Estimation of Blood Pressure Using Smartphones

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***Abstract*—Smart phones today have become increasingly popular with the general public for their diverse functionalities such as business applications, social networking, multimedia facilities and navigation. These phones are equipped with high-quality processors, cameras with high resolution, and built-in sensors such as orientation sensor,accelerometer and light-sensor. Motivated by this diverse capability of smart phones, we focus on using them for biomedical applications. We present a new application of the smart phone with its built-in camera and microphone replacing the traditional stethoscope and cuff-based measurement technique, to measure vital signs such as heart rate and blood pressure. We estimate the systolic and diastolic pressure by computing the pulse pressure and the stroke volume from the data recorded. By comparing the estimated blood pressure values with those measured using a standard blood pressure meter, we obtained good results. The application also facilitates the user to store his blood pressure readings using a database. Additionally, the method also uses the GSM service to send SMS to the mobile phone number provided by the user in case of an emergency.**

***Index Terms* - Blood pressure, finger pulse, smart phone camera, smart phone, vascular transits time, ejection time.**

I. INTRODUCTION

Measurement of vital signs in a human body is a tedious task when sudden dizziness or fainting occurs during unexpected situations. The only knowledge that we have is that these occurrences are the most common symptoms of low blood pressure. Blood pressure, which is the amount of force applied on the walls of the arteries when blood is forced throughout the body, depends on various factors such as the amount of blood in human body, the pumping rate of the heart, the flexibility of the arterial walls of the body, and the resistance to blood flow due to the size of these arteries. The blood pressure of a person varies continuously due to a physical activity, medication, emotions and anxiety. The body has unique mechanisms for regulating a person's blood flow; whenever a person's blood pressure falls, the heart rate increases to pump more and more blood and the arterial walls shrink to increase the blood pressure.

Blood pressure is typically measured using a standard mercury sphygmomanometer. However, to check a person's blood pressure during unexpected situations, there is a need for a portable, convenient apparatus or device. Despite the availability of digital arm and wrist blood-pressure meters, most of the people do not carry these devices during their daily transit to the work place, gyms, recreational facilities, etc. The only device that is present at all times with people in all the walks of life is a mobile or a smart phone. The mass production of smart phones with built-in sensors such as a camera with flash, an accelerometer and a microphone sensor has motivated us to use their benefits in the biomedical domain.

We hereby propose a mobile phone-based blood pressure estimation technique. In other words, we replace the traditional cuff and stethoscope used for measuring blood pressure, by recording the heart sounds and the finger pulse by using a smart phone's microphone and a camera. Finger pulse is recorded by implementing photoplethysmography technique in smart phones.

The estimation technique consists of three phases. The *first phase* involves locating an appropriate spot on the chest for recording the heart sounds. We use a single mobile with external microphone for recording the heart sounds. The *second phase* is the blood pressure estimation phase which involves calculation of systolic pressure, pulse pressure, and the diastolic pressure using the data measured. The *third phase* is the analysis phase, which involves the analysis of the blood pressure obtained as the result of the first two phases. If the blood pressure goes beyond a threshold value, a SMS is sent to the patient's doctor informing about the critical condition of the patient.

II. METHODOLOGY

The process of localization of heart beat is discussed in detail in this section. The recording of heart sound, pulse detection and heart rate calculation are discussed in the next sections.

A. Localization of Heart Beat

Localizing a heartbeat is an arduous task, but necessary for accurately estimating the blood pressure. A brief description of the heart sounds is as follows. Heart sounds are produced with the opening and closure of the valves. The heart produces four types of sounds in one complete heart cycle denoted as S1, S2, S3, and S4. The first heart sound S1(lub) is produced by the atrio-ventricular valves (i.e., mitral and tricuspid valves), the second heart sound S2(dub) is produced by the semi lunar valves (i.e., aortic and pulmonary valves). The third and fourth heart sounds are produced only in rare conditions due to gallop. In this paper, we are focusing in recording only the first and second heart sounds. Some experiments were conducted on the chest region to find the best spot for obtaining recordable heart sounds. As indicated in Fig. 1, the four locations of the valves were identified and selected for recording purposes.

