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Analog Front End Design of a Digital Blood Pressure Meter

Santosh Kulkarni
Dept. of ECE,
BNM Institute of Technology,
Bangalore, India

Dr.Veena. S. Chakravarthy
Professor, Dept. of ECE,
BNM Institute of Technology,
Bangalore, India

Vishweshwara Mundkur
Director,
SenseSemi Technologies,
Pvt. Ltd. Bangalore

***Abstract*— This paper describes the design of analog front end and proof of concept of a digital blood pressure monitor system using the same. Wearable gadgets can provide a high level of accuracy as there will be less human intervention and the whole system will be automated. With advancements made in the field of biomedical, it is important to come up with a more sophisticated device for blood pressure monitoring. The blood pressure monitor described in this paper follows the oscillometric method of measurement and uses a microcontroller with a high resolution ADC. This will help in achieving higher levels of accuracy and also provide the provision to store the results which can be used for further analysis. The blood pressure measurement process described in this paper is a continuous process and involves a lot of signal processing operations and thus requires a very high level of precision while computing the results. Since it is a wearable gadget, power and form factor form the major concerns from electronics point of view. The biggest challenge in the analog front end design of the BP meter is the form factor. Initially the POC of the system is developed and then the optimization is done to meet the requirements for a wearable gadget. The next level is to integrate a communication module that will be helpful in transmission of the concerned data to an analyst for further analysis to ensure that the subject's health is at minimum risk.**

Keywords—Analog, wearable, oscillometric, communication.

I. INTRODUCTION

Human health monitoring is one of the important activities that need to be carried out on regular basis. Various body parameters such as heart rate, blood glucose level, blood pressure need to be monitored to ensure proper fitness of an individual as these parameters vary with the type of activities that the subject is costumed to perform. Having one's blood pressure measured by a physician at the clinic may cause anxiety which is itself is a cause of high blood pressure. As many conditions affect blood pressure, a single measurement may not be sufficient for an accurate diagnosis. Many factors such as physical activity, anxiety or the time of the day can influence one's blood pressure. Thus it is best to try and measure the blood pressure at the same time each day, to get an accurate indication of any changes in blood pressure. Blood pressure is typically low in the morning and increases from afternoon to evening. Further it may not be feasible for every individual to get his/her blood pressure measured every day at a physician's clinic. Thus a need for low cost portable blood pressure measuring unit becomes very important.

Blood pressure measurement is carried out using the oscillometric method. The cuff or an air bag is wrapped around the subject's limb at the heart level and inflated till the oscillation pulses are obtained due blood occlusion. The pulses are then analysed to get the blood pressure readings. The pulses that need to be detected have very low voltage levels and signal processing at this level involves a lot of noise and other unwanted signals, thus proper filtration and amplification is necessary. This paper describes the design of an analog front end for measuring and processing the same for reliable digital signal processing. The processed signal has to be interpreted and analysed using sophisticated software routines that will help in determining the blood pressure levels of an individual. Once the blood pressure readings are known, they can be communicated to a physician or any other relevant person for future actions. The measurement process has to be automatic with minimum human intervention to carry out frequent measurements of blood pressure variations and hence the unit is expected to be highly accurate. The next level could be that of sending the blood pressure information across to a physician either through a GSM module interfaced to the blood pressure measuring unit, so that the physician could monitor the subject or the patient remotely.

II. DEISGN AND IMPLEMENTATION

A. HARDWARE DESIGN

Figure 1 depicts the top level setup of a digital blood pressure (BP) monitoring device.

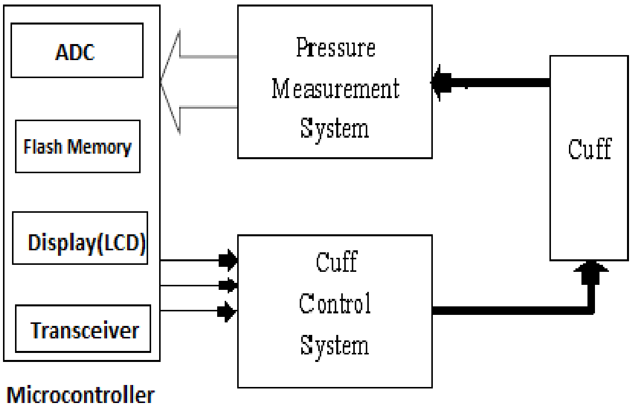


Fig.1 Design of a BP system

The blood pressure monitoring device consists of a microcontroller unit. This forms the major control unit of the entire system. The microcontroller is responsible for providing control signals to carry out the required operations at the specified time intervals.

