Embedded System-Based Mobile Patient Monitoring Device

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Abstract

This paper describes the design of a mobile medical device that can be used to monitor the human temperature and blood pressure (BP) using a stand-alone single chip microcontroller. The device hardware architecture consists of temperature and pressure sensors, signal conditioning circuits (SCC), single chip microcontroller, LCD display and GSM modem. An embedded software algorithm acquires temperature and pressure, processes, transmits, displays and stores it in the built-in EPROM of the microcontroller. A preset trigger level for the temperature and/or the BP is stored in the EEPROM of microcontroller. Once the desired programmed trigger level of any of the signal is reached, the microcontroller downloads the current value of the temperature and BP to the GSM modem. Then, GSM automatically dials presorted mobile number/s and transmits both parameters as a normal mobile message to a physician, nurse and/or emergency personal. A short database containing these parameters are collected and stored in a lookup table. This database can be used to track the patient temperature and BP history if needed.

1. Introduction

Embedded systems have become an integral part of home appliances, automobiles, smart building, telecommunications equipments and medical devices. When the embedded system is designed based on a single chip microcontroller, they become more attractive due to the built-in feature such as the programmable memories, analog-to-digital converter and programmable input/output timers. These built-in components can be used to host the embedded software algorithm that operates a device based on required function.

Several devices for telemedicine have been reported in the literature. A telemedicine design using mobile telephone was reported by Woodard et. al, 2001 [1]. The device is an integrated telemedicine system which consists of telephone, with sensors and processor for patient monitoring, and mobile telephone receiver via a standard infrared (IrDA) port. Signals from the telephone are transmitted at the standard GSM rate to PSTN network at the hospital side which is connected to a computer that acts as a server. The received signal can be downloaded to a mobile laptop computer.

The concept of a wireless distributed sensor networks for patient monitoring and care was introduced by Sichitiu, 2000 [2]. The system consists of patient sensors, an intermediate node layer consisting of the supervisor processor residing with each patient, and root node processor located at the central monitoring facility. The system provides instantaneous medical feedback from the monitored patient roaming outside of the treatment centers and within the network coverage area.

In 2000, Chan reported a www+smart card health care management system that combined the World Wide Web and smart card technologies to support a mobile health management framework [3].

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Recent publication of Pettichis et al., 2002 [4] showed an overview of Wireless Telemedicine Systems. The overview highlighted the use of wireless technologies in telemedicine areas such as emergency, tele- cardiology and remote monitoring.

Some of the above mentioned systems use the GSM technology in medical devices to acquire the data via the IrDA, which are transmitted and received at the other end by PC-based server networks for further process. This requires sending all measured data to the server via a public networks which may take long time and is subjected to error.

This paper describes the design of a stand-alone single chip microcontroller with embedded software algorithm to monitor two parameters, the human temperature (Temp) and Blood pressure (BP). The patient may wear the embedded system-GSM modem as a wrist watch or attached to his/her belt. The device can transmit the parameters to and receive commands from a mobile phone/s. Section two describes the hardware architecture followed by the device software algorithm. Section four discuses the accuracy and related error sources. The last section of the paper is roadmap for future work and conclusion.

2. Device hardware architecture:

The device hardware architecture consists of several modules: sensors pack and signal conditioning circuits, 8-bit microcontroller with two lines of LCD display, GSM modem and SIM card.

2.1. Sensors pack and signal conditioning circuits.

The sensor pack has two transducers to measure the temperature and pressure. Thermocouple is a temperature sensor with signal conditioning circuit .It has a low power operational amplifier and a couple of resistors. The output of the thermocouple will provide a 0-volt for 0 degrees centigrade and a 5-volt output for 50 degrees centigrade.

For the values between the two extremes, there is a linear relationship between output voltage and sensed temperature. The signal conditioning circuit, SCC, is used to make the sensor output compatible with the microcontroller built-in analog-to-digital converter. The relationship between the SCC input and output is linear and can be described using the following equation:

$$Y = mX + B \qquad (1)$$

Where:

Y = dependent output variable and can be expressed by decimal value of the digital output. This output is the SCC output. It is fed to ADC channel zero (An0) of the microcontroller's built-in ADC.

M = slope or conversion gain (m = 1/LSB).

LSB = the least significant bit of the analog-to-digital converter.

X = Independent variable (analog input voltage to the SCC and the output of the temperature sensor in volts).

B = Y-axis intercept or zero offset. It is assumed as zero in this application. Substituting B with zero in equation 1 gives the following result:

$$Y = mX. \qquad (2)$$

The above equation can be realized using the LM 335 temperature sensor which has the following transfer function:

$$V_T = 10\ mV / {}^{O}C \qquad (3)$$

Where is V_T the temperature sensor analog output. This output swings between 0^{O} C to 50 ^{O}C temperatures and between 0 -500 mV voltages. A signal conditioning circuit is designed to provide gain of 2.56. This will make the output voltage swing between 0-1.28V and it is equivalent to 0 ^{O}C to 50 ^{O}C. An ADC reference voltage is supplied to provide resolution of 0.1 ^{O}C. The output of the temperature's SCC is connected to channel 0 of the ADC (An0).

The pressure sensor has an input-output relationship that is similar to the temperature sensor. The output ranges from 14-300 mmhg. For the values between the two extremes, there is a linear relationship between output voltage and sensed temperature. SCC is used to make the sensor output compatible with the microcontroller built-in analog-to-digital converter. It is connected to channel 1 of the ADC (An1).

An offset and gain adjustments feature has been added to both temperature and pressure signal conditioning circuits. Both adjustments are needed to offset the long time gain and offset drift due to environment or components mismatching.

