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PORTABLE BLOOD PRESSURE MONITORING USING PULSE TRANSIT TIME

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INTRODUCTION

There is growing demand for portable devices capable of monitoring physiological information outside the doctor's office. Blood pressure is one such physiological metric that is commonly measured outside of a clinical setting. The most common and accurate method of measuring blood pressure in this setting is through the use of an inflatable cuff based system. A disadvantage of the inflatable cuff method is that the patient must remain immobile for the test and the apparatus is cumbersome to wear for periodic monitoring.

One method of estimating blood pressure in a continuous and portable manner is to measure pulse transit time (PTT). PTT is the time interval required for a pulse of blood to travel between two points in the body. PTT has been shown to exhibit a correlation with blood pressure over a relatively short period of time and requires a calibration step prior to use [1]. A system based on the PTT method has the potential to benefit those who require blood pressure measurement over a time interval, while not posing a significant hinderance to movement and activity.

This paper presents a prototype device that incorporates a two-electrode electrocardiogram (ECG) with a photoplethysmograph (PPG) located on the head to measure PTT. Using this approach the pulse transit time is estimated as the time delay between the ECG 'R' wave and the correspoding sequential peak on the PPG signal. Once PTT is measured, it can then be used to estimate blood pressure.

Methods for estimating blood pressure have involved various forms of statistical curve fitting [2] and linear regression [3] to provide a mathematical relationship between PTT and blood pressure. The proposed device utilises a two point linear regression derived from two calibration stages to approximate the relationship between PTT and blood pressure.

The purpose of this paper is to present results made with a prototype blood pressure system. The results include measurements made when the patient is under different levels of physical intensity.

PROTOTYPE DEVICE OVERVIEW

The device consists of ECG and PPG sensors and the sensor signals are sampled by analog to digital converters using a data acquisition device (NI USB-6008). Sampled signals are then post-processed using signal processing algorithms in Matlab. The sensors are powered by a single 5 V power supply and draw approximately 23 mA.

The ECG sensor consists of two electrodes attached to the patient as well as analog front end circuitry (adapted from [4]). The circuit itself can be seen in figure 1, and is comprised of an analog filtering stage, an instrumentation amplifier and an amplification stage. Analog filtering of the signal was designed to limit the signal bandwidth to a frequency range from 0.05 to 150 Hz according to existing standards [4]. A two electrode system was chosen over a typical three electrode system to allow for maximum portability and ease of use yet still provide an acceptable level of signal fidelity.

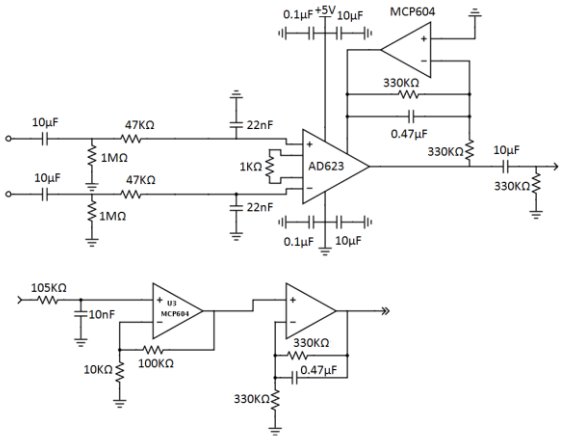

Figure 1: ECG circuit schematic.

The PPG sensor can be seen in figure 2 and is comprised of an LED, MOSFET switch, photodetector and transimpedance amplifier as well as analog filtering components. The PPG is band-limited to a frequency range between 0.1 and 10 Hz and includes a potentiometer to control signal gain. The photodetector (OPT101) was selected to offer a high responsivity to an LED with a wavelength of 905 nm. The LED and photodetector are separated from the analog filtering stage and are housed in a fabric patch held on to the subject's forehead using an athletic headband. The final implementation concept for the PPG sensor is envisioned to be located behind the ear of the user built into a commercial earphone style frame. The concept is to offer both a comfortable and easily wearable system while utilizing the mechanical stability of the behind-ear location to maintain good signal integrity even under conditions of motion.

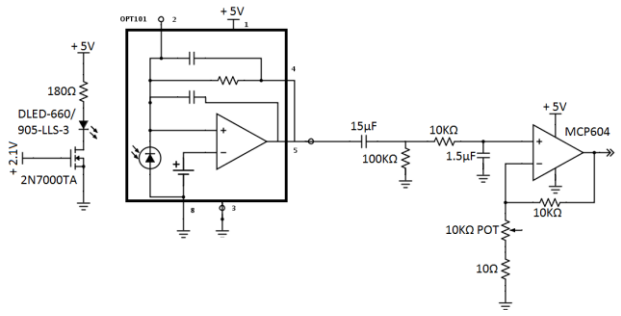

Figure 2: PPG circuit schematic.

After sampling waveforms from the ECG and PPG sensors, PTT was estimated using post-signal processing in Matlab. The signal processing includes a peak detection algorithm that identifies the time stamps corresponding to the peaks of the ECG and PPG waveforms and a script that calculates the time difference between each set of successive peaks to give a beat by beat estimate of the PTT.

