Design of Electronic Blood Pressure Testing System

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Abstract. With the continuous development of electronic technology, the previous traditional methods of blood pressure testing are far from meeting people's requirements. Fortunately, the advent of electronic blood pressure meters has shown great convenience and potential. Against the backdrop, a new electric blood pressure testing system based on a CC3200 LaunchPad is proposed in this paper, which uses a pressure sensor to collect the information of static pressure and fluctuation of blood pressure, and then transmits the processed data to the software in PC. The software in PC analyzes the data by oscillometric method and Gaussian fitting method, and then the static pressure, systolic pressure and diastolic pressure are calculated and displayed. Test results show that the blood pressure testing efficiency is greatly improved by this system with its high accuracy and reliability, which can meet the requirement of the AAMI (Association for the Advancement of Medical Instrumentation) standard.

1. Introduction
In the fast-paced age, people are paying more and more attentions to their health as pressures from work and study are intensifying. As an important index of health, the blood pressure has become the focus for people to know about their health status. Therefore, more and more people pay attentions to the regular blood pressure testing. However, the previous traditional methods of blood pressure testing measured by a mercury sphygmomanometer requires a medical staff to deal with and the testing accuracy may not be guaranteed due to the influence of potential “white coat effects” [1].

The electronic blood pressure testing system proposed in this paper uses a CC3200 LaunchPad to amplify, filter and separate signal of the blood pressure output by a pressure sensor, and then transmits it to the software in PC. The software displays the pulse wave and static pressure waveform, and calculates the blood pressure value by oscillometric method and Gaussian fitting method. Meanwhile, the software supports functions such as user login, voice broadcasting, blood pressure curves displaying and test report generating, which is much convenient for people even at home.

2. General System Framework
The general block diagram of the blood pressure testing system is shown in Figure 1, where the core processing module is a CC3200 LaunchPad. The high-performance MCU (Microprogrammed Control Unit) used in the CC3200 LaunchPad is a wireless MCU of the industry standard ARM Cortex-M4 with excellent computing power and efficient interrupt response, which also optimizes memory usage and application power consumption. The MCU subsystem supports a variety of peripherals, including an 8-bit fast parallel camera interface, multi-channel audio serial interface, SD/MMC, UART, SPI, PC and 4-channel 12-bit ADC (Analog-to-Digital Converter), etc.

The hardware of the proposed system is mainly composed of a CC3200 LaunchPad, inflatable cuff, pressure sensor, signal amplification circuit, and signal filter circuit. The system block diagram of the hardware is shown in Figure 2. The pressure sensor collects the mixed signal of the inflatable cuff
pressure and the pulse wave, separates the static pressure signal and the pulse wave signal through the signal amplifier circuit and the filter circuit. After collecting and processing the related data output by the filter circuit, the CC3200 LaunchPad interacts with the software in PC and starts sending data when the testing command is executed. The software based on LabVIEW in PC mainly processes and displays the received data.

Figure 1. General block diagram of the system.

3. System Hardware Design

3.1. Pressure Sensor and Signal Amplification Circuit
The pressure sensor selected in this design is MPS3117-006GC, which can be driven by a fixed value voltage or current. The output voltage signal proportional to the input voltage generated can reach the millivolt level and the sensor can maintain stable performance for a long time. The measurement range is 0~5.8PSI whose conversion is 0~300mmHg, which is basically equivalent to the measurement range of electronic blood pressure meters on the market, and the linear accuracy is 0.3%FS. The operating temperature range is -40~85℃, which can also be used for daily operation. In addition, its full-scale output is 75mV, and its sensitivity is 0.25mV/mmHg.

Since the output voltage of the pressure sensor is small, an amplifier circuit is required to amplify the output pressure signal. The signal amplifier circuit based on INA128 with high-precision, low-power, low bias voltage, and low temperature drift can withstand ± 40V voltage without damage.

The general pressure range of the blood pressure meter is 0~200mmHg, that is, the output voltage range of the pressure sensor is 0~50mV. After passing through the INA128-based amplification circuit, the output signal range is 0~1.439V.

3.2. Filter Circuit
The signal collected by the MPS3117 pressure sensor includes the inflatable cuff static pressure and the pulse wave, so the mixed signal needs to be separated by the filter circuit. The signal is separated respectively into the pulse wave signal and static pressure signal by a band-pass filter and a low-pass filter, in order that the blood pressure can be calculated and analyzed later.

The frequency of the static pressure signal of the inflatable cuff is low, so a low-pass filter is selected for separation. The cut-off frequency of the low-pass filter circuit is set to 0.6 Hz.

The frequency of the pulse wave signal tested is about 1~10 Hz, so the pass frequencies of the band-pass filter circuit are set to 0.65 Hz and 16 Hz. The external noise interference such as false wave signal generated by muscle jitter or mental tension is filtered out by the band-pass filter.

4. System Software Design

4.1. Program Design of Lower Computer
The program design of lower computer is mainly used for collecting and uploading the blood pressure data, which is shown in Figure 2. Firstly, the serial interface is opened and the blood pressure sensor module is initialized. Secondly, the inflatable cuff is pressurized continually to 180mmHg and then stopped. After deflation and decompression, the system will collect blood pressure data. When the pressure value reaches to 20mmHg, the process of blood pressure collection is completed.
Figure 2. Program design of the lower computer.

Based on the types of commands received from the software in PC, there are three main types of interactions between the lower computer and the software:

- When the command is ONLINE IDLE, the lower computer don’t operate;
- When the command is MEASURE, the lower computer sends the data to PC;
- When the command is RESET, the lower computer resets all modules’ states and clears the data.

4.2. Software Design in PC

4.2.1. General design procedure of software in PC. The software based on LabVIEW in PC mainly includes four modules: data communication module, data collection module, blood pressure calculation module and data processing module.

