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Development of a Cuffless Blood Pressure Measurement System

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Abstract— **This study constructs a novel blood pressure measurement device without the air cuff to overcome the problem of discomfort and portability. The proposed device measures the blood pressure through a mechanism that is made of silicon rubber and pressure transducer. The system uses a microcontroller to control the measurement procedure and to perform the necessary computation.**

To verify the feasibility of the constructed device, ten young volunteers were recruited. Ten blood pressure readings were obtained using the new system and were compared with ten blood pressure readings from bedside monitor (Spacelabs Medical, model 90367). The results indicated that, when all the readings were included, the mean pressure, systolic pressure and diastolic pressure from the new system were all higher than those from bedside monitor. The correlation coefficients between these two were 0.15, 0.18 and 0.29, for mean, systolic and diastolic pressures, respectively.

After excluding irregular apparatus utilization, the correlation coefficient increased to 0.71, 0.60 and 0.41 for diastolic pressure, mean pressure and systolic pressure, respectively.

We can conclude from these results that the accuracy can be improved effectively by defining the user regulation more precisely. The above mentioned irregular apparatus utilization factors can be identified and eliminated by the microprocessor to provide a reliable blood pressure measurement in practical applications in the future.

I. Introduction

In the United States and other developed countries, hypertension and diabetes are the most common chronic diseases amount the elderly. In addition, hypertension is the most prevalent and important contributor to cardiovascular diseases [1]. For years, blood pressure (BP) has been used as a quantitative index for evaluating the condition of the heart in both clinical environment and routine checkup [2]. Nowadays, there is increased awareness of the importance of regular BP monitoring in the diagnosis and management of hypertension [3]. And, most of the people appreciate the necessity of regular measurement of BP on a daily bases.

White coat hypertension is one of the limitations of office BP measurement [4]. Additionally, office BP is not capable of collecting BP information during usual day-to-day activities. In addition to the inaccuracy caused by the measurement principle, another major disadvantage of non-invasive blood pressure monitors that are currently available on the market is the size of most blood pressure monitor is too large and is not truly portable, restricted by the size of pressure cuff.

In order to solve the above problems, authors proposed and build a novel blood pressure monitor [5]. Similar to the pulse diagnosis in traditional Chinese medicine, doctor applies different pressures at their finger tips above patient's radial artery to acquire information about patient's blood vessel including blood pressure and heart beat. The proposed device is small enough that subjects can hold the apparatus with one hand and press it against their radial artery on the other hand. User applies a series of pressures, from gentle to heavy, the device then converts the acquired pressure information into blood pressure readings. This proposed device can overcome the limitation of size and discomfort caused by the inflating cuff in the existing automatic blood pressure monitoring device.

II. Method

There are four major function blocks in the proposed system, a cuffless pressure sensing module, a signal conditioning hardware, a signal processing unit (8051) and a display module.

A. Cuffless Blood Pressure Sensing Hardware

The cuffless pressure sensing module was constructed by enclosing a blood pressure transducer with silicon rubber doom. The silicon rubber doom can withstand firm pressure applied by the user at the measurement site. Additionally, due to the airtight and elastic properties of silicon rubber, the pressure signal can conducted into the pressure transducer with little distortion.

The signal obtained from the pressure sensor is amplified and filtered by the signal conditioning circuits. The signal condition hardware separates the pressure signal into two components, the low frequency pressure signal and the high frequency oscillometric signal, before passing them to the signal processing unit.

The pressure sensor and the signal condition hardware are integrated into the two opposite sides of a printed circuit board. The completed unit is small enough to fit into a handheld device or on the back of a watch (Fig. 1.)

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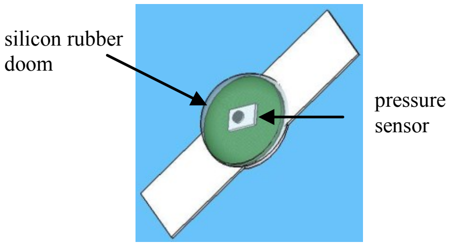

Figure 1. The design of cuffless blood pressure sensing unit.

