OCURE: OPEN SOURCE ECG SIMULATOR FOR ACADEMIC APPLICATIONS IN BIOMEDICAL SIGNAL PROCESSING AND PUBLIC HEALTH PROGRAMS

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ABSTRACT

The paper presents Ocure, a do-it-yourself electrocardiogram (ECG) simulator and monitor based on Arduino hardware and Scilab software to teach classes and laboratories in biomedical signal processing. The system simulates a human heart and an ECG machine. The ECG simulator simulates ECG signals representative of different heart conditions and graphically renders the heart providing real time visualization of the functioning of human heart and its correspondence with measured ECG signals. The ECG monitor displays the signals, computes and presents the key parameters of the signal based on QRS complex detection and heart rate calculation. The system uses the signals from the MIT-BIH Arrhythmia database.

Index Terms— ECG simulator, Open Source, QRS complex, Cardiology, Arduino

1. INTRODUCTION

The number of deaths worldwide due to cardiovascular diseases (CVDs) was 23 million in 2010 and these account for nearly 30% of all the deaths [1, 2]. The population in the low and middle income countries is the most affected accounting for 78% and 86% of all deaths due to CVDs in 1998. The heart disease is considered as a silent disease and the symptoms are not evident till the disease is in an advanced stage. The preventive care can be achieved by educating the healthy population about heart conditions. The key challenge in scalability of such public health education programs is the availability and affordability of these tools. This paper presents Ocure, an educational ECG kit for teachers and students and it addresses the above-mentioned needs of availability and affordability.

The name Ocure is an anagram of the subject Cuore which is the Italian term for heart. Cuore is the title of the widely acclaimed chidren's novel by Edmondo De Amicis first published in 1886. Ocure is designed with open source hardware and software. The open source hardware used is an Arduino UNO microcontroller. The users can buy the parts and make their own Arduino board eliminating the need to buy the board from a manufacturer. The system uses Scilab Software and OpenGL libraries for the software. A teacher or student can assemble the hardware and software in less than a day and it would cost less than 50 USD excluding the cost of the laptop. The system software algorithms have been built using the literature in the field dating back to early 1980s. The signals from the MIT-BIH Arrhythmia database have been extensively tested and have been shown to produce accurate results [3]. This calibration process ensures the accuracy of the system. Ocure can be used in both teaching and research. It can be used to teach classes in biomedical signal processing. The healthcare professionals can use it to teach classes in cardiology. The public health education programs could also benefit given the simplicity, affordability, and availability making it part of scalable health awareness campaigns on cardiovascular diseases in low and middle income countries.

2. A BRIEF HISTORY OF ECG SIMULATORS

ECG simulators are instruments used by ECG machine manufacturers to perform calibration, repair and maintenance of ECG machines either during pre-production or in-service maintenance operations. These simulators are expensive and are not suited for class room applications. There have been past work in the field of ECG simulators for education. These have been designed using virtual instrumentation consisting of data acquisition hardware and Labview software. One such system consists of a USB experiment interface board K8055 and an EKG-V2 amplifier for ECG signals. The system consumes low power and uses low sampling frequency to represent ECG signals accurately [4, 5]. A very accurate ECG simulator using Texas Instruments MSP430 microcontroller was developed as a low cost yet accurate simulator for ECG machine service applications and this has some characteristics making it suitable for academic applications [6]. A simulator based on DAC chip (0808) including an improved QRS detection program is another design that can be used in classrooms [7]. A complete ECG simulator including 12 leads to acquire ECG signals, perform signal processing using wavelet transforms based on Labview has been developed [8]. There are web based ECG simulators to show different types of ECG signals and the correspondence with heart conditions such as skillstat [9].The literature survey shows clearly there has been a lot of work done relating to ECG signal

simulators. However, there are gaps which present an opportunity to develop an educational ECG simulator. In this paper, we present a system designed and developed using Arduino [10], an open source hardware platform and Scilab, an open source numerical computation software, OpenGL libraries for visualization tools. This makes the design of Ocure unique.

