Igor Piotr KURYTNIK, Bohdan BOROWIK
UNIVERSITY OF BIELSKO-BIAŁA, FACULTY OF MECHANICAL ENGINEERING AND COMPUTER SCIENCES,
DEPARTMENT OF ELECTROTECHNOLOGY AND AUTOMATIONS

Using the dsPIC microcontroller for ECG QRS complex interpretation

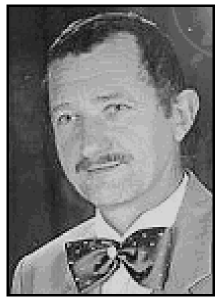
D.Sc. PhD. Eng. Igor KURYTNIK

He received the M.Sc in 1968 in the Faculty of Electronics and Automation of the Lvov Polytechnic. In 1973 received PhD, and in 1987 DSc degree. For a year 2000 is working in the Faculty of Mechanical Engineering and Computer Sciences of the University of Bielsko Biała. At present he is a professor and a chairman at the Department of Electrotechnology and Automations. His research activities focuses on signal processing and measurements with particular interests in systems analysis and synthesis.

e-mail: ikurytnik@ath.bielsko.pl

PhD. Eng. Bohdan BOROWIK

Lecturer at the Department of Electrotechnology and Automations of the Technical-University in Bielsko-Biała. He is a graduated of the Institute of Electronics in Cleveland. He underwent doctoral studies in the Department of Electronics, Automation Computer Science and of Electrotechnology, of the Academy of Mining and Metallurgy in Cracow in 1996-2001 years. In the year 2001 defended a PhD thesis. His research activity focuses on signal processing and measurement with particular interest in data acquistion.



e-mail: borowik@tatrynet.pl

Abstract

The paper provides a QRS descriptive analysis of the ECG plots obtained from a Digital Signal Processing circuitry. In the considered here project there has been used a high performance DSP 16-bit microcontroller of the dsPIC33F family. Its capabilities comprise of digital signal filtering and processing. The authors have attempted to provide here a descriptive analysis of the ECG tracing, especially of the QRS complex. At the beginning the analog data from ECG electrodes has been converted into a digital form for further DSP processing. In the next step data has been sent through the SPI bus to the mass storage device, such as the removable Flash-based media card for further analysis. For a practical reason a versatile SD card has been used.

Keywords: DSP, cardiac signal, microcontroller, QRS, ECG, PICmicro.

Badanie i interpretacja zespołu ECG-QRS w układzie mikrokontrolera dsPIC

Streszczenie

W pracy przedstawiono zastosowanie układu przetwarzania sygnałów do badania zespołu QRS, przy interpretacji danych EKG. Zespół QRS odzwierciedla elektryczno-impulsową aktywność serca. Reprezentuje on pobudzenie, czyli depolaryzację komór serca. Ma on także szerokie widmo częstotliwości. Celowe staje się tu zastosowanie procesora sygnałowego DSP, pozwalającego na przetwarzanie sygnałów. Charakterystyka i kształt zespołu QRS dają najwięcej informacji o pracy serca. Analizę QRS w dziedzinie częstotliwości przeprowadza się za pomocą specyfikowanego modułu mikrokontrolera: DSP Engine do przetwarzania sygnałów, w którym wykorzystywany jest specjalny zestaw instrukcji DSP Instruction Set. Znajduje tu zastosowanie dyskretne przekształcenie Fouriera DFT. Do analizy zespołu QRS wykorzystana jest także funkcja autokorelacji. Przy analizie częstotliwości sygnału wykorzystywany jest kolejno fragment QRS w oparciu o funkcję okna, znajdującą się w programie.

Słowa kluczowe: mikrokontroler, PICmicro, QRS, EKG.

1. Introduction

A very important factor in a diagnosis of heart diseases plays an ECG surveillance. Nowadays, to improve a human health care there is a great need for mobile devices that could interpret and test QRS complexities obtained from ECG. A new generation of microcontrollers offer a great deal of computing capabilities for the above-mentioned task. This may appear to be helpful for generating a better diagnosis and for observing occasional cardiac arrhythmias, which are difficult to identify using a traditional method. A microcontroller driven system may offer more precise diagnosis, thorough assessment of such heart operation parameters as: Rate, Rhythm, Intervals (PR/QRS/QT), Axis, Hypertrophy, and Infarct (QRST changes). For patients which have more transient symptoms a cardiac event monitor with a data storage device could be used for the purpose of analyzing a bigger span of time.

