Gürcan TAŞPINAR et al./ IU-JEEE Vol. 14(2), (2014), 1809-1815

A PROTOTYPE DESIGN OF HOLTER ECG SYSTEM

Gürcan TAŞPINAR[1], Mehmet ENGİN[1], Erkan Zeki ENGİN[1]

[1]Ege University, Faculty of Engineering, Electrical & Electronics Eng. Department, Turkey
gurcan.taspinar@ege.edu.tr, mehmet.engin@ege.edu.tr, erkan.zeki.engin@ege.edu.tr

Abstract: *Cardiovascular diseases are the leading cause of death in the world. Holter ECG devices that have a great importance in the diagnosis of cardiovascular diseases are simple and useful devices that take the heart signals by non-invasive method. Because of the rapid developments in microcontrollers and Digital Signal Controllers (DSC) capable of real-time signal processing, it is intended that the use of DSC in the devices will create some advantages.*

Due to the developments of Digital Signal Controllers technology, holter device was preferred to be based on dsPIC by taking the skills of real-time signal processing of these controllers. Secure Digital Card (SDC), Liquid Crystal Display (LCD), Buzzer and Universal Serial Bus (USB) converter circuit were used in the device as peripheral units. It was enabled for patient or those around patient to take precautions by adding device the feature of calculating instant beating during the record in the situations of tachycardia and bradycardia that was possible to take precautions by hearing the aural warning. In addition, a Graphical User Interface (GUI), which provided transferring and processing the data to a computer for the medical specialist, was designed.

Keywords: *Cardiovascular, Holter ECG, non-invasive, Digital Signal Controllers, dsPIC.*

1. Introduction

Cardiovascular diseases can be occurred in heart and in vessels of the brain and heart. Cardiovascular diseases, which are the most common cause of death in the world according to World Health Organization, cause the death of more than 17,300,000 people every year. More than 3 million of these people are below the age of 60 and it is possible to prevent the most part of these deaths [1]. Hence, diagnosis and treatment of cardiovascular diseases have been of the prime importance.

Expenditures made on treatment of chronic heart diseases in developed countries are between 1-2% of the total budget of health. Heart health industry should develop methods for reducing this economic burden [2].

Holter ECG measurement devices, which are used for diagnosis of cardiovascular diseases and reducing economic burden of diagnostic processes, are split into two types as analogue and digital. Digital Holter ECGs have become more common than the analogues as soon as digital technology has developed. Especially, after large capacity and small size digital storage units became widespread, digital development of these measurement devices has gradually accelerated. These systems are preferred due to their easy, useful, resistant, and reliable designs together with widespread technology. Thus, studies on digital ECG recorders do not transfer data from point to point in the literature are analyzed.

Cybulski et al. [3] had designed a 4-channel ECG device operating with six AA alkaline batteries with 1.5 V and having LCD and 80C552 microcontroller. Data was recorded in Personal Computer Memory Card International Association flash memory card having 20 MB memory. Segura-Juarez et al. [4] had designed a device with two AA batteries with 1.5 V, having 0.1 to 100 Hz band-pass filter and LCD and that could receive 1250 samples with 12-bit resolution and record the data on Smart Media Memory Card.

Deniz and Yılmaz had designed a 3-channel Holter ECG device in their studies [5]. Gain of the device could be adjusted between 100 and 10,000. Sampling frequency of the analogue data was converted to digital version by using an Analogue Digital Converter (ADC) with 8 or 10 byte resolution that might be adjusted between 100 to 500 Hz and was recorded on the Multimedia Card (MMC) in the device having 0.05 to 100 Hz band-pass filter. Not only long-time record and low-price opportunities were created with this device but also data was transferrable.

Cifrek et al. had designed Holter ECG device operating with three AAA NiMH batteries in their studies [6]. MSP430F149 microcontroller having 1.6 to 37 Hz band-pass filter and an interior analog to digital converter that can receive 1000 samples with 12-bit resolution were used in that device. Data converted to digital form has been recorded to Smart Media Memory Card. Because of the lack of forces of device's batteries, ECG record had been recorded for only 5-days.

