Microcontroller Based Heart Rate Monitor

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Abstract: *This paper describes the development of a heart rate monitor system based on a microcontroller. It offers the advantage of portability over tape-based recording systems. The paper explains how a single-chip microcontroller can be used to analyse heart beat rate signals in real-time. In addition, it allows doctors to get the heart beat rate file of the patient by e-mail 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 repetitively in real-time. The hardware and software design are oriented towards a single-chip microcontroller-based system, hence minimizing the size. The important feature of this paper is the use of zero crossing algorithm to compute heart rate. It then processes on real-time the information to determine some heart diseases.*

Keywords: *Microsystems, microcontroller, real-time, heart rate monitoring, zero crossing algorithm.*

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1. Introduction

Early diagnosis for heart disease is typically based on tape recording of ElectroCardioGram (ECG) signal which is then studied and analysed using a microcomputer. This paper however, presents the design and implementation of a compact microcontroller-based portable system used for control of heart rate 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.

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 [2, 5]. 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 shows the P, Q, R, S and T waves on an electrocardiogram tracing (lead 1) illustrating the three normally recognizable deflection waves and the important intervals.

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 or tachycardia either for adult or children. The system connected to the parallel port of a microcomputer is able to transmit the information or the collected data to the cardiologist by e-mail 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. Hardware System

The hardware design is based on an embedded system implementation using the PIC16F876 microcontroller from microchip [10].

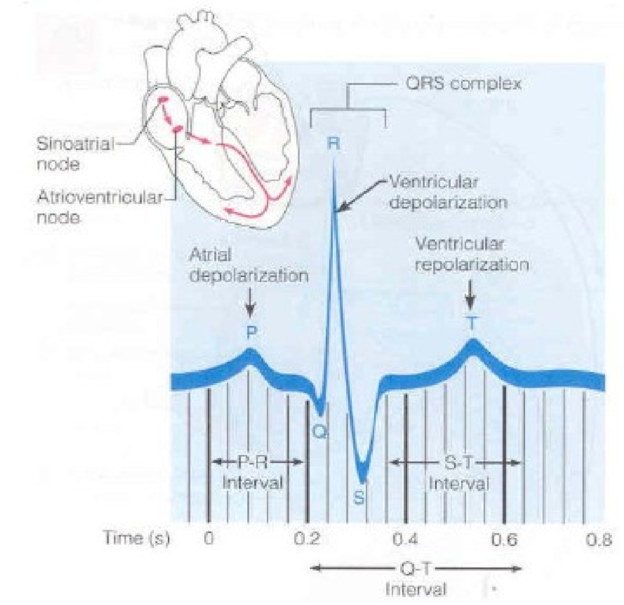

Figure 1. An electrocardiogram tracing (lead 1) illustrating the three normally recognizable deflection waves and the important intervals.

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.

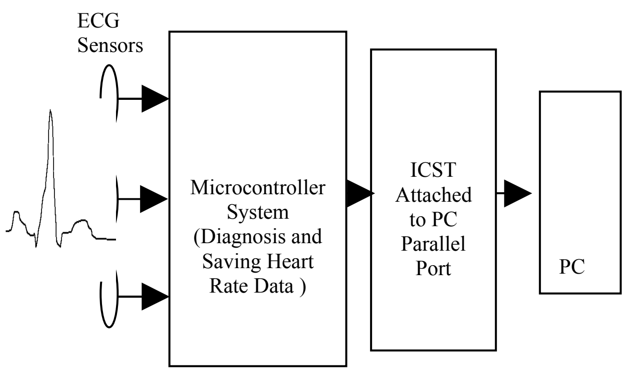

Figure 2. Block diagram of the system.

2.1. 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].

2.2. 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 technics 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 artefacts caused by the patient moving [3].

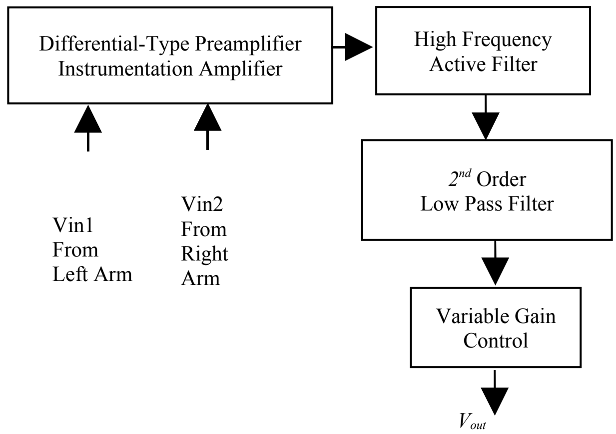

Figure 3. Input unit.

2.3. The Microcontroller Block

A Microchip microcontroller PIC16F876 is used to collect and process data and then stores it in a serial EEPROM. This microcontroller had been used before at the laboratory and gave good results. The PIC16F876 is an 8k instructions program EEPROM, 256 bytes data references EEPROM, 368 bytes of RAM, three timers, and a 10-bit A/D converter microcontroller. It has RISC architecture and can use oscillators for frequency up to 20 MHz. Its power consumption is about 25 mW (at 4 MHz), thus it is ideal to be used as an embedded system.