It is interfaced to a cuff control system which is responsible for inflation and deflation of the cuff. The cuff control system has an Air pump and a solenoid. The Air pump inflates the cuff to the required level based on the individual or the subject under test. The Air pump is controlled by the microcontroller through a PWM waveform and hence the speed of its operation is decided on the pulse period and pulse width of the applied pulses.

The solenoid is used as an air release valve which helps in deflating the cuff. The solenoid is also controlled by the microcontroller through PWM pulses and is functional as soon as the Air pump is switched on. The release of air or deflation of the cuff is determined based on an algorithm and depends on the subject under test.

A pulse measuring device is interfaced to the microcontroller which performs the function of the stethoscope as in the traditional method of measuring blood pressure and is responsible for detection of pulses which occur due to cuff inflation and blood flow. The detection of pulses is done after filtering the obtained signal from the pressure sensor. Figure 2 shows the interface to the microcontroller.

The pressure measurement system contains a pressure sensor. The pressure sensor plays a very important role in determination of blood pressure values. The cuff pressure is converted into voltage readings and these readings are used for further processing. The pressure gives a differential output which is generated due to the inflation of the cuff wrapped around the subject's wrist. The pressure sensor output is then amplified and filtered to obtain the oscillometric data and then correlated with dc pressure of the cuff to obtain the exact blood pressure readings. The operation of Air pump as well as solenoid is also controlled based on the oscillometric pulses that are obtained due to the cuff pressure.

Once the oscillations have been extracted the pulses so obtained are used to determine the mean arterial pressure, the systolic and diastolic pressure. Figure2 shows the data that is obtained from the pulse measuring unit and applied to the microcontroller for further processing to obtain the blood pressure readings.

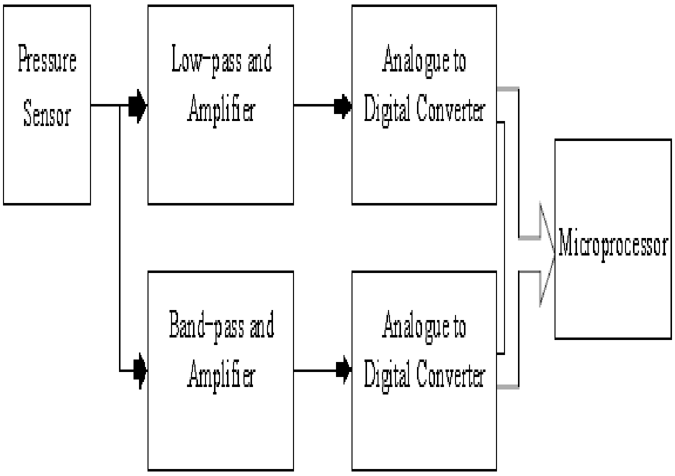
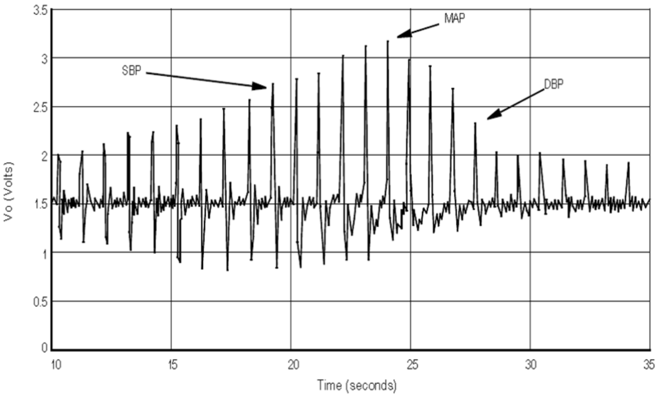


Fig. 2 interface to the microcontroller

The amplifier output is then fed to the microprocessor i.e. to the A/D converter. The extracted oscillation signal is as shown in Figure3.