B. Signal Processing

Due to the fact that the pressure sensing module is operated by the subject, the pressures applied by the user may not increase monotonically. This non-monitonic behavior hinders the use of conventional technique for blood pressure determination. Thus, in addition to the new sensing hardware design, the system uses a novel digital signal processing algorithm to extract blood pressure information from the pressure signal.

After the essential digital lowpass filtering, the digital signal unit detects the maxima and minima in each and every heart beats, from the oscillometric signal, in order to determine the magnitude of pulse pressure. The corresponding pressure readings are collected and sorted. At the same time the pulse pressures are rearranged according to their pressure reading values (Fig. 2.) After rearranging, the mean blood pressure, systolic pressure and diastolic pressure can be determined using the conventional oscillometric principle.

C. Experiment

Ten volunteers were recruited to validate the proposed system. They were asked to sit upright and operate the device as instructed. Ten blood pressure readings were obtained for each volunteer. At the same time, the subject's blood pressures were simultaneously measured using a bedside monitor (90367, Spacelabs Medical).

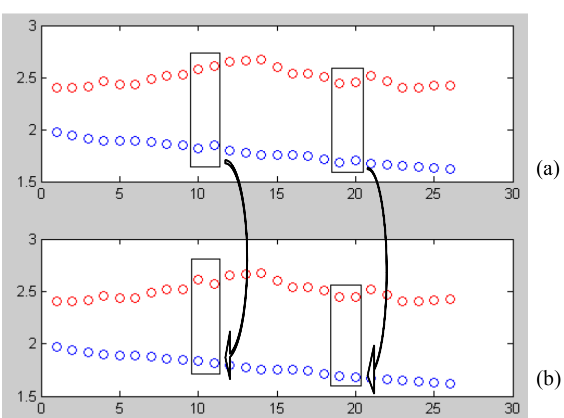

Figure 2. Rearranging the pulse pressures. The pressure readings at each heart beat (blue circles) are collected and sorted. The pulse pressures (red circles) are rearranged according to their pressure reading values. (a) before rearranging and (b) after rearranging according to the pressure reading.

III. Results

A. System Hardware

Figure 3 illustrates the completed pressure sensing module circuit board. The silicon rubber doom was constructed over the pressure transducer (MPS-3117, Metrodyne, Taiwan) afterward.

During the measurement, the user holds the cuffless sensing module in one hand and place the silicon doom on top of the radial artery on the other hand. By pressing the initialization button, a color bar appears at the bottom of the display indicating the amount of pressure that is applied by the user on the artery. Figure 4 demonstrates the mode of operation of the proposed system and its display. It is the user's responsibility to maintain the applied pressure increase as linear as possible. The color pressure bar increases linearly with the applied pressure to serve as a visual aid. For most of the user, after several practices, it is not too difficult to complete the task of applying monotonically increased pressure using the color pressure bar visual aid.

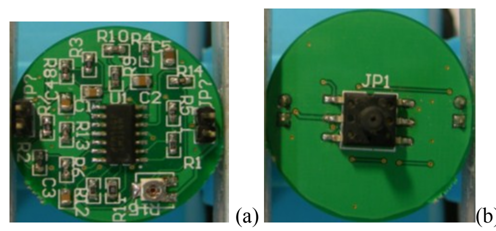

Figure 3. The front (a) and back (b) of pressure sensing circuit board.

