Design of Automated Oscillometric Electronic Sphygmomanometer Based on MSP430F449

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***Abstract* - This paper presents an automated oscillometric electronic sphygmomanometer. It uses MSP430F449 single-chip microcomputer as the controller kernel. Firstly the tiny signal which is detected by MPS2107 pressure sensor is amplified by the dedicated chip INA128, then the amplified signal will be divided into cuff-pressure oscillation signal (AC) and cuff pressure signal (DC). Secondly AC and DC signals are filtered and conditioned by the OP amp LM324. Thirdly the filtered and amplified signal will be sampled by ADC module of MSP430F449. AC and DC voltage series will be got. By oscillometric method, systolic pressure and diastolic pressure can be calculated out and displayed in LCD. The serial communication and real-time clock are also included in the system. The automated electronic sphygmomanometer performs satisfactorily when compared with conventional auscultation method and has realized accurate measurement of blood pressure.**

Index Terms* - *Ocillometric sphygmomanometer; MSP430; Interference resistance

I. INTRODUCTION

It is very important to get the accurate blood pressure of the patients for the diagnostic purpose. Among the routine physical checks done by the people themselves, the monitoring of the blood pressure is also an essential item. Conventional noninvasive methods for blood pressure measurement rely on the use of an inflatable occlusive cuff followed by analysis of the Korotkoff sounds by either stethoscopic or electronic auscultation methods. But the mercury in the mercury sphygmomanometer has potential threaten to health and environment, the mercury sphygmomanometer must be operated by health care workers and the measurement result is affected by operators. The oscillometric method has the advantage that no special transducers or microphones need to be applied to the subject in addition to the arm cuff [1]. Thus, blood pressure measurement can be performed by an untrained observer or by the subject. This paper presents an automated oscillometric electronic blood pressure monitor based on MSP430F449 microprocessor, which can indicate systolic, mean and diastolic pressure. The oscillometric sphygmomanometer is very convenient for nonprofessional users who want to monitor their blood pressure at home. It is handy, and easy to operate for those people who perform a daily self-examination.

II. OSCILLOMETRIC METHOD

The oscillometric method of measuring blood pressure, which uses the amplitude of cuff-pressure oscillation, provides two transitions during cuff deflation: a sudden increase in oscillation amplitude and clear maximum amplitude of oscillations [2]. The cuff was inflated quickly to above 180 mm Hg, and then deflated at a rate of 3 mm Hg per heart beat. As the cuff pressure (DC component) decreases, the oscillations amplitude (AC component) in cuff-pressure will change regularly. The oscillation signals in cuff-pressure were amplified and band-pass filtered (0.6 6.4 Hz) and recorded simultaneously, as shown in Fig.1. It has been established by Mauck et al. [3] and Posey et al. [4] that the pressure for maximal oscillations corresponds to mean arterial pressure (MAP). The oscillometric maximum is ultimately caused by buckling of the brachial artery under the cuff. Systolic pressure (SP) is concurrent to the moment of sudden increase of the oscillation height, and diastolic pressure (DP) occurs at the first abrupt drop of the oscillation height. But it is hard to find out the moments of sudden increase and the first abrupt drop of oscillation height from the oscillation-amplitude-of-cuff-pressure curve. A numerical solution is provided for the oscillations in cuff pressure for one cycle of cuff inflation and deflation.

In order to obtain systolic, mean and diastolic pressure from the characteristic change, two ratios are used for identifying systolic and diastolic pressures from the amplitude of the oscillations. Most of the microcomputer manufacturers refuse to disclose the algorithm to be followed when blood pressure is measured by the oscillometric method. In this paper, the systolic detection ratio was determined to be 0.593, and the diastolic ratio was 0.717 [5]. In other words, during the cuff deflation when the ratio of the cuff-pressure oscillation amplitude and maximum amplitude is 0.593, the cuff pressure at this time will be SP, while the cuff-pressure oscillation amplitude reaches the maximum, the cuff pressure at this time will be MAP, when the ratio decreases to 0.717, the cuff pressure at this time will be DP (see Fig. 1). These values corresponded well with those determined by empirical techniques over a wide range of arterial blood pressures. These ratios alter with blood pressure, but the tightness of the cuff wrap did not change their value.