Extracted Oscillation Signal at the Output of Amplifier

Fig. 3 Oscillometric data

Analogue to digital converters

The signals should now be digitised for processing. They must each be digitised with sufficient accuracy and at a sufficient rate to capture the salient features:

- The microprocessor will need to correlate pressure at any given moment in time with the amplitude of fluctuation at that point in time. Consequently, the A/D converters should run at the same rate and, ideally, take samples at the same times.
- The highest frequency signal we wish to sample is the cardiac synchronous fluctuation signal. 5 Hz is a reasonable upper limit for the heart rate. Nyquist sampling theory indicates that the minimum rate at which sampling will not lose information is therefore 10 Hz. However, in this case it is necessary to characterise the fluctuations in some detail and so it is necessary to take 5 to 10 samples per cardiac synchronous fluctuation. A sampling rate of 50 to 100 Hz would therefore be appropriate.
- *vb* must be digitised with sufficient accuracy to describe the underlying pressure to 1 or 2 mmHg in a range of 300 mm Hg. 9 bits give a dynamic range of 512 which should be sufficient.

- If the pressure sensor output is 1 mV per mmHg then the instrumentation amplifier, including the low−pass section, must amplify 300 mV to close to the maximum input of the A/D converter. If the A/D converter has a range of 0 to 5 V then the pass−band gain must be 16.7.
- vf must be digitised with sufficient accuracy to describe the fluctuations with sufficient accuracy so that the relative amplitude of each fluctuation can be determined. 8 bits gives a dynamic range of 256 or a step of 1/256 which is less than half a percent, which should be sufficient given that fractions given earlier.

Microprocessor

The microprocessor runs a program which controls the cuff (via the three phase cuff control circuitry, as considered above for the automation of the method of Korotkoff) and interprets the two pressure signals. The fluctuation signal will be analysed to determine the amplitude of the fluctuations at any point in time. The point of maximum fluctuation will be when the underlying pressure is the Mean Arterial Pressure (MAP). Having determined this, the Systolic Pressure can be determined by reviewing the data already acquired and selecting the underlying pressure which corresponds to an amplitude of 0.55 of the fluctuation amplitude at the MAP. The Diastolic Pressure will be the underlying pressure when the amplitude of the fluctuations has decreased to 0.85 of its maximum value. The accuracy of the systolic and diastolic pressures could be increased through the use of interpolation. Once this has been determined the cuff can be deflated and the readings returned. Finally, the microprocessor may also calculate the Pulse Rate of the patient. The fluctuations that have been analysed for amplitude information are cardiac synchronous and so determining their frequency will give a Pulse Rate.

B. SOFTWARE DESIGN

The hardware unit is made noise free with sufficient amount of filtration and the ensured that only the relevant data is sent across to the microcontroller for processing to get the required information regarding the blood pressure. The software part consists of different stages with relevant modules that will be helpful in carrying out the processing of raw data. The ADC unit of the microcontroller is made use of in order to get the digital equivalent of the analog data obtained from the pressure sensor and the subsequent hardware components. All the programming for this project is done using C language with the help of mbed compiler for implementing the algorithm and developing the program. The putty hyper terminal is configured accordingly as it is used for displaying the relevant processed data or information regarding the blood pressure levels obtained for the working model of the developed prototype.