Ho et al. [7] had designed a device, which could measure up to 6 derivations, has 50 Hz notch filter and a 0.1 - 100 Hz band pass filter, 1000 times gain, could take 1000 samples with 12-bit resolution and used MSP430F149 microcontroller and SL811HS Universal Serial Bus (USB) converter integrated circuits. USB flash memories were

Received on: 17.01.2014
Accepted on: 23.08.2014

used to record data.

Jin and Mao [8] had designed a device with right leg drive circuit, 50 Hz notch filter, 0.05 - 160 Hz band-pass filter, 1000 times gain, ADC with 200 Hz sampling frequency and 12-bit resolution, MSP430 series microcontroller and SL811HS USB converter integrated circuit. Thanks to the design which was very similar with Ho et al.'s [7] design, the registration of data could be realized by using USB flash memories while it was possible to take records more than 24 hours before.

Galjan et al. [9] had designed a 3-channel device with the right leg drive circuit which could record up to 10 days with standard three AA batteries with 3 A and ADC with 16-bit resolution. This device could record data to a Compact Flash Card (CFC). In order to reduce the power consumption and use memory more efficiently, it was focused on reducing power consumption that data were compressed.

Yawei et. al. [10] had created a new technology in ECG systems in terms of power consumption by using separate microcontrollers to retrieve data and real-time data processing and controlling LCD and Secure Digital (SD) card. By using this design, the presence of QRS signals and Premature Ventricular Contraction (PVC) could be diagnosed and 48 hours data recording could be done by using 3.7 V - 2 A lithium batteries.

Karadeniz et. al. [11] had designed a Holter recorder device with 3-channel, 0.05 - 100 Hz band-pass filter, where 18F4520 controller was used, can take the number of sampling between 100 - 1000 with 8 or 10-bit resolution as adjustable to digital with circuit logarithm and when used up to 1 GB, data could be recorded on Multimedia Card (MMC) in File Allocation Table (FAT) format during 26 hours.

Guo et. al. [12] had designed a device which can use one of four units of derivation, has 35 and 50 Hz notch filters and 0.05 - 100 Hz band-pass filters, 1000 times gain, ADC with 12-bit resolution, C8051F021microprocessor and SL811HS Universal Asynchronous Receiver Transmitter (UART) - USB converter integrated circuit. This designed device were emerged in terms of ease of use and being small device which has low-power consumption and making a stable operation and a suitable device to make 24-hours recording of ECG. In this study, thanks to the data transfer via USB interface that is developing, it became possible to record ECG data to U-Disks and ECG display device became a portable one.

As well as examining these studies in the literature, because of the rapid developments in Digital Signal Controllers (DSC) which have microcontroller and real-time signal processing skills, the use of DSC was thought to create some advantages in Holter ECG devices. In the literature, there exists only one study [13] about Holter ECG by using digital signal processor. It was designed a device which has 0.2 to 40 Hz band-pass filter and it was adjusted to take 1200 samples with 12-bit resolution in one second for ECG on condition that was adjustable, has TMS320C10 digital signal processor and it could record data to 512 kB static Random Access Memory (RAM). They got 40 hours record when they used 4 AA alkaline batteries as power source in their designs.

A 16-bit signal controller which has low-power consumption and high-performance was used in the proposed system. ECG signals which were converted to digital by 1758 Hz sampling frequency and 10 bit resolution recorded to SD card. 0.48 – 96 Hz band-pass filter was used in the system to suppress the noises on ECG signal. ECG signals which were taken from body with low amplitude levels were gained approximately 600 times. A UART – USB conversion circuit, an LCD and a buzzer was added to the system. In addition, a graphical user interface, which provides transferring and processing the data to a computer for the medical specialist, was designed and added to the design.

Using a DSP in this system supplies us to make a few operations in the same time. The devices in the literature given above have generally different type microcontrollers and they do not have this feature. Also, one advantage of the proposed system is to calculate instant beating during the record in the situations of tachycardia and bradycarida and gives an aural warning in an overcoming situation. Another advantage of the system is low-cost. However, this design gives us a disadvantage about recording time. And lastly, our system has only one channel. The devices in the literature have multi-channel, but the proposed system could be increased up to 6 channel.

2. Methods

An artificial heart signal and ECG signals taken via electrodes connected to a 26-year-old healthy male test subject according to first derivation were processed as digital after processing analogously and recorded to an SD card. The general block diagram of system was shown in Figure 1.