The ECG signal is fed to the A/ D converter within the PIC16F876. The sampling rate of the system is 1 KHz which means 1000 simples were acquired in a second and then processed in order to detect zero crossings. The internal timer is used to emulate real-time clock. In this case, the ECG signal is processed, if six consecutive zero crossing were detected and separated by at least 40 ms (40 simples), then the process increments a register called ZCC (zero crossing counter).

Memory requirements are 1k of program memory for storing the system operation program, and 256 bytes of data EEPROM for storing up to 80 different heart diagnosis conditions. Only three bytes are required for each diagnosis (two bytes for the time and one byte for the heart condition). The number of samples of ECG signals stored depends on the available memory.

2.4. 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 a set of LED to indicate some diseases such as bradycardia and tachycardia. It also contains a buzzer to prevent the patient from detected problem and time to transfert data by e-mail.

2.5. In Circuit Serial Transfert (ICST)

To transfer data from EEPROM to PC, an easy in circuit serial transfer based on I2C protocol was developed. This circuit has two lines data transfer. The SCL and SDA lines from EEPROM are buffered with an integrated circuit 74LS07, and connected to the parallel port via Db-25 male connector. In order to transfer data 'ECG file' to the doctor, the patient or user needs to connect the system to the PC parallel port. 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 4.

3. Software System

The software is based on two parts design. One, for getting and processing ECG signal which is implemented within the PIC16F876. The other one is a Graphic Unit Interface easy to use by the patient. It is Developed by using the Delphy language under Windows as operating system.

3.1. Microcontroller Software

In this case, the method consists of computing a cardiovascular rate of the person each minute. A pre-processing step is needed to perform an amplification of the signal and a hardware filtering to eliminate noise. Many algorithms had been investigated to chose the best fit method for the microcontroller [7, 13].The QRS pulse has higher energy and a heart pulse can be detected within five to six zero crossing of the signal as illustrated in Figure 5. The rate counter, representing the number of pulses during one minute, is incremented at detection of a QRS pulse. It 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 enfant 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. 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, three bytes would be stored. These bytes represent the rate count, the hour and the minute of the internal clock.

As aforementioned, a graphic unit interface easy to use by the patient, using Delphy language under Windows as operating system has been developed. The main menu of the application provides the user with acquisition, display and transfert.

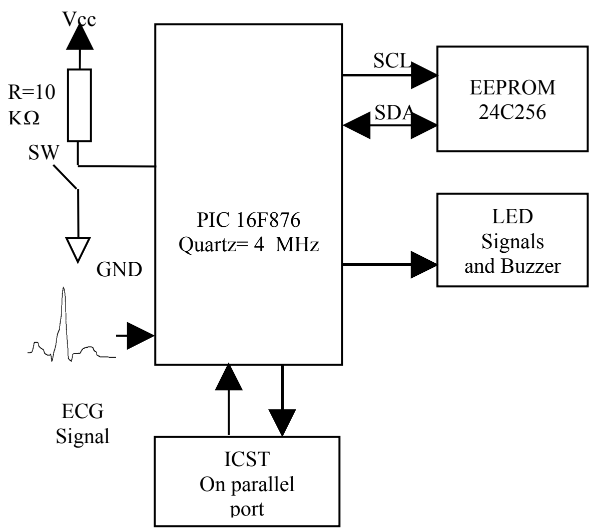

Figure 4. Configuration of the system.

3.2. PC Software

In the acquisition function, the ICST 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 the doctor an attached ECG file.

By using the same application, the doctor can display an ECG file and then takes a better diagnosis concerning the status of the patient. Hence the doctor would receive better information on the evolution of the patient heart rate.

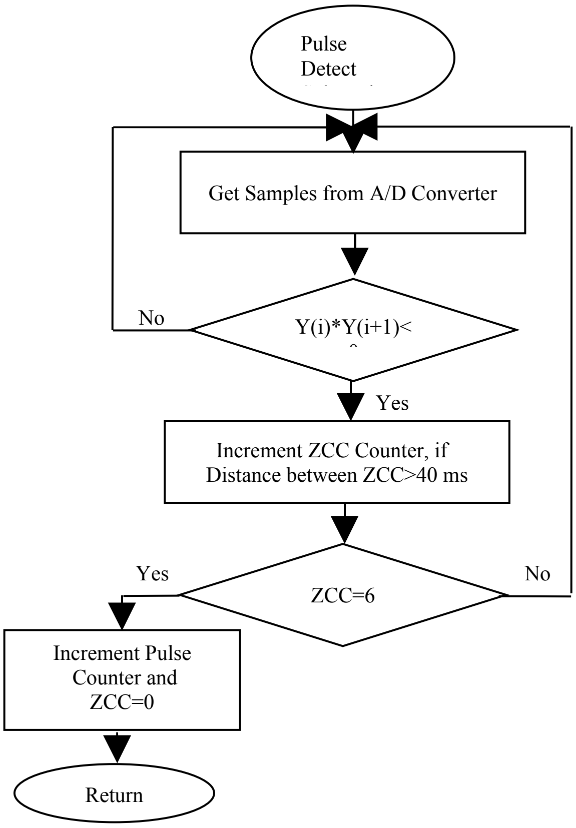

Figure 5. Flow chart of zero crossing algorithm.