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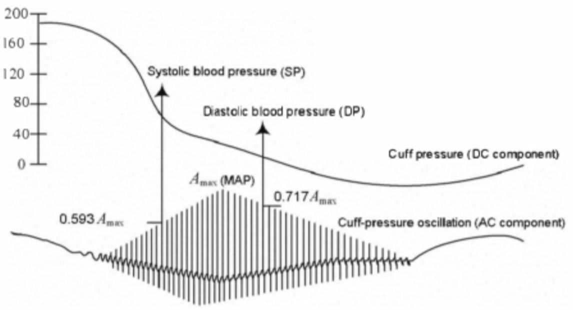

Fig. 1 Fundamental of oscillometric method

III. SYSTEM PRINCIPLE

The MSP430 family of ultra-low-power 16-bit RISC mixed-signal processors from Texas Instruments (TI) provides the ultimate solution for battery-powered measurement applications. TI has created the MSP430 which enables system designers to simultaneously interface to analog signals, sensors and digital components while maintaining unmatched low power. So MSP430F449 is used as the micro controller unit. The air pump and KSV05B-6J type solenoid valve are driven by ULN2803 which is a monolithic high-voltage, high-current Darlington transistor array, the chip ULN2803 is connected with pin 3.0 and pin 3.1 of MSP430F449. The cuff pressure can be adjusted by air pump and solenoid valve working together. The cuff was inflated quickly to above 180mm Hg, and then deflated at a rate of 3 mm Hg per heart beat. In the exhaust process, the cuff pressure was transferred to 0 75mV voltage by MPS2107 pressure sensor. The output voltage of sensor was firstly amplified in 50 times by instrument amplifier INA128. Then the amplified voltage was divided into AC component which is cuff-pressure oscillation and DC component which is cuff pressure. The DC component was low pass filtered (0.6Hz) and analog-digital converted by ADC module in MSP430F449. The AC component was band pass filtered (0.6 6.4Hz), amplified further in about 10 times and sampled by ADC module in MSP430F449. If the sampling frequency is enough, DC voltage series and AC voltage series will be obtained. Using oscillometric method stated previously to analyze AC voltage series, the detection moments of SP and DP would be found out. According the detection moments, SP and DP would be obtained from the DC voltage series. In the whole process, the cuff pressure was displayed by LCD in 2 seconds per interval. In the end, SP, DP and heart rate were displayed by LCD, too. The measurement results and time from DS1302 RTC would be put into memory of MSP430F449. These data can be uploaded to computer through serial port by UART. To do this will help the doctor to analyze the patient history of physical condition. Fig. 2 is the schematic diagram of system structure.

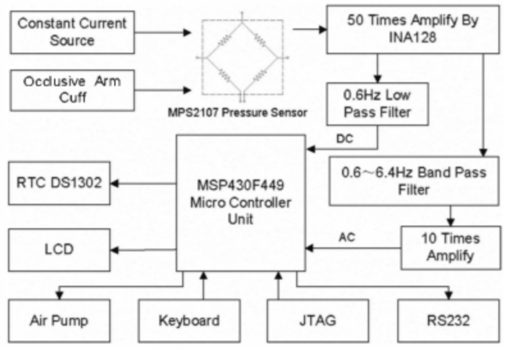

Fig. 2 Schematic diagram of system structure

IV. SIGNAL PROCESSING CIRCUITS

4.1 Pressure sensor circuit

The pressure sensor is the core component of sphygmomanometer. Resistive pressure sensor MPS2107 which is manufactured by Metrodyne Microsystem Corp. is applied in the system. MPS2107 includes a Wheatstone bridge which is constructed by four silicon wafer resistors and the output voltage of the bridge alters with outside pressure because of piezoresistive effect. MPS2107 has many advantages: solid-state reliability, easy to use, wide operating temperature range, easily embedded in portable equipment. Fig.3 is terminal connection diagram for MPS2107. Tab.1 is the parameters of MPS2107.

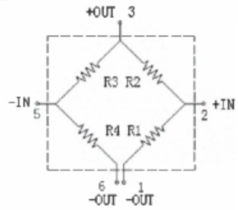

Fig. 3 Terminal connection

Tab.1 Parameters of MPS2107

Parameter	Range or value
Pressure range	5.8psi(40KPa)
Temperature Range	-40 85
Excitation voltage	5V
Full scale span voltage	75mV
Sensitivity	1mv/4mmHg

MPS2107 is driven by 1.5mA constant current source (see Fig. 4). As MPS2107 output signal is very weak and not matched with MSP430F449 requirement, the sensor signal must be amplified by instrument amplifier (IA). IA can be structured by three operation amplifiers, but the precision resisters are hard to obtain, so dedicated chip IN128 is adopted. The versatile 3-op amp design and small size make INA128 ideal for a wide range of applications. The INA128 is laser trimmed for very low offset voltage (50μV), drift (0.5μV/°C) and high common-mode rejection (120dB at Gain ⩾100). A single external resistor sets any gain from 1 to 10,000. The gain can be calculated using (1).

$$G = 1 + 50k\Omega / R_4 \quad (1)$$

4.2 Cuff pressure detection circuit

In the exhaust process, cuff pressure changed very slowly. The frequency of cuff pressure signal is slow. So a low pass filter (0.6Hz) is adopted to extract the cuff pressure. Because second-order low pass filter decays faster and has better filtering effect for high frequency signal than first-order filter, so second-order filter is used. Fig. 5 is the circuit designed by Filter Wizard software.