. The initial stage is concerned with capturing the ADC values and sampling at the required rates before buffering the sample values. Two ADC channels are used and each is sampled at a different rate. One channel as mentioned before is sampled at 250Hz and the other is sampled at 2Hz. The filtered signal from the INA(Instrumentation Amplifier) is sampled at 250Hz and the unfiltered signal from the INA is sampled at 2Hz. There are two ways or approaches to determine the blood pressure readings, one being that during inflation of cuff and the other while deflating the cuff. The approach adopted in this system is the first one i.e. during inflation of the cuff. Gradual rise in dc pressure and filtering the dc pressure values gives the required data for processing. The speed of inflation is controlled by the Air pump's speed of operation; the air pump is driven by PWM pulses whose pulse widths determine the speed of operation or inflation of the cuff. During this period, as the solenoid is linear in nature, it is kept off by switching it on. This is also controlled using PWM pulses and is given a high voltage level to keep it off mechanically. In other words the pulse width is maximum and the period is 0.Due to this approach, the deflation of the cuff is done instantly and there is no gradual change in the cuff pressure, it drops to 0 level immediately as the release valve is opened. The filtered signal is buffered and processing on it is done dynamically to determine the peak values of the filtered data. The peak values are helpful in determining the cut off point or the point where the air pump has to be switched off to stop the inflation and the release valve has to be opened to release the pressure and start deflation. The point of cut off is determined by setting a threshold value and checking if any of the peak values fall under the threshold point i.e. as long as the peak values are greater than the threshold values, the inflation is done or the data is buffered. Once the peak value falls below the set threshold point, the air pump stops functioning or it switches off and the release valve is opened. This point indicates that the required data for computing blood pressure readings have been gathered and processing on this data has been started. As gathering of data is done while inflating the cuff, it is to be noted that the release valve is opened immediately and the air pump is stopped abruptly and that there is no gradual decrease in pressure during this operation. The values required for processing are buffered in a local memory location in the microcontroller. A fixed memory size for the buffer is initially allocated and the filtered values are stored in the buffer. The buffer may not be full all the time as the values only uptill the cutoff point are stored and hence the buffer may be having some excess memory locations which may be storing some junk or garbage values and these values may lead to deviations of computed values from the required or expected pressure readings. To avoid this, all the buffer are initialised to 0 and then the filtered values are overwritten onto the 0 values. The non zero buffer values are then used for computation of blood pressure readings. The other channel of the ADC is used for capturing the dc pressure values. The linear rise in pressure value is recorded. This channel is sampled at a much lower rate and the values so obtained are stored in a separate memory location. The sampled values of both the ADC channels are mapped to obtain the desired blood pressure readings.

Once the values have been buffered, the computation involves mapping of filtered data to the dc pressure or the unfiltered data to obtain the blood pressure readings in the desired format i.e. in units of pressure (preferably in mmhg). The mapping algorithm plays a very important role in determining the blood pressure levels and hence must be very efficient. The accuracy of the mapping algorithm determines the correctness of the blood pressure readings. The computations comprise of determining systolic pressure, diastolic pressure, pulse pressure and the heart rate.

III. RESULTS AND CONCLUSION

Figure 5 depicts the output of the INA before feeding the outputs to the microcontroller unit.

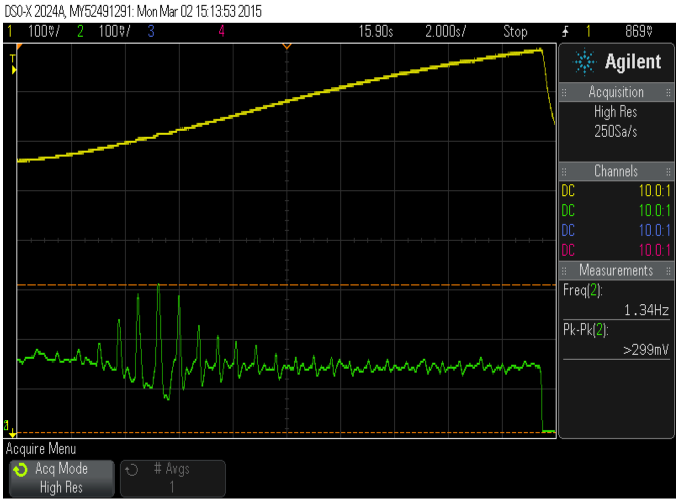
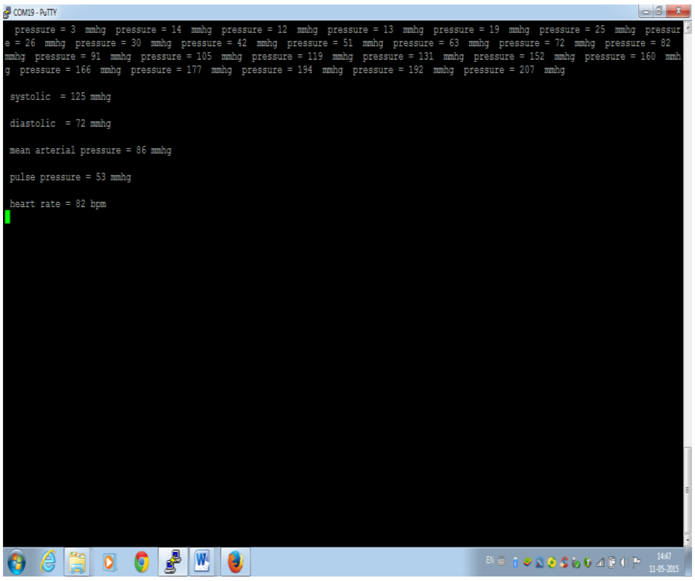


