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Ambulatory Health Monitoring System Using Wireless Sensors Node

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Abstract

In this paper, we propose an improvement of our previous work in this field by developing a heart rate , body temperature and blood pressure monitor system based on new Arduino Mega micro-system device. It offers the advantage of portability over old embedded system (tape-based recording systems). The paper focus on: how we implemented algorithms to analyze heart beat rate signals in real-time, how to fusion data of different sensors mainly here temperature and blood pressure and to transmit the data via radio frequency (Xbee module). Then explain a web server application for healthcare givers to access the data. In addition, it allows doctors to get the heart beat rate file of the patient by email every twenty four hours. It can also be used to control patients or athletic person over a long period. The system reads, stores and analyses the heart beat rate signals, body temperature repetitively in real-time. The hardware and software design are oriented towards a single-chip microcontroller-based system, hence minimizing the size. The important features of this paper are the implementation of extremums and energy in the algorithm to compute patient heart rate and detect any anomaly within the P wav in ECG signal. The first tests were encouraging.

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Keywords: Heart Rate, Arduino Microcontroller, sensors, Classification;

1. Introduction

Decades ago, diagnosis for heart disease was typically based on tape recording of Electro-CardioGram (ECG) signal which is then studied and analyzed using a microcomputer. This paper however, presents the design and

implementation of a compact microcontroller-based portable system used for control of heart rate, temperature and blood pressure on real time. Diagnosis of heart disease using ECG signals, may be achieved by either correlating the pattern of the ECG signal with a typical healthy signal [4], characterizing the typical ECG signal using basic logical decisions [9], or more complicated algorithms to process in depth the heart disease [2, 3, 14, 19]. The first approach requires complicated mathematical analysis to obtain the required diagnosis, while the second one involves only simple analysis in most cases. Today, wireless network provide mobile telemedicine which allows patients to engage their daily routines while they are monitored continuously anytime, anywhere. In healthcare application wireless sensor network small, lightweight sensors are used to be placed on the patient's body. Benefits of E-health system are used for transmission of blood pressure, heart beat rate, level of oxygen (SpO₂), body temperature from patient to a web server using GPRS.

A long-term study of ECG signal during everyday activity is required to obtain a broad spectrum of heart disease categories based on heart rate changing. Many techniques have been implemented, such as the use of a minicomputer in intensive care to observe patients [15], or microprocessor-based card in portable system [11, 18]. In this case, the disadvantage is the restriction of patient movement. A wire-free system connected to a hospital minicomputer allows patient mobility within restricted area in the hospital. Tape systems for recording ECG signals are bulky, heavy and prone to mechanical failure. In addition, these systems need large batteries.

In order to reduce the size, weight and power consumption of the system, a single chip Reduced Instruction Set Computer (RISC) architecture microcontroller was chosen. To keep the patient free of movement at home [14, 19], a data transmission protocol using e-mail is implemented in the system [25].

Aspects that have been carefully considered are:

- The logic and arithmetic involved in the data acquisition and the analysis of the ECG signals.
- The nature of the information to be stored.
- Most single-chip microcontrollers are characterized by the limitations of the arithmetic instruction.

It is therefore advantageous to use a simple mathematical analysis of the ECG signal. Regarding memory, representation of the complete ECG signal by an equivalent diagnostic word appreciably reduces the memory size required. Figure 1.a shows the P, Q, R, S and T waves on an electrocardiogram tracing (lead I) illustrating the three normally recognizable deflection waves and the important intervals. While figure 1.b illustrates the Atrial fibrillation signal compared to normal ECG signal

The method in storing information related to the ECG signal is considered in this paper. In this method, only the time and type of variation compared to the reference heart rate are registered. At the same time, the rate is processed to detect any disease, such as, Bradycardia, Tachycardia or Atrial Fibrillation [3] [4] and [5] either for adult or children.

The system connected to the serial port of a home microcomputer, via wireless transmission using Xbee protocol, is able to process in depth the data collected and take the decision either to transmit the information or the collected data to healthcare giver by e-mail instantly or every end of the day. Further on, provision for storing a number of ECG signals assists the cardiologist to formulate his personal analysis and to be more confident of system performance.