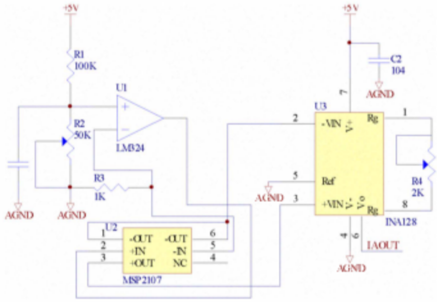

Fig. 4 Pressure sensor and INA128 amplification circuit

The second order low pass filter has been simplified in order to reduce the error amplification, the transfer function is (2).

$$G(s) = ka_0 / (s^2 + a_1 s + a_0) \quad (2)$$

In Fig.5, $K = 1, a_1 = 1/C_2(1/R_1 + 1/R_2), a_0 = 1/R_1R_2C_1C_2$, because of $f = 0.6Hz, a_0 = \omega^2$, if assuming $C_1 = C_2 = 10\mu F$, $R_1 = 20k\Omega$, then $R_2 = 35K\Omega$ can be calculated out. There is no $35K\Omega$ resistor, so $R_2 = 36K\Omega$. Fig. 6 is the amplitude-frequency characteristic of low pass filter simulated in Multisim10 software.

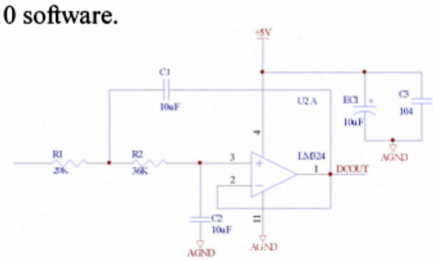

Fig.5 Second order low pass filter (0.6Hz)

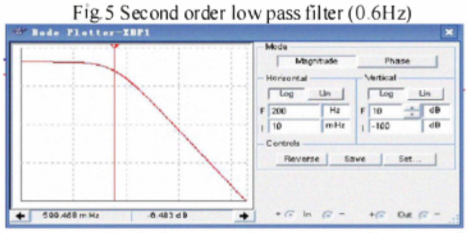

Fig.6 The amplitude-frequency characteristic of low pass filter

4.3 Cuff-pressure oscillation detection circuit

The output of pressure sensor includes cuff pressure signal, cuff-pressure oscillation, 50Hz power interference and some other random interference. The frequency range of cuff-pressure oscillation signal is 0.6 6.4Hz, so a high pass filter whose cutoff frequency is 0.6Hz and a low pass filter whose cutoff frequency is 6.4Hz are designed. The parameter calculation is same with the second order low pass filter. It is omitted. Fig.7 is the circuit designed by Filter Wizard software, Fig.8 is the amplitude-frequency characteristic of low pass filter simulated in Multisim10 software.

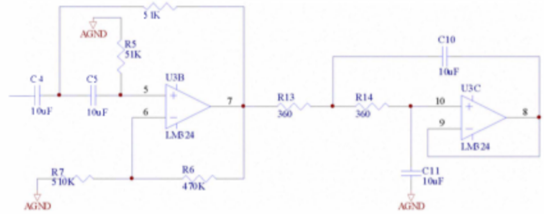

Fig. 7 The band pass filter(0.6 6.4Hz)

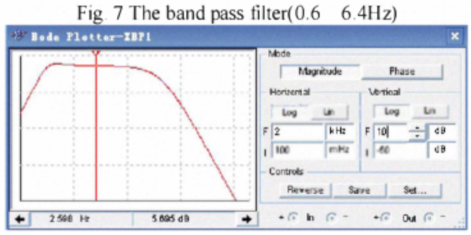

Fig. 8 The amplitude-frequency characteristic of band pass filter

The output signal of band pass filter is the cuff-pressure oscillation signal. But it is not matched with MSP430F449 ADC module. So the signal should be amplified further in about 10 times by reverse amplifier. By sampling AC voltage series will be obtained [6].