Fig5. INA outputs (Source 1 is unfiltered and source 2 is the filtered output)

Figure 6 shows the final output of the system. The hyper terminal putty is used as a display unit for displaying the results on the console via serial communication protocol.



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 pressure = 3  mmhg  pressure = 14  mmhg  pressure = 12  mmhg  pressure = 13  mmhg  pressure = 19  mmhg  pressure = 25  mmhg  pressur
e = 26  mmhg  pressure = 30  mmhg  pressure = 42  mmhg  pressure = 51  mmhg  pressure = 63  mmhg  pressure = 72  mmhg  pressure = 82
mmhg  pressure = 91  mmhg  pressure = 105  mmhg  pressure = 119  mmhg  pressure = 131  mmhg  pressure = 152  mmhg  pressure = 160  mmh
g  pressure = 166  mmhg  pressure = 177  mmhg  pressure = 194  mmhg  pressure = 192  mmhg  pressure = 207  mmhg

 systolic  = 125 mmhg

 diastolic  = 72 mmhg

 mean arterial pressure = 86 mmhg

 pulse pressure = 53 mmhg

 heart rate = 82 bpm
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Fig6. Final output of the BP monitoring device

IV. CONCLUSION

The results obtained are in good agreement with the theoretical concepts. Each unit has been tested separately for correct functionality before carrying out the integration of all the components together. The speed of inflation will be controlled based on the occurrence of pulses and will be taken care that none of the samples are missed. The intention is to minimize the power consumption by writing an efficient software routine for controlling the entire operation of estimating the blood pressure level for any individual. Once the blood pressure levels are known, monitoring an individual would the next step in case of abnormalities. Sending out the required information (blood pressure levels) to the concerned physician could help in avoiding health hazards. One way of sending the information would be to use a Bluetooth module by interfacing it to the blood pressure measuring unit. A digital blood pressure measuring unit equipped with a Bluetooth module for short range communication is shown in figure 7.

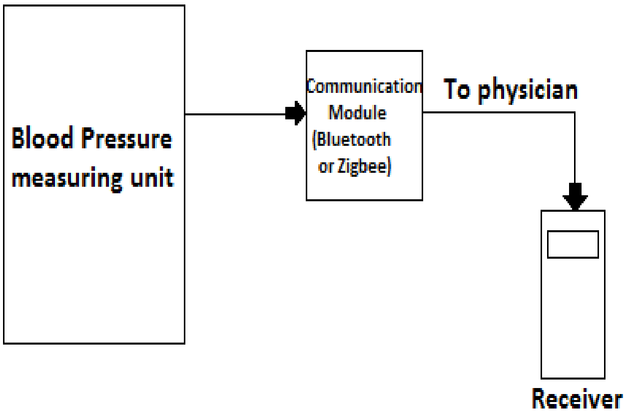

Fig.7 BP unit interfaced to a communication module

V. ACKNOWLEDGEMENT

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