4. Results

The system has been designed to incorporate the ECG signal diagnosis capability, the real-time ECG 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 ms. 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 microswitch (SW) is connected to the ground (GND) for adult patient and to logic '1' (Vcc) for children. By reading the microswitch 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 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.

5. Conclusions

In this paper, the implementation of an embedded system based on a microcontroller for real-time analysis of ECG signals has been investigated. The system has been tested successfully on simulated ECG signals for different heart diseases. In this method, a logical approach has minimized overall memory size by storing only three bytes for each heart rate variation. 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. 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 hospitalisation and assistance costs. In addition, patients and families quality of life are increased. Furthermore, we believe that elderly people [5] as well, may benefit from this system.

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References

[1] Abenstein J. and Tompking W., "A New Data-Reduction Algorithm for Real Time ECG Analysis," *IEEE Transactions Biomedical Engineering*, vol. 29, no. 1, pp. 43-47, 1982.

[2] Arif C., "Embedded Cardiac Rhythm Analysis and Wireless Transmission (Wi-CARE)," *MS Thesis,* School of Computing and Software Engineering, Southern Polytechnic State University, Marietta, Georgia, USA, 2004.

[3] Ayang-ang C. and Sison L., "Electrocardiograph Pre-Filtering, QRS Detection, and Palm Display Programming for Biomedical Applications," *in Proceedings of the ECE Conference*, University of St. Tomas, Manila, 2001.

[4] Balm G., "Cross-Correlation Techniques Applied to the Electrocardiogram Interpretation

Problem," *IEEE Transactions on Biomedical Engineering*, vol. 14, no. 4, pp. 258-262, 1979.

[5] Celler B., "Remote Monitoring of Health Status of the Elderly at Home," *International Journal of Biomedical Computing*, vol. 40, no. 2, pp. 147-153, 1995.

[6] Choi W., Kim H., and Min B., "A New Automatic Cardiac Output Control Algorithm for Moing Actuator Total Artificial Heart by Motor Current Waveform Analysis," *International Journal of Artificial Organs*, vol. 19, no. 3, pp. 189-197, 1996.

[7] Enderle J., *Introduction to Biomedical Engineering*, Academic Press, USA, 2000.

[8] Lee H., Park S., and Woo E., "Remote Patient Monitoring Through the World-Wide Web," *in Proceedings of the 19th International Conference of IEEE*, Chicago, IL, USA, pp. 928-931, 1997.

[9] Leffler C., Saul J., and Cohen R., "Rate-Related and Autonomic Effects on Atrioventricular Conduction Assessed Through Beat-to-Beat PR Interval and Cycle Length Variability," *Journal of Cardiovascular Electrophysiology*, vol. 5, no. 1, pp. 2-15, 1993.

[10] Microchip Manual, PIC16F87X Data sheet 28/40-Pin 8-bit FLASH Microcontrollers, Microchip Technology Inc., 2001.

[11] Morizet-mahoudeaux P., Moreau C., Moreau D., and Qharante J., "Simple Microprocessor-Based System for on-Line ECG Arrhythmia Analysis," *Medical and Biological Engineering*, pp. 497-500, 1981.

[12] Mulder Van Roon A. and Schweizer D., "Cardiovascular Data Analysis Environment (CARSPAN) User's Manual," *Groeningen, The Netherlands*, 1995.

[13] Prieto A. and Mailhes C., "Multichannel ECG Data Compression Method Based on a New Modeling Method," *Computers in Cardiology*, vol. 28, pp. 261-264, 2001.

[14] Prybys K. and Gee A., "Polypharmacy in the Elderly: Clinical Challenges in Emergency Practice," *Part 1 Overview, Etiology, and Drug Interactions, Emergency Medicine Reports*, vol. 23, no. 11, pp. 145-151, 2002.

[15] Schamroth C., *An Introduction to Electro Cardiography*, Blackwell Science Publishing, 7th edition, 2001.

[16] Shemwetta D. and Ole-Meiludie R., "The Physical Workload of Employees in Logging and Forest Industries," *Wood for Africa Forest Engineering Conference*, pp. 178-185, 2002.

[17] Tura A., Lambert C., Davall A., and Sacchetti R., "Experimental Development of a Sensory Control System for an Upper Limb Myoelectric Prosthesis with Cosmetic Covering," *Journal of Rehabilitation Research and Development,* vol. 35, no. 1, pp. 14-26, 1998.

[18] Woodward B. and Habib R., "The Use of Underwater Biotelemetry for Monitoring the ECG of Swimming Patient," *in Proceedings of the 1st Regional IEEE-EMBS Conference*, New Delhi, India, pp. 107-108, 1995.

[19] Yang B., Rhee S., and Asada H., "A Twenty-Four Hour Tele-Nursing System Using a Ring Sensor," *IEEE International Conference on Robotics and Automation*, Leuven, Belgium, 1998.

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