The peak detection algorithm consists of four main stages: pre-filtering, locating maxima, scaling, and primary filtering. The first step removes any low frequency noise present in the signal. This is done by transforming the desired signal into the frequency domain using a Fast Fourier Transform, and then filtering the signal with a high pass filter. The signal is then converted back into the time domain and a window function that detects the local maxima is applied. The window function detects local maxima present in the signal, and in some cases erroneous signal components that were not removed in the pre-filtering phase. In order to eliminate the detection of erroneous maxima, the signal is scaled and then passed through a threshold filter which will only pass signal components that have amplitudes greater than the threshold value. The output of the peak detection algorithm is an array consisting of detected peaks of unit value and their corresponding timestamps.

TESTING METHODOLOGY

The first step in the verification of the blood pressure measurement system was to calibrate the sensor with a known reference. During calibration, the test subject's ECG and PPG signals were recorded while the test subject sat at rest over a 2.5 minute timespan. At the midpoint of the time interval, the blood pressure was measured using an Omron HEM-741CAN inflatable cuff measurement device. After capturing the signals, the timing of the peaks were found using the peak detection algorithm. Any errors in the peak detection process were manually corrected. Using this data, the pulse transit time was calculated for each pulse and then averaged for the duration of the trial. This process was then repeated while the subject sat and engaged in heavy weight-resistance exercise for the duration of the trial.

From these two calibration steps, a linear equation was established to estimate systolic (S) and diastolic (D) blood pressure for different values of pulse transit time measured in the test. The models are:

$$S = -1.183 \times PTT + 283.987 \quad (1)$$

$$D = -0.592 \times PTT + 135.494 \quad (2)$$

A series of six trials where then completed using different levels of weight resistance lifted by the subject. The same process was used as in the calibration stage, and averages of the pulse transit time were then used in equations (1) and (2).

Trials were conducted in 5 minute intervals with a 2.5 minute rest between each trial. The subject remained sitting and connected to both the Omron and prototype measurement system for all of the trials. The physical intensity for each trial was randomly varied.

RESULTS

As shown in Figures 3 and 4, a good correlation can be seen between the estimated and reference blood pressure for the different trials. Blood pressures measured with the inflatable cuff (calibration reference) are denoted as 'measured' while those obtained using the experimental system are denoted as 'estimated'. In figure 3, trials -1 and 0 correspond to the resting and heavy-weight calibration stages, respectively. Figure 3 shows the pulse transit time along with the reference systolic and diastolic blood pressure. As shown, PTT falls when blood pressure rises which is expected for high intensity activities. The measured values of PTT are then used in equation (1) and (2) to estimate blood pressure. Figure 4 shows a comparison of the estimated blood pressure versus measurements made with the inflatable cuff reference. The two measurement methods are very similar and the correlation constants for the measured and estimated blood pressures were calculated to be 0.986 for systolic and 0.717 for diastolic.

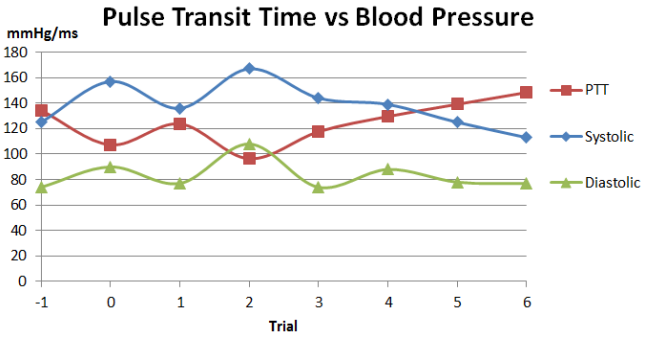

Figure 3: Pulse transit time versus systolic and diastolic blood pressure over six trials plus calibration stages.

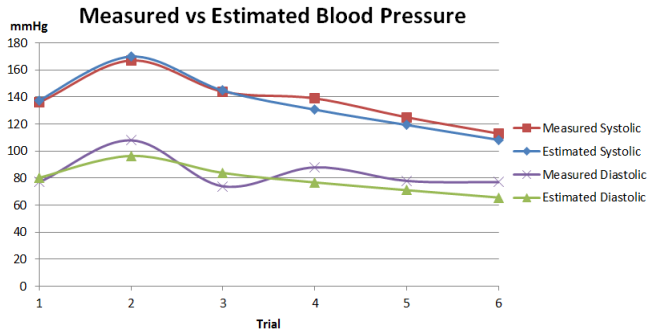

Figure 4: Estimated versus measured blood pressure over six trials.

DISCUSSION AND FURTHER WORK

There are many steps remaining for testing and completing the prototype. From these first results, it can be seen that there is good potential for accurate and portable blood pressure measurement using the PTT method. Further refinements are planned such as increasing the systems resilience to motion artifacts through secure sensor placement and improved signal processing techniques. With these improvements, it is expected that a portable blood pressure system can be developed for clinical and athletic monitoring applications.

ACKNOWLEDGEMENTS

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