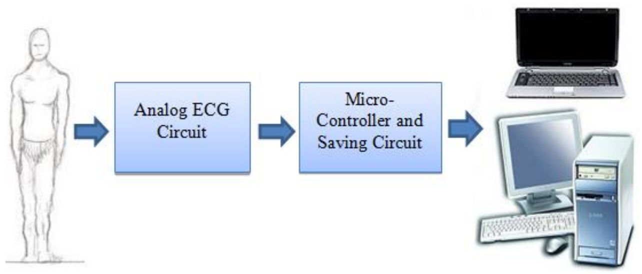


Figure 1. General block diagram of the system

2.1. Analog Hardware Design

ECG analog circuit consists of four main units that are instrumentation amplifier except of electrodes, band-pass filter, 50 Hz active notch filter and Right Leg Drive (RLD) circuit as seen in Figure 2.

Amplitude of heart signals were amplified 46 times by using pre-amplifier circuits and filtered with a 0.48 - 96 Hz band-pass filter. Amplified and filtered signal was prepared

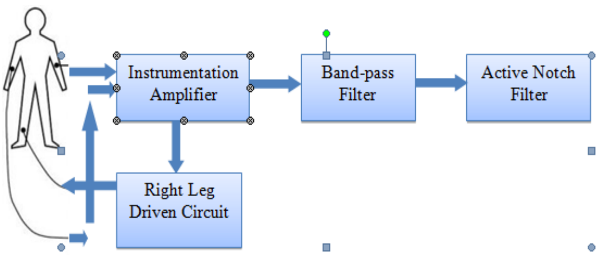


Figure 2. ECG analog circuit

to send to the controller by amplifying again 13 times in the last part of analog hardware design and suppressing possible network noise.

The grounding connection and digital hardware parts were separated from each other by using ferrit beat coils in order to prevent noise in the analog circuit. By this way, analog part was protected to catch noise from digital part.

2.2. Digital Hardware and Software

The recording time of ECG signals were taken from body with digital hardware and its software and analog circuit and brought to the amplitude values big enough to be processed by the controller was accomplished. According to reference voltages selected via controller, ECG signal was digitized and sent to high-capacity flash memory unit through Serial Peripheral Interface (SPI). The block diagram of the digital part of the system was shown in Figure 3.

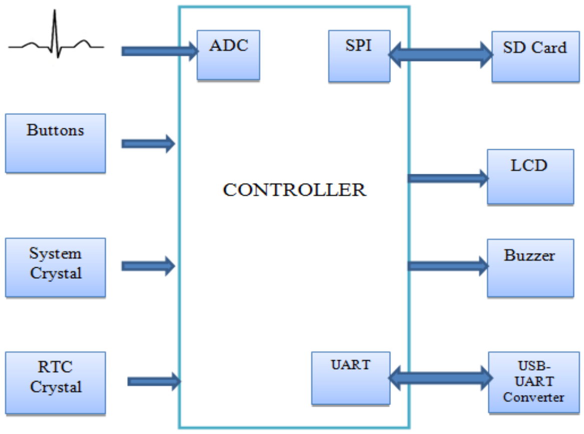


Figure 3. Block diagram of the digital part of the system

It is thought to use one analog input which will be converted to digital and the numbers of analog inputs could be increased to 6 by the use of feature of preferred controller. The dsPIC33fj128mc802 controller was used in this study and the reason of choosing this controller is to enable the future development processes. Thanks to selecting Digital Signal Controllers (DSCs) instead of a programmable interface controller (PIC) and because of the reason that selected controller's operating voltage range is compatible with SD card's operating voltage, the ability of real-time signal processing skills could be added to the system in the future.

ECG signal having with increasing amplitude level of the right size for analog circuit controller was converted into digital data by implementing one of the 6 Analog Digital Conversion (ADC) modules and this digital data was recorded to SD card by using one of the two ADC modules of the selected controller. An LCD and two buttons were added into the system. The tasks of these materials are providing the controller to count the right time by receiving the time and showing patient the number of beating calculated by the controller in real-time. Thus, the system would have had a menu at the same time.

