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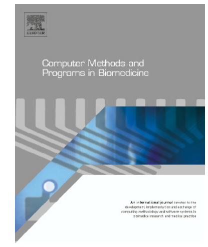

Development of a wireless blood pressure measuring device with smart mobile device

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ABSTRACT

Today, smart mobile devices (telephones and tablets) are very commonly used due to their powerful hardware and useful features. According to an eMarketer report, in 2014 there were 1.76 billion smartphone users (excluding users of tablets) in the world; it is predicted that this number will rise by 15.9% to 2.04 billion in 2015. It is thought that these devices can be used successfully in biomedical applications. A wireless blood pressure measuring device used together with a smart mobile device was developed in this study. By means of an interface developed for smart mobile devices with Android and iOS operating systems, a smart mobile device was used both as an indicator and as a control device. The cuff communicating with this device through Bluetooth was designed to measure blood pressure via the arm. A digital filter was used on the cuff instead of the traditional analog signal processing and filtering circuit. The newly developed blood pressure measuring device was tested on 18 patients and 20 healthy individuals of different ages under a physician's supervision. When the test results were compared with the measurements made using a sphygmomanometer, it was shown that an average 93.52% accuracy in sick individuals and 94.53% accuracy in healthy individuals could be achieved with the new device.

1. Introduction

Today, smart mobile devices (phones and tablets) are equipped with high-speed processors, high-resolution cameras and numerous receptors (accelerometer, light sensor, orientation sensor etc.). For this reason, the use of these devices is becoming increasingly widespread. People take photographs, connect to the internet, get directions and listen to the radio using the devices' in-built features or sensors or via an additional apparatus attached to the devices.

According to a report released by the market research company eMarketer, 1.76 billion people in the world were using smartphones (excluding tablets) in 2014; this number is predicted to increase 15.9% to 2.04 billion in 2015 [1]. In other words, approximately one-quarter of the world's population will have owned a smartphone by the end of 2015. These data are important since they give an indication of the size of the target audience for the biomedical applications developed on these devices.

Due to its prevalence and the size of the economic burden it causes, hypertension is a social problem, causing permanent

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disability and death all over the world. Yet hypertension is top of the list of "preventable causes of death" according to data reported by the World Health Organization [2]. The fact that a considerable number of patients are not aware of the existence of the disease makes addressing hypertension even more important. As the effects of high blood pressure emerge suddenly, and these effects have potentially fatal risks, it is vital to measure blood pressure accurately and to encourage patients to take necessary action. The importance of measuring blood pressure at home to predict organ damage due to hypertension is underlined in European and Canadian hypertension guides published in recent years [3,4]. Measurements of blood pressure levels taken in a hospital environment are unreliable because of the psychology of the patient and stress levels associated with that environment. Furthermore, in these studies it was reported that the motivation of the individuals using automatic (digital) measuring devices at home for tension treatment improved and they also had higher treatment continuation rates [4].

Recently, various studies have been carried out to measure blood pressure levels by means of smartphones [5–11]. A wireless blood pressure measuring device running on smartphones with different operating systems (Android, iOS, Blackberry), which makes measurements by means of the oscillometric method, was developed in one of these studies [5]. However, an analog filter was used as the signal processing and improvement method in this device. Also, the device that was developed was tested only on ten healthy individuals. The results obtained were compared with those from a digital commercial tension device and only an average accuracy level of 85% could be reached. Electrocardiogram (ECG) and photoplethysmography (PPG) signals were used to calculate pulse transmission times and blood pressure was estimated using smartphones in the second study [6]. However, a second smartphone was used in this study to obtain the ECG signals. The experiments were conducted only on five people and an average accuracy level of 95% could be obtained. Similarly, ECG and PPG signals were used in the third study [7]. However, another ECG module was required to estimate the blood pressure. In addition to that, this study explored its use as a driver safety monitoring system. A smartphone was used in place of a manometer only in one other study where a traditional sphygmomanometer and smartphone were used together [8]. However, the device that was developed was tested only on five healthy individuals and the results were compared with a digital and commercial tension measurement device. Accuracy levels of only 85.5% and 95% could be obtained for the systolic and the diastolic pressure, respectively. In the study proposed in [9], a wireless blood pressure measuring device was developed for devices with an iOS operating system, again using the oscillometric method. However, an analog filter was again used for the prediction of both blood pressure and heart rate values in this device. The device was checked by using a blood pressure simulator in the laboratory and in a clinical environment with 19 individuals. In the clinical tests, the difference for systolic blood pressure was 2.66 ± 2.71 mmHg and 3.42 ± 4.42 mmHg for diastolic blood pressure. Visvanathan et al. developed a smartphone-based blood pressure indicator using PPG signals [10]. PPG signals were obtained from a finger placed on a camera lens, using software developed for smartphones with an iOS operating system. These signals could only be processed, allowing blood pressure and heart rate values to be predicted, by means of the software on the computer. Finally, the results obtained were shown to the user via a smartphone. In another study by Lee et al., a Bluetooth blood pressure and heart rate monitor and mobile care system integrated with a smartphone was developed and designed [11]. This system developed for hypertension patients reports the patients' physiological parameters to their family members at certain intervals via a wireless network. 95% of the health personnel on whom the device was tested agreed that the device can be useful in terms of medical cost, distant health services and obtaining useful reference data.

A wireless blood pressure measuring device used with a smartphone was developed in this study. With the interface developed, the mobile device was used both as the indicator and as the control device; the blood pressure measuring values were recorded to the database within the device itself. Thus, it is possible to make queries related to this data and the results of such queries can be sent to the relevant person by means of email or SMS. The cuff communicating with the smartphone device via Bluetooth was designed to measure blood pressure via the arm. A digital filter was used on the cuff instead of an analog signal processing and filtering circuit.

2. Methods

2.1. *Blood pressure measuring methods*

Blood pressure (tension) is defined as the pressure that blood applies on the walls of an artery. There are two types of tension: systolic blood pressure and diastolic blood pressure. The tension measured during the contraction of the heart is called systolic blood pressure while the one measured during the relaxation of the heart is called diastolic blood pressure. 120 and 80 mmHg levels are the normal values for systolic and diastolic blood pressures, respectively [12]. Two different methods, invasive and non-invasive, are used to measure blood pressure [13]. Invasive methods are generally used in hospitals and intensive care units by means of placing a catheter inside the appropriate artery. Non-invasive methods, on the other hand, do not require penetration through the skin. Instead, they measure by blocking the blood flow passing through the arm by means of a cuff which is filled with air. The most common methods among these are the auscultatory method and the oscillometric method [14].

2.1.1. *The auscultatory method*

This method was first defined by Nicolai Korotkoff in 1905. In this method, the sounds produced by the arm artery as a result of the varying pressure applied by the cuff wrapped around the arm are used for estimating blood pressure. Korotkoff sounds, listened to by means of a stethoscope over the brachial artery right below the cuff, change with the pressure applied on the artery by the tightening cuff. Korotkoff sounds have a bandwidth ranging between 20 Hz and 300 Hz [15]. The blocking cuff is inflated until it reaches a value over the systolic pressure value and is deflated slowly with a speed of 2–3 mmHg/sec. The blood gushes inside the vein under the cuff and causes