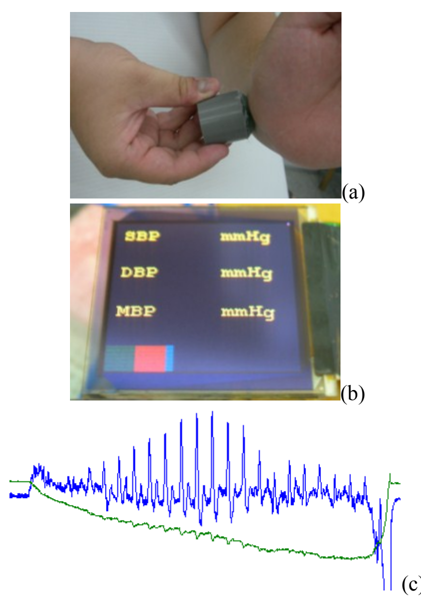

Figure 4. (a) The mode of application, (b) the display, and (c) a typical recording of the acquired pressure signal using the proposed device. Where the blue tracing is the oscillometric signal and the green tracing is the pressure signal from the pressure sensor. Notice that lower pressure signal indicates higher pressure.

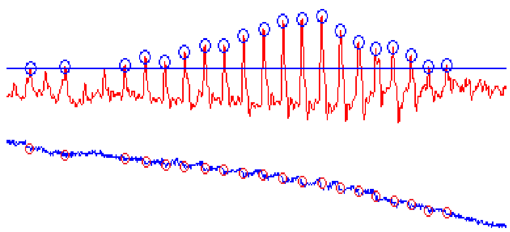

Figure 5. A typical recording of the oscillometic and pressure signals. The blue and red circles indicating the maxima of oscillometic in each heart beat and corresponding pressures detected by the signal processing unit, respectively.

B. Signal Processing

Figure 5 illustrates a typical recording of oscillometric and pressure signals. At the end of measurement, the pulse pressures and the corresponding pressures of each heart beat are determined by the signal processing unit automatically. The collected pressure readings are examined for monotonic increase. If there were pressures that were not monotonic increase, they were rearranged and the corresponding pulse pressure readings were rearranged accordingly.

After the rearranging processing, the systolic and diastolic pressures were determined according to the oscillometric principle using the characteristic ratio method. In this study, the characteristic ratios for systolic and diastolic pressures were 0.5 and 0.7, respectively. The procedure of the mean blood pressure was first determined as the pressure corresponding to the highest oscillometric amplitude.

C. Experiment

The results of ten volunteers indicate that the system overestimated MBP, SBP and DBP with no significant differences. However, the correlation between bedside monitor and the proposed system are 0.15, 0.18 and 0.29 for MBP, SBP and DBP, respectively (Table 1.)

Re-exam the signal, it was found that there were subjects applied the pressure too slow (Fig. 6b.) On the opposite, some subjects applied the pressure too fast and too abruptly (Fig. 6a.) When the pressure was applied too slow, the applied pressure did not reach the systolic pressure and the determination of systolic pressure was not possible. On the other hand, when the pressure was applied too fast, the number of heart cycle in the measurement period was inadequate. It is found that when the number of heart cycles is less than 8 the errors in systolic and diastolic pressures increase dramatically. By excluding these recordings, the correlation coefficients between bedside monitor and the proposed system are 0.60, 0.71 and 0.41 for MBP, SBP and DBP, respectively (Table 2).

TABLE I. THE RESULTS OF VALIDATION STUDY. (ALL SUBJECTS, N = 10)

	SBP	MBP	DBP	HR
Correlation	0.18	0.15	0.29	0.37
T test	0.33	0.62	0.7	0.95

TABLE II. THE RESULTS OF VALIDATION STUDY AFTER EXCLUDE UNSUITABLE TRIALS. (N = 10)

	SBP	MBP	DBP	HR
Correlation	0.71	0.6	0.43	0.74
T test	0.4	0.46	0.56	0.3

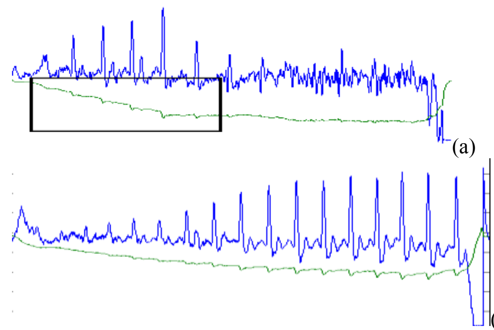

Figure 6. A typical recording of subjects who applied the pressure too abrupt (a) or too slow (b). When the pressure was applied too slow, the applied pressure did not reach the systolic pressure and the determination of systolic pressure was not possible. When the pressure was applied too abrupt, the number of heart cycle in the measurement period was inadequate.