Analog input channel in digital circuit was 10-bit sampling resolution and making digitization in approximately 1758 Hz sampling frequency. In this study, the software of the hardware part used in the controller fulfills 4 basic functions as follows:

- Digital conversion of analog ECG signals,
- Recording the data converted to digital on GS card via SPI; saving recording time by asking the current date and time from the user by menu of the controller and make the time counted correctly,
- It displays the value of real-time pulsation level of patient at the LCD and it alarms through buzzer when these determined values get out of the defined range,
- It helps to read the received data from the inside of SD card when order of receiving data comes from the computer.

The software developed to work on the controller is MPLAB IDE v.8.60 which is the licensed product of Microchip Company is written using programming languages of C30 and C. The compiled programs were written on flash memory of dsPIC33fj128mc802 controller program by the picKit 3 PIC programmer.

Nowadays, USB connection is used for data transfer method in almost every computer that the feature of orders conversion to the UART serial data conversion format of the controller sent from the USB port of the computer was added to the design.

2.3. ECG Processing and Software

The ECG signal which was filtered and gained via analog hardware was converted into digital data and recorded to SD card. These data needed to be transferred to the computer where they would be processed. It was created in a form that a medical expert, who would examine through the ECG by the use of GUI software, could understand easily. It would be enough to run the GUI file after installing the program and copying the files to the computer which medical expert would use. The interface program could provide data transfer and archiving, accomplishing drawing of beats and time and signals for the general and desired time intervals of heart signs.

3. Experimental Studies and Results

Measurements of analog and digital parts were obtained in the test phase of the device. The offset value of each filter stage was measured first for the analog part. 5-minute recordings were taken with an artificial ECG signal for the digital part test and a real ECG signal was taken from a test subject.

3.1. Analog Hardware Measurements

Approximately, zero off-set effect was measured between input and output by setting the potentiometer about off-set effect of off-set null operational amplifier on the of each filter stage. The results shown in Table 1 were obtained in made off-set measurements in this situation.

Table 1. Off-set values of analog part

Input Voltage Value	Output of Right Leg Driven Circuit	Output of High Pass Filter Circuit	Output of Low Pass Filter Circuit	Output of Notch Filter Circuit (Analog Part)
0V	0.015V	0.030V	-0.020V	-0.005V

The measurement amplifier stage was disabled in order to obtain frequency response of analog part of the device and the gain of active notch filter was set to 1. The measurements were performed under these conditions and frequency response graphic shown in Figure 4 were obtained.

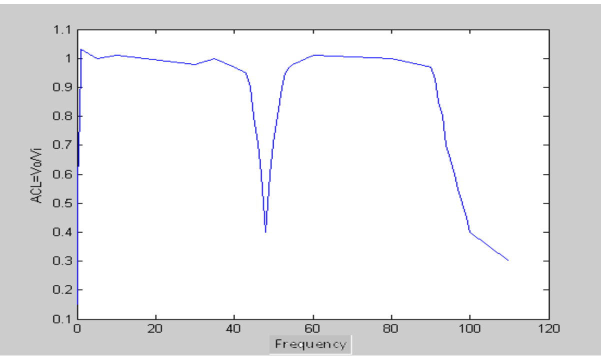
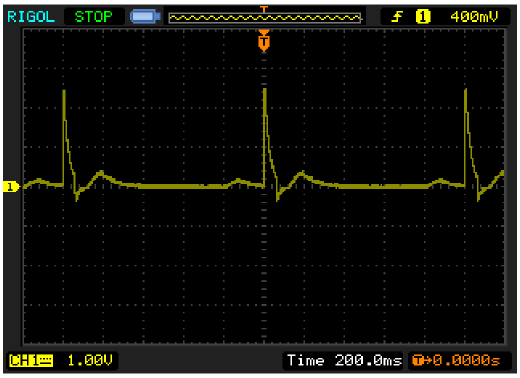