4.2.2. Data communication module. The main function of the data communication module is to realize command interactions between the software in PC and the lower computer. The data communication module corresponds to three Boolean buttons of "Connect", "Reset" and "Start Detection" in the main interface of the blood pressure testing system. The detailed procedures of these three commands are as follows:

- Connect: The serial interface number is set and the serial interface baud rate is configured as 115200 by the VISA (Virtual Instrument Software Architecture) serial interface configuration function. Then "L+\n" is sent to the lower computer by the VISA writing function. If the lower computer receives "L+\n" in two seconds and replies "OK+\n", the lower computer module is online;
- Reset: "T+\n" is sent to the lower computer by VISA writing function, and then the function of clearing I/O buffer is running in the software. Meanwhile, the lower computer calls the blood pressure module driver library function MelodyBP.clear( ) to clear the previously saved data;
- Start detection: "R+\n" is sent to the lower computer by VISA writing function. After receiving the reply from the lower computer, the software starts testing, and prepares for...
receiving the blood pressure data sent by the lower computer. The lower computer will judge whether the testing is completed or not. If the testing is completed, the lower computer will process the data and send it to the software in PC.

4.2.3. Data collection module. The lower computer starts to monitor the signal after it sends the collecting command. “DS” and “DW” are used as the sending marks to distinguish static pressure data and pulse wave data, and then these data are uploaded to the software in PC. After receiving the data, the software imports the data into a 2-D array, and then calculates the size of the array as the X value by loop counting. Then the data are bundled into clusters, which are imported into the XY chart function to create an XY waveform.

4.2.4. Blood pressure calculation module. The blood pressure calculation algorithm is shown in Figure 3. Firstly, the static pressure array and the pulse wave array in the 2-D array of blood pressure are separated by the array indexing function. Then the pulse wave array is imported into the peak detection VI, where the threshold and width are set. The width is the number of consecutive data points used in the least-squares fitting method. Theoretically, it should be no more than half of the half-width of the peak, because a larger width may reduce the amplitude displaying of the peak and change its display position. Then the peak detection VI will output the detected peak position and amplitude, and bundle two 1-D arrays as a cluster.

In this paper, a simple and fast Gaussian function is used for curve fitting [2-3]. When the clusters output by the peak detection VI are unbundled, the unbundled data is imported into the Gaussian curve fitting VI as variables. The scattered points of the peak detection are output as Gaussian fitting curve. The peak of the Gaussian fitting waveform is calculated through the centre point coordinates in the Gaussian fitting function. Then the abscissas of the diastolic blood pressure and systolic blood pressure [4-5] in the curve are obtained with the amplitude coefficient method. Finally, the systolic pressure, diastolic pressure and average pressure are respectively calculated corresponding to the static pressure curve.

![Figure 3. Block diagram of blood pressure calculation algorithm.](image)

4.2.5. Data processing module. The data processing module supports functions such as blood pressure recording, historical blood pressure viewing, test report generating, data saving, data importing, and voice broadcasting. The function of blood pressure recording can save the blood pressure value array
and the corresponding testing time array to a text file, which is the source data for the historical blood pressure curve. The function of historical blood pressure viewing is mainly to view the historical blood pressure curve, which includes the systolic pressure, diastolic pressure and average pressure. The test report generating function can export a blood pressure test report based on the testing results of systolic and diastolic blood pressure. Data saving and data importing are mainly to save and import the blood pressure array data. Voice broadcasting is mainly to play the blood pressure value with an audio output device, such as a speaker.

5. Tests and Analysis
The interface of the software is shown in Figure 4. The main functions include data collection, BP (Blood Pressure) calculation, historical BP curve displaying, test report displaying, data saving, data importing, and voice broadcasting, etc.

![Figure 4. Interface of the software.](image)

The testing methods include repetition and comparison. The same testee is continually tested in the same period to observe the consistency and accuracy of the test results. Meanwhile, an accurate electronic blood pressure meter on the market is selected for comparison, so the test results of these two meters for the same testee are compared. The test results are shown in Table 1.

| Testee  | Proposed system  | BP meter on the market |
|---------|------------------|------------------------|
|         | Systolic BP (mmHg) | Diastolic BP (mmHg) | Systolic BP (mmHg) | Diastolic BP (mmHg) |
| Testee 1| 138              | 69                     | 135                | 65                     |
|         | 136              | 67                     | 135                | 65                     |
|         | 131              | 73                     | 133                | 72                     |
|         | 125              | 56                     | 124                | 67                     |
|         | 128              | 59                     | 123                | 73                     |
|         | 126              | 64                     | 129                | 73                     |
|         | 113              | 70                     | 109                | 62                     |
| Testee 2| 117              | 65                     | 108                | 60                     |
|         | 118              | 66                     | 106                | 67                     |

It can be seen from Table 1 that the test results of the proposed system contain certain errors compared with the BP meter on the market, but the errors are all within a reasonable range to meet the
testing requirements. It can be seen from the multiple sets of results from the same testee that the proposed system has better repeatability and consistency, and also has good individual adaptability for those testees with different physical conditions.

Meanwhile, the standard deviations of diastolic and systolic blood pressure of the proposed system in different cases are less than 8 mmHg, which meet the standard deviation requirements recommended by AAMI [6]. So the proposed system can obtain fairly accurate blood pressure value.

6. Conclusions
In this paper, an intelligent electronic blood pressure testing system based on CC3200 and LabVIEW is designed and implemented, where a CC3200 LaunchPad functions as the data collector and processor, and the LabVIEW is used as the user graphical interface. The test results show that the proposed system can meet the requirement of blood pressure testing. The proposed system has a friendly human-computer interface with high accuracy, efficiency and reliability, which can be widely applied in family health care.

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