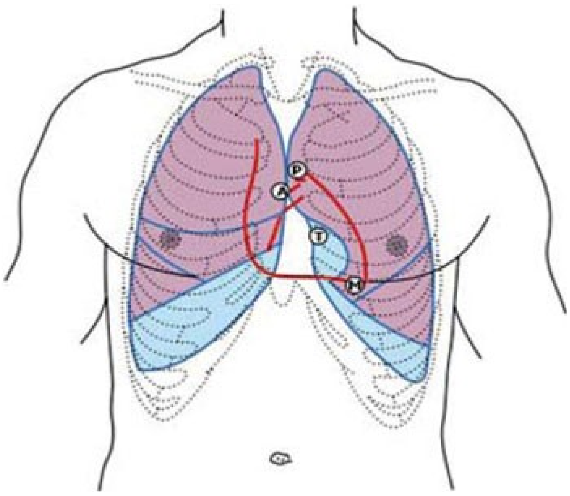

Fig.1. Heart sound locations: S1 (lub) is produced by mitral (M) and tricuspid (T) valves; S2 (dub) is produced by aortic (A) and pulmonary (P) valves

Based on the experiments, the heart sounds captured from the microphone were heard the loudest in the pulmonary region which contains the pulmonary valve. Since the pulmonary valve is associated with the S2 sound, in most cases the decibel level of S2 is higher than that of the S1.

B. Calculate heart rate

In this setup, we record heart sounds via an audio recording application. The microphone of the smart phone is placed close to the heart, and the audio recording is started. The heart sounds are captured in this audio recording. The number of times the heart beats in a minute is the heart rate.

C. Pulse Detection and Heart Rate Calculation

The human body is filled with blood running through all parts of the body including fingers. By placing the finger over the camera of a smart phone and turning on the flash through a video recording application, the following observations were made. During a systolic pulse, when the capillaries are rich in blood, more amount of light was absorbed by the blood, leading to a low reflective index and darker frame intensities. Likewise, during a diastolic pulse, most of the light was reflected leading to brighter frames. The change in intensity of light passed through the finger creating an alternative pattern of waves. These changes in intensity with time were used to obtain the pulse of a person.

The pixel information from the video was split into individual red, green, and blue components. In most of the frames observed, the noticeable color was red. Then we split the frame of the video on a fixed length window (Wt) and check for the number of peaks (n) which occurs at equal intervals of time. We then calculate the Heart rate (HR) given by

$$\mathbf{HR = (\mathit{n} * 60)\mathit{Wt}}.$$

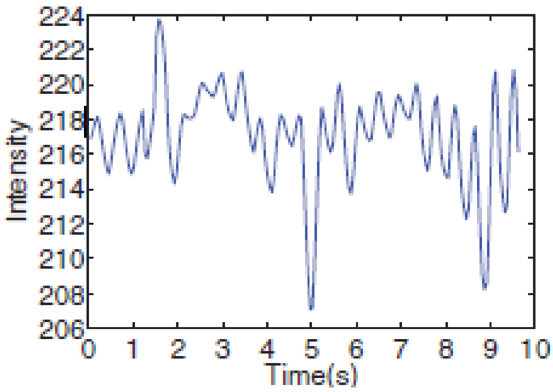

Fig.2. Data from frames.

D. Integration of Components

The results obtained by the audio and video recording are integrated in this step. The audio recording gives us the heart rate and the video recording gives us the pulse rate. Now, these two entities are integrated using parameters to estimate the blood pressure of the concerned person. Finally, if the blood pressure is beyond a certain threshold value, a SMS is sent to the person's family doctor or relative. The blood pressure of the person is stored in a database on the smart phone application.

III. MATHEMATICAL ANALYSIS

This section describes the method of calculating systolic and diastolic pressure values using the preprocessed heart beats and finger pulse.