Figure 4. Frequency response of the analog circuit

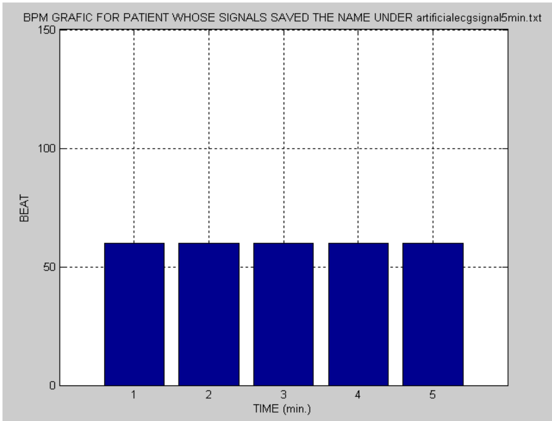
3.2. Digital Hardware Measurements

Artificial ECG signal and real ECG signal was taken from a male test subject of 26 years old and five minutes records were taken for the digital part. The image of oscilloscope screen of measured analog circuit output during recording and general and interval drawings after sample beating in the range of 1:7 of data taken via interface program and general real-time graphics were given.

The image of oscilloscope screen of amplified signal during measurement was shown in Figure 5-a. Beat-time graphic realized after transferring data of artificial ECG signal from SD card to the computer was shown in Figure 5-b and the drawing of it for the desired time interval was shown in Figure 5-c. It was observed that there was not any distortion, when the image of oscilloscope screen and the data transferred to the computer were compared. In addition, it was determined that the real-time graphic values are stable and in the value of 60 that were generated by artificial ECG signals interface program that the time period of it was one second.



(a)



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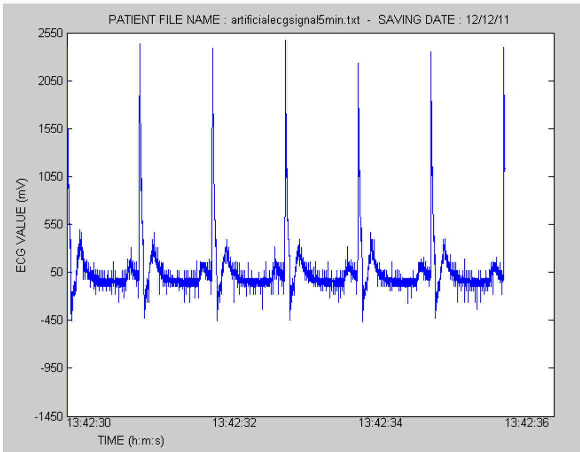
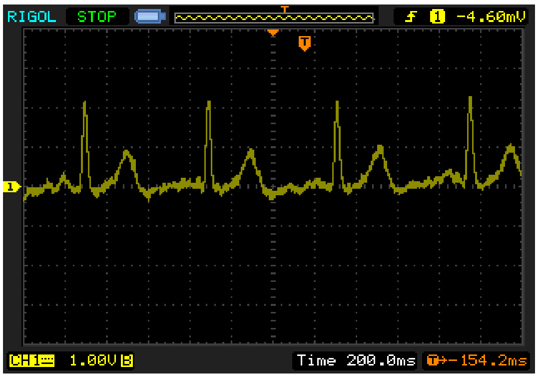


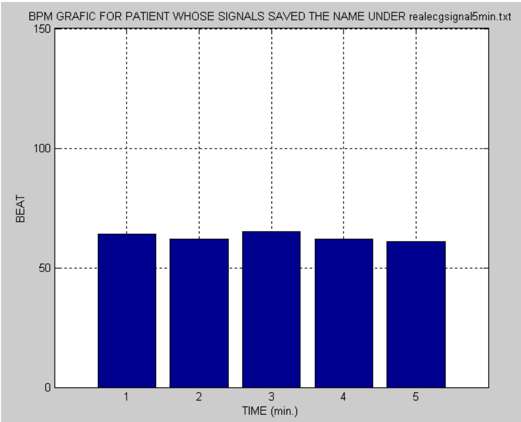
(c)

Figure 5. ECG signal: a) The image of oscilloscope screen, b) Beat-time graphic, c) Preferred time interval drawing

Real ECG was taken from a healthy male, who was 26 years old. The image of oscilloscope screen of real ECG signal was shown in Figure 6-a, realized beat-time graphic after transferring data of artificial ECG signal from SD card to the computer was shown in Figure 6-b and the drawing of it for the desired time interval was shown in Figure 6-c. It was observed that there was not any distortion, when data transferred to the computer and the image of oscilloscope screen was compared. It was determined that the beat-time graphic was created through real ECG signal's interface program was same with the pulse value observed at LCD during the recording of device.