2. Atrial Fibrillation detection

Atrial Fibrillation, the most common atrial sustained arrhythmia, is a result of multiple re-entrant wavelets in the atria, which conducts to its partial disorganization. Although it is not a lethal disease, it may lead to very disabling complications such as cardiac failure and atrial thrombosis, with the subsequent risk of a stroke. One of the characteristics of AF episodes is the absence of P waves before the QRS-T complex of the ECG, which are replaced by 'sawtooth'-like pattern waves along the cardiac cycle (see Figure 1). Additionally, these waves are associated with irregular cardiac frequency. During the last years, these two main characteristics of AF have been object of intense research for the detection and prediction of AF.

Real time AF detection is one of the main priority aspects of the proposed algorithm. Since the information contained in single beats is not sufficient to discriminate AF episodes, a sliding window analysis is used. A minimum of 12 beats per analysis window is established. For real time applications, the length of the present analysis window is estimated based on the heart rate frequency observed in the previous window. For offline operation, each window length is set according to the established number of beats. In each analysis window a set of five features is extracted,

belonging to one of the three AF characteristic types. P wave absence is quantified by measuring the correlation of the detected P waves to a P wave model. Heart rate variability is accessed by assuming that the observed ECG is a nonlinear transformed version of a model. The statistical similarity is determined from the Kullback - Leibler divergence. AA is extracted using a wavelet analysis approach, based in the algorithms reported in [12]

3. Hardware System

The hardware design is based on an embedded system implementation using the Arduino Mega microcontroller from Atmel. This was used to verify the various ideas and the requirements for the final system design. The block diagram of the hardware system is shown in Figure 2.

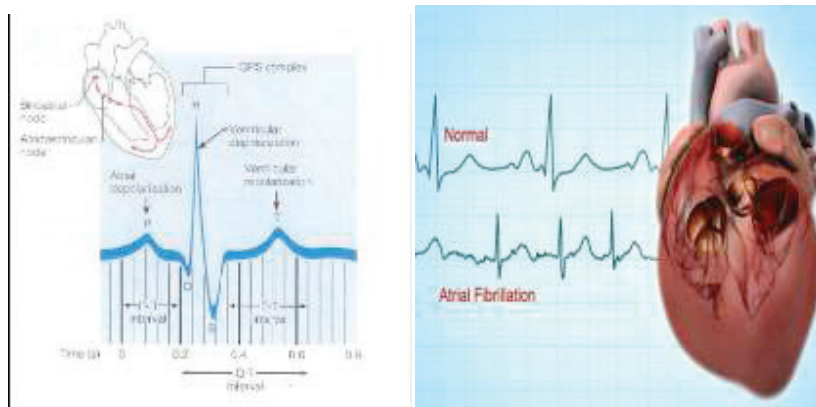


Fig.1.(a) An electrocardiogram tracing (lead I) illustrating the three normally recognizable deflection waves and the important intervals. (b) Normal and Abnormal ECG signals