The pressure sensor cuff is inflated by its compressing Digital output (D0) and deinflating using digital output (D1). The pressure sound indicator is connected to analog signal (An2).

2.2. The microcontroller:

The microcontroller consists of an 8-bits processor that has 8-channels analog to digital converter (ADC) and several digital input/output ports. The ADC resolution is designed to have 0.1 ^{O}C and x mmhg. The built-in EPROM is used to host the embedded software algorithm that takes care of the parameters acquisition, processing, displaying, transmitting and receiving. The built-in EEPROM is used to save the online measured parameters along with their hourly and daily averages. The RS-232 is utilized for the GSM modem communication to upload and download messages that contain related patient's information and status.

2.3. The GSM modem:

The GSM modem offers high speed wireless connection. It is attached to the data adapter RS-232 and can be used as a stand-alone modem. Via the RS232, it can be connected to a personal computer or other devices such microcontroller. It supports five technologies for wireless data transfer, which can be used where GSM networks is available. The GSM modem is used as a short message server (SMS) device. It can send and receive messages containing a maximum of 160 characters. It supports call forwarding, call restriction, call transfer, multiparty calling and security options such as call barring [5].

In this application, The GSM modem is interfaced with the 8-bit microcontroller via RS-232 adapter. The modem receives a message from the microcontroller that contains the patient's information such as Name, ID, current temperature and pressure. It will then transmit the information as an SMS to pre-stored mobile phones. The receiver can be a health care personnel such as on call physician, nurse or/and emergency aid worker. Also, it can receive SMS messages from any one of the health care personnel acquiring more information. In the following section, a detailed embedded software algorithm for parameters acquiring, processing, displaying, transmitting and receiving are developed. Figure 1 shows the hardware layout of the proposed device.

3. Device software development

The embedded software is written using the microcontroller native language. Based on reset or power up, the microcontroller start to inflate the cuff with air and the blood pressure sound indicator is monitored until it fades away. One second later the microcontroller stops inflating the cuff and enable the release actuator to start deflating the cuff air pressure slowly. Meanwhile, the microcontroller starts the ADC conversion process and reads the pressure value every 16 μ-sec along with the indicating pressure signal. This process continues until the indicating signal is enabled again. When the trigger level of the indicating signal is reached it implies that the cuff air pressure is equivalent to the systolic blood pressure. This value will be stored as current systolic blood pressure. Along with this reading, the system will save the current value of the temperature. Microcontroller keeps listening to the indicating signal. Once it fades and is no longer heard, the value of the diastolic blood pressure is registered and saved along with the current temperature.

The above process is a real-time interrupt driven event. The main program, the acquired and processed values are converted to BCD then displayed on the LED. If the acquired blood pressure and or temperature exceed a pre- stored warning level, the following sequence of events will take place:

- A SMS message will be transmitted to the attached GSM modem via the RS232 with the following information:
  - Patient Name and ID.
  - Current value of the blood pressure and temperature.
  - Mobile number to dial to: one of the healths personnel.
- The GSM modem then calls the attached mobile number and sends the above SMS to the first priority mobile number in the list.
- Once the message is read, the reader must acknowledge by replying to the system. Otherwise, the system sends the above message to the second priority mobile number in the list.
- If there is no acknowledgement within two minutes, it will send the message to the third priority mobile and wait for acknowledgement.
- The system repeats the above chain of commands until an acknowledgment is received.
- Worst case scenario, the system repeats the above procedure x number of times, if there is no answer and the patient status is getting worse then it will call 911. Assuming 911 has SMS message center.

Once the health personnel receive the SMS message, he/she can acquire more parameters from the system by sending SMS message such as the pressure and temperature average values for the last hour and day. The health personnel may send SMS or calls the patient direct for further instructions.

4. Accuracy and error analysis:

The system accuracy depends on several factors. The signal conditioning circuits' components mismatching, aging factor, output offset and environment effect, the ADC quantization error and rounding error due to the reminder from the fraction division. Some delay time that may be caused by the the interrupt procedure. The subjects of this error are under investigation and further work will be carried out to enhance the device accuracy and stability. It is worth mentioning that the major objective of this paper is the GSM-microcontroller integration that enhance the mobility of the patient and communicate with the health personal from anywhere anytime.

5. Future development and conclusion

A prototype of GSM-based mobile patient has been design, developed and tested using off–the-shelf components. The device gives more freedom for patients to roam around the GSM-Network coverage area and allow the health personnel to keep in touch with patient without being around the hospital bedside. The system is scalable and extended to have up to eight different signals from the patient.

6. References

[1] B. Woodward, R S. H. Istepanian and C. I. Richards, "Design of a Telemedicine System Using A mobile Telephone. IEEE Transactions on Information Technology, Vol, 5, No. 1, March 2001. pp. 13-15.

[2] Bauer, P.; Sichitiu, M.; Istepanian, R.; Premaratne, K.; "The mobile patient: wireless distributed sensor networks for patient monitoring and care", Proceedings of the Information Technology Applications in Biomedicine-IEEE EMBS International Conference, 2000, Pp: 17 -21

[3] A. T. S. Chen, "WWW + Smart card: towards a mobile health care management system", International Journal of Medical Informatics", Vol., 57, Issue 2-3, July 2000, pp. 127-137.

[4] S. Pattiches, E. Kyriacou, et., "Wireless Telemedicine Systems: An Overview", IEEE Antenna's& Propagation Magazine, Vol. 44, No., April 2002, pp 143-153.

[5] Nokia 30 GSM Connectivity Terminal User's Guide for modem use, 2002 Nokia Corporation, www.noka.com.

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