3. OCURE SYSTEM DESCRIPTION

Ocure ECG simulator and monitor consists of

1. Hardware
    a. Arduino UNO microcontroller
    b. Laptop or Desktop computer

2. Software
    a. Scilab
    b. Communication Programs
        i. Ocure Heart Simulator
        ii. Ocure ECG Monitor
    c. Signal Processing Programs
        i. ECG signal viewer
        ii. QRS complex viewer
        iii. Heart rate view

3.1. Hardware

3.1.1. Arduino UNO microcontroller

Arduino Uno is an open-source electronics prototyping platform based on the ATmega328 and it is a flexible, easy-to-use hardware. It has the capability to communicate with a computer, another Arduino, or other microcontrollers. The key features of the board used in Ocure is listed in the table below

S.No.	Feature	Specification
1	Power Supply	6 – 20 V
2	Memory	32 kB
3	Communication	UART TTL

3.1.2 . Laptop or PC

A laptop or desktop computer is required to perform the computation, communication and visualization tasks in Ocure.

3.2. Software

3.2.1. Scilab

Scilab is an open source software for numerical computation providing a powerful computing environment for engineering and scientific applications. Ocure uses Scilab to communicate with Arduino hardware to generate the ECG signals corresponding to different heart conditions. Scilab is also used to perform the signal processing and visualization functions.

3.2.2. Communication Programs

The Arduino board must be programmed to function as signal generator and signal receiver. The signal generator is the Ocure Heart Simulator and the signal receiver is the Ocure ECG Monitor.

3.2.3. Ocure Heart Simulator

The ECG signals from the database can be sent to another computer, another Arduino board or oscilloscopes by programming the Arduino board to function as a signal generator. The generated signal is available at one of the six analog output channels. The output signal from Arduino board is pulse width modulated (PWM). A modulator RC circuit (R=4kΩ and C=10μF) is used.

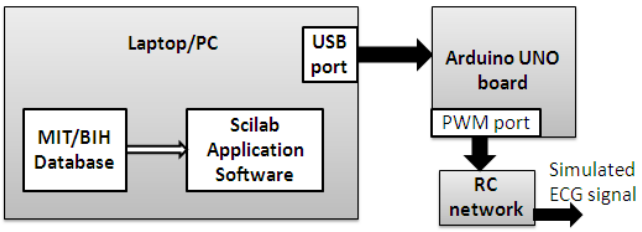

Figure 1: Ocure Heart Simulator-Architecture

3.2.4. Ocure ECG Monitor

The receiver Arduino board is programmed to receive the signals at the analog input ports and send to the serial port. The Scilab serial communication programs can read these signals and store it in the computer for processing and visualization.

3.2.5. Signal Processing Programs

ECG signal viewer

The viewer reads the signals acquired from the heart simulator and displays it in a chart. This is a real time display.

QRS complex viewer

This viewer function displays the output of the QRS Complex detection function in Ocure. The details of the

QRS complex detection algorithm are outlined in the section 5.1.

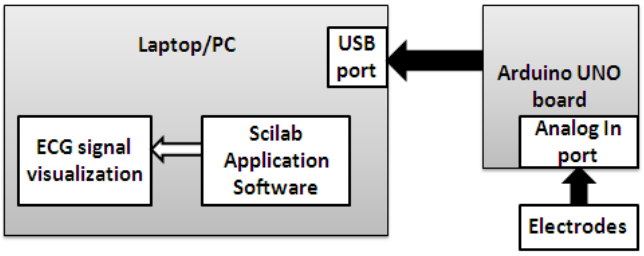

Figure 2: Ocure ECG Monitor-Architecture

Heart rate view

This viewer function displays the output of the heart rate calculation function in Ocure. The formulae used are presented in the section 5.2.

4. HEART CONDITIONS

Ocure also shows the heart condition corresponding to the ECG signal. It can be used to explain the conditions such as Sinus Rhythm, Sinus Bradycardia, Sinus Tachycardia, Sinus Arrhythmia, Atrial Flutter.