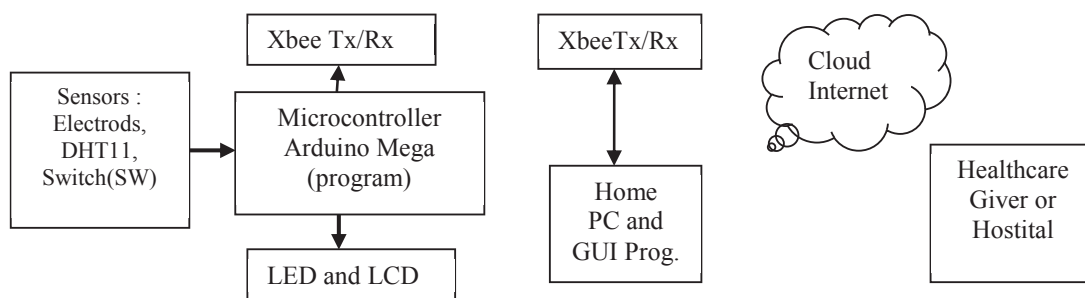


Fig. 2. Block diagram of the proposed system

3.1. Health Sensors

- ECG sensors: Even if they are not called ECG-sensors, ECG-similar sensors exist. They use less number of measuring points on the body but they still give heart rate according to the same principles as ECG. The market leader is the Finnish company ‘Polar Electro OY’. Their heart rate monitoring system consists of a belt worn around the chest and a receiving unit [12, 17].
- Body temperature sensors: We used a linear body temperature sensor, easy to use and interface with microcontrollers, The DHT11 temperature sensor incorporates a band-gap type temperature sensor and 9-bit ADC (Delta-Sigma Analog-to-Digital Converter). The temperature data output of the DHT11 is available at all times via the I2 C bus. If a conversion is in progress, it will be stopped and restarted after the read. A digital comparator is also incorporated that compares a series of readings, the number of which is user-selectable, to user-programmable set point and hysteresis values. The comparator trips the O.S. output line, which is programmable for mode and polarity [11].
- Digital Blood Pressure unit: Digital Blood Pressure Meter concept which uses an integrated pressure sensor, analog signal-conditioning circuitry, microcontroller hardware/software and a liquid crystal display. The sensing system reads the cuff pressure (CP) and extracts the pulses for analysis and determination of systolic and diastolic pressure. This design uses a 50 kPa integrated pressure sensor (Freescale Semiconductor, Inc.P/N: MPXV5050GP) yielding a pressure range of 0 mm Hg to 300 mm Hg [21].

3.2. The Pre-Processing

Removal of the undesirable noise requires filtering. Noise can be filtered through the use of analogue circuitry or digital signal processing. The weak nature of the ECG signal and the noise affecting it, requires the implementation of a range of filters and differential amplifiers.

The following techniques can be used to improve the reduction of noise:

- The SNR may be achieved on the basis of different statistical properties of signal and noise. The energy mean of noise is cross to zero compared to ECG signal which has energy mean greater than zero.
- Twisted-pair wiring use for the cable between sensors and processing system.

The input unit, as shown in Figure 3, consists of a differential-type preamplifier, a high frequency filter, a 50 Hz notch filter, a low-pass filter, and a variable gain control. ECG signal are picked up by three electrodes and are fed to the high frequency filter to limit noise from electro-surgical equipment. The preamplifier is protected from over voltage by diodes and is a differential type with CMRR (Common-mode rejection ratio) better than 60 dB. This is achieved by a matching filter and the use of close-tolerance resistors in a dual-in-line package. Both high frequency filter and preamplifier are screened against high-frequency interference.

The signal is also passed through a second-order low-pass filter and variable gain amplifier controlled by the microcontroller to obtain a normalized output. The frequency response for the amplifier section is 0.3-35 Hz at -3 dB, which is capable of eliminating any muscle artifacts caused by the patient moving [3].

3.3. The Microcontroller Block

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 (datasheet) [10]. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

The Arduino Mega can be powered via the USB connection or with an external power supply. The board, also, can operate on an external supply of 6 to 20 volts. The ATmega2560 has 256 KB of flash memory for storing code, 8 KB of SRAM and 4 KB of EEPROM . Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalWrite() functions. Each pin can provide or receive a maximum of 40 mA

and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. The board has 16 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). Moreover, Arduino Mega2560 has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. It provides four hardware UARTs for TTL (5V) serial communication. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the ATmega8U2/ATmega16U2 chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A Software Serial library allows for serial communication on any of the Mega2560's digital pins. The ATmega2560 on the Arduino Mega comes loaded with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files). We can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header using Arduino ISP or similar; see these instructions for details [10].

3.4. Data Storage and Display

The 24C256 serial EEPROM, which has eight Kbytes capacity, is used to store up to eight ECG signals sampled as described above. At each variation within the number of heart beats in a minute, three bytes representing the new number and time corresponding are stored in the EEPROM. The output unit consists of an LCD 2 lines 16 characters to indicate some diseases such as bradycardia, tachycardia or Atrial Fibrillation. In first line, it indicates type sporadic defects and in second line in displays heart beat rate and body temperature. It also contains a buzzer to prevent the patient from detected problem and time to transfer data by e-mail or internet.