(a)



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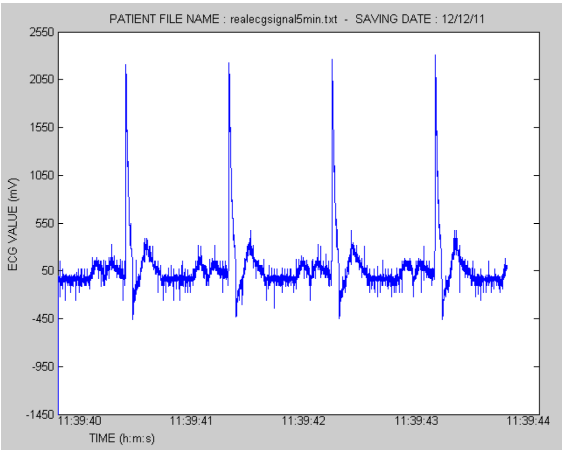

(c)

Figure 6. Real ECG signal: a) The image of oscilloscope screen, b) Beat-time graphic, c) Preferred time interval drawing

3.3. Mounting Displays of the Device

The mounted displays of the assembled device were shown in Figure 7-a and 7-b. The display of menu at the run-time and the displays which allows the observation of real-time pulse measurement during study were shown in Figure 8-a and 8-b.

(a)

(b)

Figure 7. View of the device: a) Top, b) Side

4. Conclusion

In this study, the ECG signals were received from human body in a clean way and processed in analog part of the system were saved to an SD card and these data were transferred to computer via USB port as a text file in order to create a data archive to be named by a medical expert. Signal display and real-time graphics were drawn correctly according to general and desired time interval for ECG data. It was determined that more than one process can be implemented in the desired manner by using DSC during the study. The number of channels of Holter ECG device might be increased. Thus, more than one biological signal could be recorded at the same time. Up to 6 inputs could be added to design because the controller used in design has 6 analog digital converters. Analog digital circuit speed used in design will be in sufficient level due to data types which will be desired to record in the situation of use of 6-channel.

The system gain adjustment could be made. Thus, the inconveniences because of heart signal amplitudes varying from patient to patient will be prevented. The communication property could be added to the system. By adding communication property obtained data could be transmitted to medical expert or health care units. Information might be transmitted to appropriate places in

(a)

(b)

Figure 8. Outlook of the device in activation: a) Menu, b) Real-time pulse measurement

an emergency situation of real-time calculations. In addition, the cut-off frequencies of the filters can be made adjustment, working time of the device can be extended, and sampling frequency and transferring time of the ECG signals from the device to the computer can be reduced. An alarm circuit for disconnection of the electrodes can be added to the system. The properties of event marking, notifying of battery charge level, automatic off-set measurement and calibration can also be added to the system.

Acknowledgement

This work was supported by Scientific Research Unit of Ege University (Project No: 09-MUH-023).

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Gürcan TASPINAR received B.Sc. degree from Gazi University and M.Sc. degree from Ege University, 2008 and 2012, respectively. And also, he is currently continuing his Ph.D. education at IYTE. From 2010 to 2012, he was Lecturer at Electronics Technology Department of Usak University. He is currently Lecturer at Electronics and Automation Technology Department of Ege University. His research interests include biomedical signal and image processing, medical instrumentation design.

Mehmet ENGIN received M.Sc. degree from Marmara University and Ph.D. degree from Kocaeli University, 1988 and 1996, respectively. From 1996 to 1999, he was Assistant Professor at Electronic and Computer Education Department of Kocaeli University. He is currently Associate Professor at Electrical & Electronics Engineering Department of Ege University. His research interests include biomedical optical imaging, medical instrumentation design, biomedical signal and image processing, wavelet transform and its applications.

Erkan Zeki ENGIN received B.Sc. M.Sc., and Ph.D. degree in Electrical and Electronics Engineering from Ege University, 2000, 2003, and 2010, respectively. He is currently Assistant Professor at Electrical & Electronics Engineering Department of Ege University. His research interests include biomedical signal and image processing, biomedical instrumentation, voice/speech processing/analysis.