The electrical analog signals from a heart via series of electrodes attached to a patient's chest have to be recorded. Then during the analysis signals from all the 12 channels must be compared with each other. The leads are:

- 3 unipolar augmented limb leads: AVR, AVL, AVF,
- 3 bipolar limb leads: I, II, III,
- 6 precordial leads: V_1, V_2, V_3 (on the right side of the chest),
- 6 precordial leads: V_1, V_2, V_3 (on the left side of the chest).

The above leads are attributed to particular parts of the electrical control system of the heart.

The Basic Lead Groups are:

- Inferior leads - II, III, AVF,
- Septal leads - V1, V2,
- Anterior leads - V2 to V4,
- Lateral (left-sided) leads:
  - Lateral precordial leads - V4 to V6
  - High lateral leads - I, AVL.

2. QRS complex

The QRS interval represents the time it takes for a ventricular depolarization to occur. The QRS complex is a structure on the ECG that corresponds to the depolarization of ventricles. Because ventricles contain more muscle mass than the atria, the QRS complex is larger than the P wave.

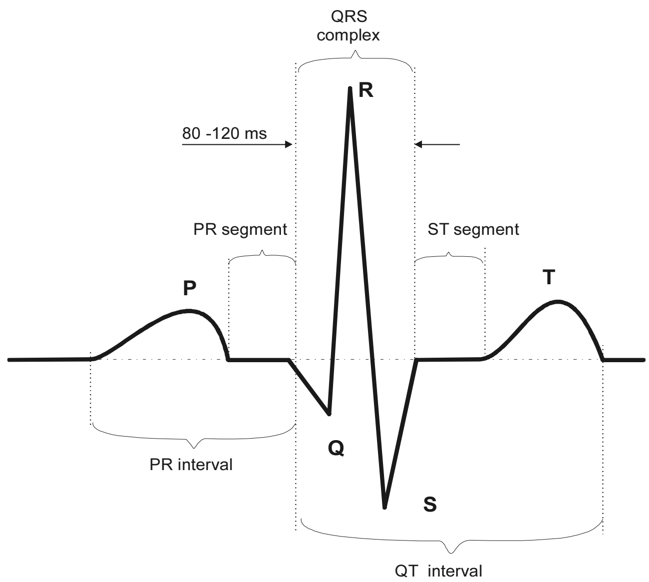


Fig. 1. Representation of the QRS complex (part of a normal EKG plot)
Rys. 1. Przebieg EKG wraz z zaznaczonymi załamkami QRS

A normal QRS complex duration equals to the range 80 –120 ms, what is represented by three (or less) small squares, but any abnormality of conduction takes longer, and causes that QRS complexes get widener. Not every QRS complex contains Q wave, R wave and S wave. In Figure 1 it is shown the complete plot of the QRS complex for a healthy resting adult.

The most important is to assess the tracing for QRS changes.

For this purpose, the AVR lead can be ignored.

The other 11 leads have to be scanned for Q waves and checked for R wave progression, especially, if there is a tall R wave in lead V1. Then all leads (except AVR) have to be checked for changes in the ST segment (i.e. for elevation or depression) and/or changes in the T wave.

In a normal ECG, right-sided precordial leads (V1 and V2) are predominantly negative, whereas left-sided leads (V5 and V6) are predominantly positive.

The area, where the R wave becomes greater than the S wave (transition) - occurs normally between V2 to V4.

The microcontroller has to compare real plot with the pattern for normal healthy subject, and to thresholds.

QRS duration can be measured from any of the 12 leads of a standard ECG.

If the QRS is wide then there are only 3 possibilities: there may be Right Bundle Branch Block, Left Bundle Branch Block, or it must be the presence of IntraVentricular Conduction Delay. The 3 key leads (and the only 3 leads) needed to determine the types of a conduction defect (RBBB, LBBB, or IVCD) are leads I, V1, and V6, as pointed to by [4].

