

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