A. Systolic Pressure

The times of arrival of S1 and the corresponding systolic peak are noted down. The difference in these two times of arrival gave a parameter called vascular transit time (VTT). VTT is defined as the time taken by blood to travel from the heart to any extremity of the body for one complete stroke of the heart. The change in the systolic pressure can be derived from the change in VTT with respect to a reference value as shown in (1).

$$\triangle Ps = -0.425 \times \triangle \mathrm{VTT}. \quad (1)$$

Based on (1), the systolic pressure values corresponding to the VTT can be generated. Thus, the estimated systolic pressure is given by.

$$Ps = -0.425 \times \mathrm{VTT} + 214. \quad (2)$$

To derive the relation between systolic pressure and VTT we performed linear curve fitting between the estimated VTT and the measured systolic pressure values to obtain a regression relation. The above constant '214' is obtained from this regression relation.

B. Pulse Pressure and Stroke Volume

The pulse pressure *Pp* and the stroke volume SV were computed as follows. For stroke volume, we used (3)

$$SV(mL) = -6.6 + 0.25 \times (ET - 35) - 0.62 \times HR + 40.4 \times BSA - 0.51 \times Age \quad (3)$$

where ET(ms) is the ejection time and BSA is the body surface area, given by

$$BSA = 0.007184 \times Weight^{0.425} \times Height^{0.725}.$$

Ejection time is defined as the time of ejection of blood from the left ventricle, beginning with the opening of the aortic valve and ending with closing of the aortic valve. The identification of the two sounds, namely S1 accompanied by opening of the aortic value and S2 accompanied by closing of the aortic value, was explained in section II-B.

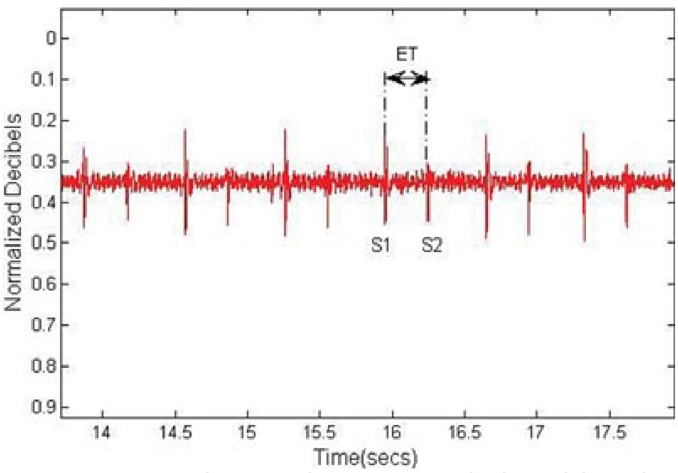

Fig.3. Heart beat data recorded with the microphone: the two points markedin the waveform correspond to S1 and S2 sounds. The time difference betweenthese two sounds gives ejection time.

As shown in Fig. 3, the time difference between S1 and S2 sounds is taken as the ET.

With the computed stroke volume, the pulse pressure was calculated in units of mmHg using (4) as

$$Pp = \frac{SV}{(0.013 \times Wt - 0.007 \times age - 0.004 \times HR) + 1.307} \quad (4)$$

C. Diastolic Pressure

Having obtained *Ps* and *Pp*, the diastolic pressure *Pd* was calculated from the following equations:-

$$Ps = Pm + 2/3Pp \quad (5)$$
$$Pd = Pm - Pp/3 \quad (6)$$

Subtracting (6) from (5), we get

$$Pd = Ps - Pp \quad (7)$$

IV. CONCLUSION

This paper describes a cuffless differential blood pressure estimation technique using smart phones. Further as an extension, we also described a method which sends a SMS to the concerned person's doctor in case of an emergency. We then discussed the mathematical formulations used to estimate the systolic and diastolic pressure. By obtaining accuracies between 85–90%, we showed with this technique that ubiquitous mobile phones could be used by people to measure blood pressure. This study could very well be used for normal and non-pathological cases.

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