3. QT Interval

The QT interval is measured from the beginning of the QRS complex to the end of the T wave. Normal values for the QT interval are between 0.30 – 0.44 s. The QT interval as well as the correlated QT interval are important in the diagnosis of the long QT syndrome and short QT syndrome. The QT interval varies based on the heart rate, and various correction factors have been developed to correct the QT interval for the heart rate. The QT interval represents in an ECG the total time needed for the ventricles to depolarize and repolarize.

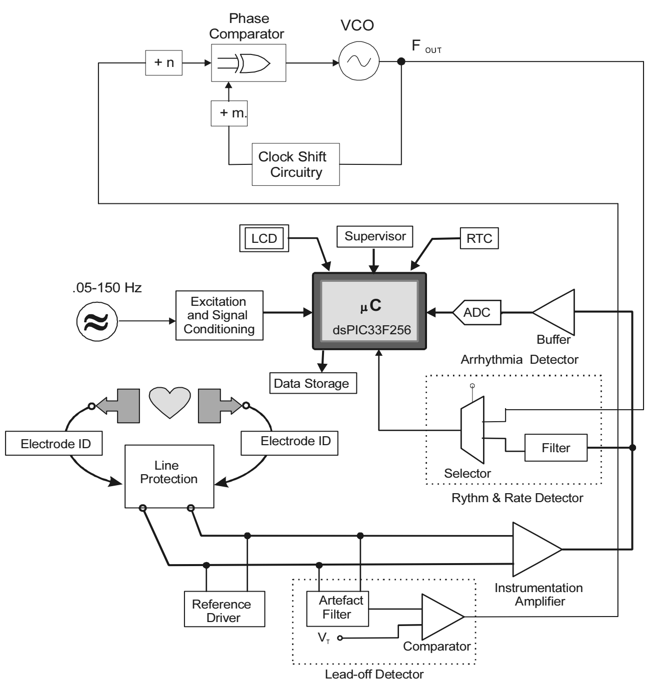


Fig. 2. Block Diagram of electrocardiography and analysis system
Rys. 2. Schemat blokowy EKG wraz z systemem analizy sygnału

The most commonly used method for correcting the QT interval for rate is the one formulated by Bazett [5].

Bazett formula is:

$$QTc = \frac{QT}{\sqrt{RR'}}$$

where: *QTc* is the QT interval corrected for rate, *RR'* is the interval from the onset of one QRS complex to the onset the next QRS complex measured in seconds.

The block diagram for the electrocardiography and analysis system is shown in the Fig. 2

Signals from the artial and verticular leads used as electrodes are initially processed and analyzed using DSP capabilities of the finite impulse response filter (FIR). For this purpose the use of the dsPIC33 [3] is the proper choice. It combines high instruction throughput with the DSP capabilities. It has big computational power, fast A/D converter, as well as vast connectivity capabilities. It has also Data Analysis and DSP software to evaluate and analyze signals. Data can be analyzed in both: time and frequency domain, waveforms and graphs can be generated.

The Visual Digital Filter Design Tool provides desired filter's characteristics.

4. DsPIC33F features

All mentioned before functions are fulfilled by one microcontroller. The dsPIC33F is 16-bit multiply and 0 overhead looping. It includes dual 40-bit accumulator and single 16x16 MAC. Main functions and architecture of dsPIC33FJ are shown in Figure 3.