3.5. Wireless Circuit Serial Transfer (WCST) based on XBee

To transfer data from EEPROM of the microcontroller to Home Personal Computer for further analysis of the data, an easy circuit serial transfer based on I2C protocol was integrated in both sides. This circuit has two lines data transfer. The SCL and SDA lines from EEPROM are buffered with an integrated circuit 74LS07, and connected Xbee module. The Xbee shield allows an Arduino board to communicate wirelessly using Zigbee. It is based on the Xbee module from MaxStream. The module can communicate up to 100 feet indoors or 300 feet outdoors (with line-of-sight). It can be used as a serial/usb replacement or you can put it into a command mode and configure it for a variety of broadcast and mesh networking options. The shields breaks out each of the Xbee's pins to a through-hole solder pad. It also provides female pin headers for use of digital pins 2 to 7 and the analog inputs, which are covered by the shield (digital pins 8 to 13 are not obstructed by the shield, so you can use the headers on the board itself).

There are multiple parameters that need to be configured correctly for two modules to talk to each other (although with the default settings, all modules should be able to talk to each other). They need to be on the same network, as set by the ID parameter, the modules need to be on the same channel, as set by the CH parameter. Finally, a module's destination address (DH and DL parameters) determine which modules on its network and channel will receive the data it transmits. Again, this address matching will only happen between modules on the same network and channel. If two modules are on different networks or channels, they can't communicate regardless of their addresses.

In order to transfer data 'ECG file' to the doctor, the patient or user needs activate the wireless communication between microcontroller and PC Via Xbee modules attached to both Arduino and serial port of the PC. Afterwards, he should activate a PC program that reads the data EEPROM and then stores the data bytes on an ECG-file. This will be transmitted via e-mail to the patient doctor. The final configuration of the system is shown in Figure 3.

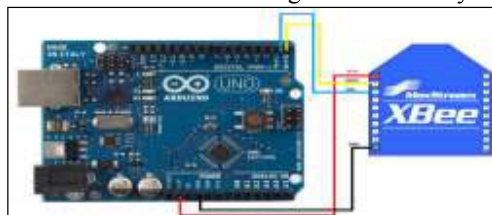


Fig. 3. Interconnection of Arduino microcontroller with Xbee module (from Google Images)

4. Software System

The software is based on two parts design. First, for getting and processing ECG signal and temperature data given I2C code, this is implemented within the Arduino Mega. The other one is a Graphic Unit Interface easy to use by the patient. It is developed by using the C# language under Windows as operating system.

4.1. Microcontroller Software

In this case, the method consists of computing a cardiovascular rate of the person each minute. A preprocessing step is needed to perform an amplification of the signal and a hardware filtering to eliminate noise. Many algorithms had been investigated to choose the best fit method for the microcontroller [6, 7, 13]. The QRS pulse has higher energy, a heart pulse can be detected within higher variation in energy between Q-R and R-S wave as illustrated in Figure 1.a. The rate counter, representing the number of pulses during one minute, is incremented at detection of a QRS pulse. Moreover, we keep in memory times between successive pulses to detect any recurrence of Atrial fibrillation, the QRS pulse is then compared with two references representing Bradycardia and tachycardia for adult or children. These referenced values were taken by statistical computation. The adult normal heart rate is in the range of 70 and 90 beats, while that of an infant is in the range of 100 and 170 beats per minute at rest [16].

If the heart rate counter is different from references then a LED indicator is lightened and an audio signal is generated. After a minute, the rate count is stored in the external EEPROM, if it is different from the previous count. The system acquires also the user body temperature and analyzes it then indicates it on An LCD display. This is followed by an internal clock time which should be synchronized with real-time clock. Thus, at every sensitive variation of the pulse rate, five bytes would be stored. These bytes represent the rate count, the time difference between two successive pulses, temperature, the hour and the minute of the internal clock. As aforementioned, a graphic unit interface easy to use by the patient, using C# language under Windows as operating system has been developed. The main menu of the application provides the user with acquisition, display and transfer. The flowchart of the program implemented within the Arduino Mega is illustrated in figure 4.