5. ALGORITHM

5.1 QRS detection

Figure 3 shows an ECG signal in Ocure and the QRS complex, which is a characteristic feature in ECG signals.

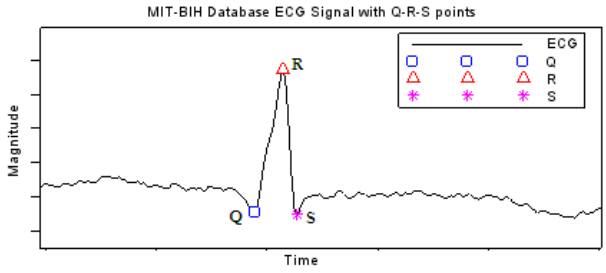

Figure 3: QRS Complex in an ECG Signal

QRS detection is a challenging problem due to the physiological changes of the QRS complexes. There are many methods to detect the QRS complex of an ECG signal. One of the fundamental methods is based on Pan-Tompkins algorithm [11]. It uses a low pass and a high pass filter to reduce the noise from different sources such as muscle noise and the signal artifacts due to electrode motion. The transfer functions of low pass filter and high pass filter in z transforms are H(z) and G(z)

$$H(z) = \frac{(1-z^{-6})^2}{(1-z^{-1})^2}$$

$$G(z) = \frac{(-1+32z^{-16}+z^{-32})}{(1-z^{-1})}$$

The filtered ECG signal is differentiated to calculate the slope of the QRS complex. The resultant signal is squared to make the waveform positive. The threshold is automatically adjusted to raise the signal above the noise floor in the ECG signal.

5.2 Heart rate estimation

Heart rate is the number of heart beats per unit of time. The heart rate is derived using the R locations in the ECG signal. The heart rate is computed by averaging the RR intervals.

6. PEDAGOGICAL EXAMPLES

In this section, we outline two examples to demonstrate ways to use Ocure in a biomedical signal processing class or laboratory.

6.1 Example 1: ECG Signal Processing

Figure 4 shows a flowchart outlining the steps in Ocure to study ECG signals and the steps involved in computation of the key parameters of the signal.

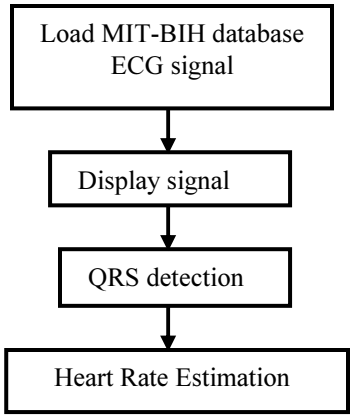

Figure 4: ECG Signal Processing with Ocure

The results are shown in Figures 6 and 7.

6.2 Example 2: ECG Signal Simulation using Arduino

Ocure can be used to teach students to do programming with Arduino boards to generate and receive signals. Figure 5

shows the flowchart of ECG signal simulation and real-time visualization in Ocure.