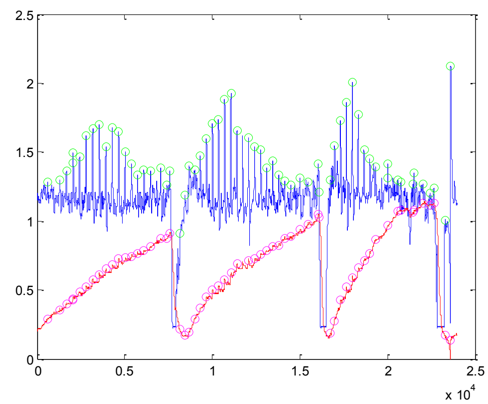

Figure 7. A new signal processing technique allows the user to apply pressure multiple times

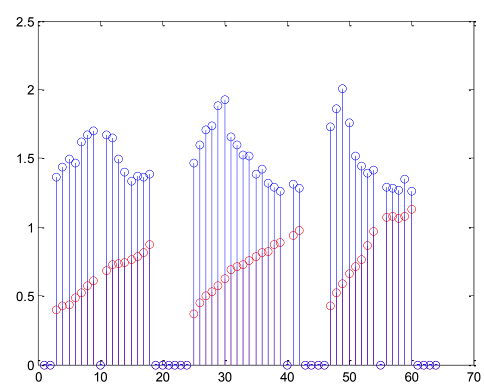

Figure 8. Signals are segmented into individual pressuring sections and merged into one measurement section

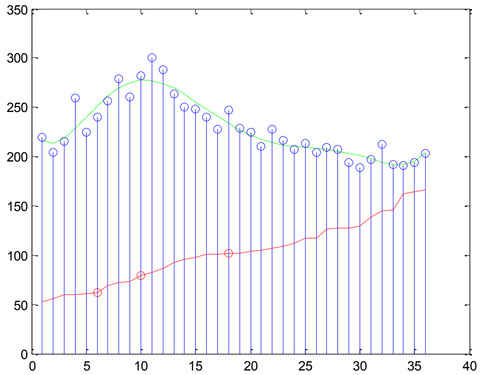

Figure 9. Individual pressuring sections are rearranged to form a combined section. The systolic and diastolic pressures will be determined according to the characteristic ratio principle after the curve fitting [6].

IV. Discussions

The above results indicate two major drawbacks in this study, the accuracy and ease of routine use. The need to apply linear pressure onto the radial artery can be a real challenge to some user. Thus, a new signal processing technique is under investigation that allows the user to apply pressure multiple times (Figure 7.) Signals will then be segmented into individual pressuring sections and will be merged into one measurement section (Figure 8.) The rearranging processing will then be applied to this final combined section (Figure 9) and the systolic and diastolic pressures will be determined according to the characteristic ratio principle after the curve fitting [6].

This new signal processing scheme should not only improve the user friendliness but also increase the accuracy of the proposed device. On the other hand, the characteristic ratios that are used in the oscillometric method are a major source of inaccuracy in the determination of systolic and diastolic pressures. Thus, a further study with larger subject population is needed to establish suitable characteristic ratios for the proposed device.

V. Conclusion

In conclusion, a novel cuffless blood pressure monitoring system is proposed and constructed. The device is not only lightweight but also small enough can be fitted into a watch or the edge of a cellular phone. The user operates the device by pressing the silicon doom against the radial artery. Using rearranging technique, the proposed signal processing procedure can eliminate any non-monotonic pressure increase and obtain the systolic and diastolic pressure with fair correlation. In the future, advance signal processing technique will be incorporated in order to increase the user friendliness.

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