4.2. Home PC Software

In the acquisition function, the WCST circuit should be connected to the parallel port of the PC and the process of reading the EEPROM with saving data in a file is done. On the other hand, the display function shows to the user the contents of the EEPROM in hexadecimal

mode. It also draws a graph representing the variations of the ECG signal during the last twenty four hours. Finally, the transfert function activates the Microsoft Outlook to send to healthcare provider an attached ECG file. By using the same application, the doctor or health provider can display an ECG file and then takes a better diagnosis concerning the status of the patient, he has possibility to detect any recurrent Atrial fibrillation or other malignant rhythm disturbance. Hence, depending on healthcare provider's evaluation the patient can be directed to either follow-up with his primary care physician, or go to the nearest emergency room.

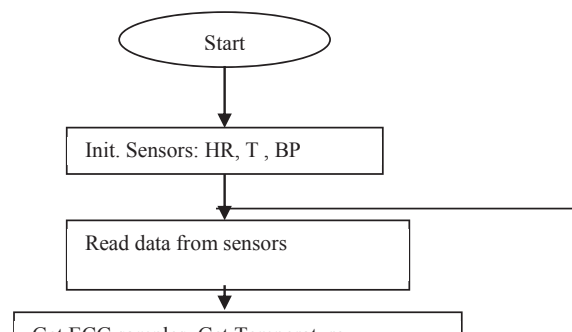


Fig. 4. Flowchart of microcontroller software

5. Results

The system has been designed to incorporate the ECG signal diagnosis capability, the real-time ECG and human body temperature processing, the remote control of a patient and the transportability. The diagnosis capability of the logical algorithm used has been tested using a simulated ECG signal. In addition, the diagnosis bytes associated with each heart signal are being verified but further statistical studies on real ECG signals are required for more evaluation of the system validity. The processing time required for generating and storing the diagnosis byte is 1.25 mili seconds. This is believed to be sufficiently short compared with typical heart signal variation. Hence the system is fast enough

to track any changes in heart condition.

In this system, the micro switch (SW) is connected to the ground (GND) for adult patient and to logic '1' (Vcc) for children. By reading the micro switch position, the system loads the corresponding references such as normal heart beat rate, tachycardia and bradycardia rate. Implementation of the system on a single-chip microcontroller reduces the overall weight and power consumption of the hardware required in the measurement, diagnosis and storage of ECG signals. In the software, we implemented a procedure that computes the energy and the variation of P wave to detect some anomaly in Atrial fibrillation. In addition, this system is quite reliable compared with magnetic recording system. This design may also measure other human health parameters such as temperature, and blood pressure. The data is transmitted as a packet to the host computer for further diagnosis

6. Conclusions

In this paper, the implementation of an embedded system based on a new micro-system device for real-time analysis of ECG signals has been investigated. The system has been tested successfully on simulated ECG signals for different heart diseases including files containing atrial fibrillation cases where P wave change in the form and duration. In this method, a logical approach has minimized overall memory size by storing only three bytes for each heart rate variation. We integrated a blood pressure sensor and temperature sensor to the previous work. We focused on improvement of software for real time diagnosis embedded on microcontroller. A graphic user interface was added, not in the previous work [1], to facilitate the interaction and assimilation of patient data from the care givers either nurses or doctor. Hence the overall diagnosis time and the amount of data handled is also minimized. The time taken for the state of any heart condition to be assessed is the time to record two successive diagnosis bytes.

The real-time decision is taken to inform the patient on his heart rhythmic conditions. It should be noted that this system can be ported either by patient or sport-person. Health provider can display an ECG file and then takes a better diagnosis concerning the status of the patient, he has possibility to detect any recurrent Atrial fibrillation or other malignant rhythm disturbance. Hence, depending on healthcare provider's evaluation the patient can be directed to either follow-up with his primary care physician, or go to the nearest emergency room.

The programmable methodology employed in the design also allows others biomedical signals, such as breathing rate and patient movements to be transmitted.

In summary, a new medical wearable device has been developed as part of a study targeted to heart rate control by e-mail. Final goals of this paper are reducing the hospitalization and assistance costs. In addition, patients and families quality of life are increased. Furthermore, we believe that elderly people and sportive persons as well, may benefit from this cost less system.

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