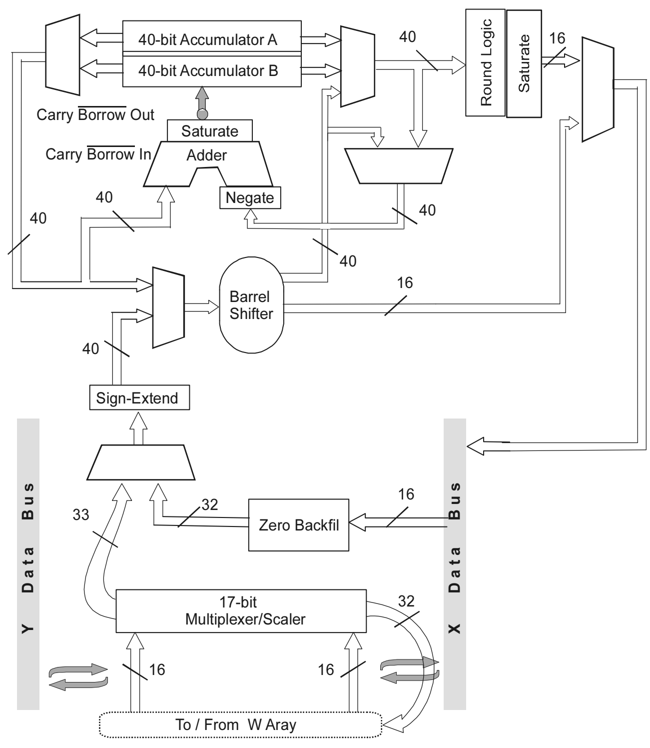


Fig. 3. The main functions and architecture of dsPIC33FJ
Rys. 3. Funkcje procesora sygnałowego dsPIC33FJ

The dsPIC CPU Central Processing Module has a 16 bit (for data) modified Harvard architecture. An enhanced instruction set gives significant support for DSP. The dsPIC has 16-bit working registers. The dsPIC instruction set has two classes of instructions: MCU and DSP. These two instruction classes are seamlessly integrated into a single CPU. The instruction set includes many addressing modes and is designed for optimum C compiler efficiency. The data space is split into two blocks, referred to as X and Y data memory. Each memory block has its own independent Address Generation Unit AGU. The MCU class of instruction operates solely through the X memory AGU, which accesses the entire memory map as one linear data space. Certain DSP instructions operate through the X and Y AGU's.

Preprocessed signals from the microcontroller are recorded using a SD card.

The software code has been written by one of the authors in assembler [2], nevertheless the manufacturer provides now numerous software tools and libraries suited for particular applications. Specially of interest are: MPLAB ASM30 Assembler/Linker/Librarian, MPLAB SIM Software Simulator, MPLAB C30 C Compiler/Linker/Librarian, DsPIC33F DEVELOPMENT TOOLS AND APPLICATION LIBRARIES: Memory Disk Drive File System Library, used with SD cards and other Flash technology-based devices.

Digital Lock-In Amplifiers Library. It uses the phase-sensitive detection to measure the presence of small signals buried in large amount of noise. By using the built-in signal processing capabilities of the dsPIC33F it is possible to perform high speed, high accuracy measurements.

5. Conclusions

Analyzing signal from ECG electrodes with library functions provides help for interpreting the ECG plot.

DSP libraries facilitate tracing the signals and they help to discover undulation and deflection (which otherwise get unnoticed). Also the pattern can be provided as a reference for the comparison with the plot. There can be used a plot of normal ECG or subject's previous ECG plot. A physician in the context of a patient's age, presenting compliant and the clinical history, should next be able to interpret the findings identified. The investigation results in substantial reduction of the erroneous or a lack of diagnosis during conveying patients ECG treatment.

Further research in developing cardiac diagnosis tool based on DSP microcontroller system should be continued because of complexity of concerned medical area and broadening of the market.

6. References

[1] Borowik B., Kurytnik I. P.: Mikrokontroler PIC w zastosowaniach. Książka recenzowana, Warszawa, Wyd. PAK 2009.

[2] Garcia T. B., Holz N.E.: Introduction to 12-led ECG the Art. of Interpretation. Jones and Barnett Publishers Inc. 2003.

[3] Borowik B.: Ćwiczenia z mikrokontrolera PIC z wykorzystaniem języka maszynowego. Książka recenzowana, 2008, 136 s.

[4] Borowik B, Borowik W.: Meandry języka C/C++. Warszawa, PWN, 2006, 130 s.

[5] Skubis T. Opracowanie wyników pomiarów. Przykłady. Wydawnictwo Pol. Śląskiej 2003.

[6] www.microchip.com

[7] Grauer K.: 12-Lead ECG's. Matthew Price, Florida, 2001.

[8] Bazett H.C.: An analysis of the time-relations of electrocardiograms, Heart 7, 1920.

otrzymano / received: 17.12.2009
przyjęto do druku / accepted: 03.02.2010 *artykuł recenzowany*