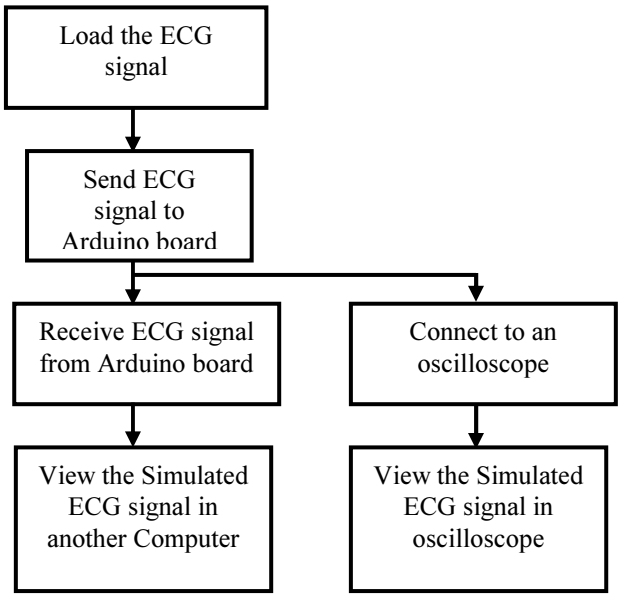

Figure 5: ECG Signal Simulation with Ocure

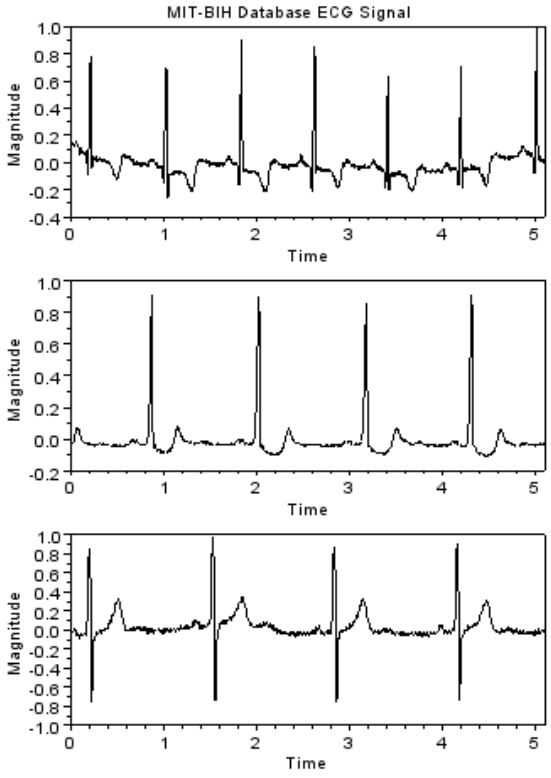

Figure 6: ECG Signals in Ocure

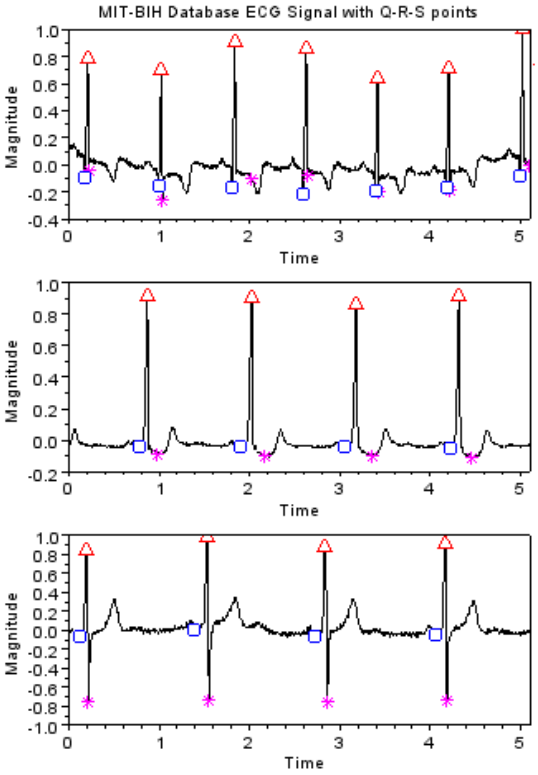

Figure 7: QRS Complex of ECG Signals in Ocure

7. CONCLUSIONS

Ocure is a simple build it yourself simulator for academic applications designed entirely using open source hardware and software components to teach ECG signals and their characteristics. However, the system can be redesigned for other classroom and laboratory applications. The clinical training of doctors requires a subject, an ECG amplifier and a monitor. The availability of subjects to demonstrate all types of heart conditions is not practically feasible. The use of Ocure would replace the subject. Ocure is also a vital tool for ECG calibration and testing and it can be incorporated in clinical environments. Ocure has the potential to positively influence education in much the same way Cuore served as an inspiration for academic achievement. Ocure would empower the teachers and the students and make the teaching learning experience inspirational.

8. REFERENCES

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