4.4 Other function modules

In order to record the measured time and date, real time clock (RTC) chip DS1302 manufactured by DALLAS Corp. is adopted. By serial port chip MAX232 manufactured by MAXIMUM Corp., the measured data can be uploaded into computer. The air pump and KSV05B-6J type solenoid valve are driven by ULN2803 manufactured by Texas Instruments Incorporated. Custom 160 segments LCD can reduce effectively power consumption. In MUX4 mode, MSP430F449 can drive directly the 160 segments LCD, no other circuit is needed.

V. SOFTWARE DESIGN

5.1 Software filtering

Although the hardware filter can filter most interference, the results of ADC should be filtered by software. Limiting filter, median filter, average filter, recursive average filter, and first order lag filter are common. The cuff pressure signal changes slowly and the difference of two sample points is limited, so limiting filter can eliminate pulse interference. The limiting filter can remove the sample point which changes too much. The filter code is followed.

```
#define A 10
char value;
char filter()
{
    char new_value;
    new_value=get_ad();
    if((new_value-value>A)||(value-new_value>A))
        return value;
    reture new_value;
}
```

The frequency of cuff-pressure oscillation signal is high, and the signal is periodic signal, so first order lag filter is used. This filter can suppress effectively the periodic interference. The filter code is followed.

```
#define a 50
char value;
char filter()
{
    char new_value;
    new_value=get_ad();
    returen (100-a)*value+a*new_value;
}
```

5.2 System workflow

The key of software design is to obtain AC voltage series and DC voltage series. According to Shannon sampling theory, the sampling frequency should be 2 times of input signal frequency at least, so 200Hz is enough to sample cuff-pressure oscillation signal. The ADC module of MSP430F449 has 4 modes, repeated sequence of conversion mode is used to sample cuff pressure and cuff-pressure oscillation signal. In a second, 200 AC voltages and 200 DC voltages will be got. In the 200 AC voltages, we can find out the peak by comparison. If an AC voltage is bigger than the front five voltages and the back five voltages, then it is a peak. There is perhaps only one peak if the heart rate is very slow or there are several peaks if the heart rate is fast. This AC voltage peak and corresponding DC voltage are put into AC voltage series and DC voltage series, From the AC voltage series, we can find out the maximum A_{max}, the corresponding DC voltage is MAP, and the $0.593A_{max}$ can be found out forward in the AC voltage series, the corresponding DC voltage is SP, the $0.717A_{max}$ can be found out backward, the corresponding DC voltage is DP. When the DC voltage is lower than 0.5v, it shows that the cuff pressure is lower than 50mm Hg, the solenoid valve is opened and cuff exhausts fast, the measurement is over. Fig. 9 is the workflow chart.

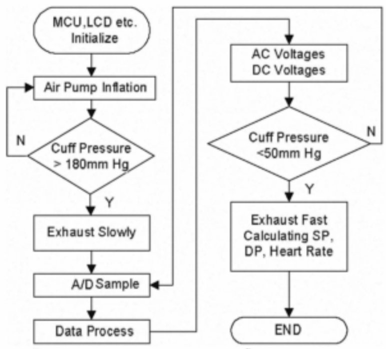

Fig. 9 The main program flow chart

VI. Measurement result comparison and analyse

To test the measurement result of electronic sphygmomanometer, it is compared with the conventional auscultation method result (Tab.2). From Tab.2, it can be seen that the measurement results of electronic sphygmomanometer are similar with auscultation method results. In the measurement process, there is some small difference between the pressure sensor output signal, the output signal of the filtering circuit and the real value, therefore there is some error [7].

Tab.2 In comparison with auscultation method

	Electronic Sphygmomanometer			Auscultation Method		
	Heart Rate	SP	DP	Heart Rate	SP	DP
Tester 1	75	69	110	78	64	109
Tester 2	72	64	108	70	61	106
Tester 3	91	82	135	88	69	128
Tester 4	79	77	110	75	74	110

VII. Conclusions

The proposed electronic sphygmomanometer performs satisfactorily when compared with conventional auscultation method. The right instrument design leads to a reliable device realization within acceptable accuracy limits and reasonable construction costs. Special attention has been given to the design of appropriate signal processing circuits so that errors due to environmental conditions or random arm movements are minimized and the desired signal is clearly distinguished from noise levels. Further improvements in instrument accuracy are possible through optimized oscillometric method. Optimum oscillometric maximum and the systolic and diastolic detection ratios can reduce further instrument errors.

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