ECG Acquisition Based AVR Microcontroller and Java Application for Visualisation via Email Service

[1]Christian TCHAPGA TCHITO, [2]Gaby Eric TCHIMMOUE, [3]Daniel TCHIOTSOP, [4]Enow ABUNAW T., [5]Michael SONE EKONDE, [6]Anaclet FOMETE

[1, 2, 4, 5] Dpt. of E.E.E, University of BUEA, Cameroon
[3] Dpt. of Electrical Eng., Univ. of Dschang, Cameroon
[6] Dpt. of Physics, University of Dschang, Cameroon

Abstract— In this paper, we propose a portable efficient low cost healthcare system to establish a mobile telecare environment for low income countries. This system acquires ECG signal and enables monitoring patient remotely rather than keeping them in emergency care due to the lacking of expensive ECG devices. The system composes of two main parts linked by and SD card, the first part is all about acquiring ECG data, with a cheap AVR microcontroller implementing a RTOS through the AD8232 differential amplifier, and the second module is the dedicated versatile Java application for displaying those signals via the MySQL DBMS.

Keywords— ECG, RTOS, Java, AD8232, Arduino, MySQL, datalogger.

I. INTRODUCTION

The body acts as a giant conductor of electrical current. Electrical activity that originates in the heart can be detected on the body's surface through an electrocardiogram (ECG). Electrodes are applied to the skin to measure voltage changes in the cells between the electrodes. These voltages change are amplified and usually displayed on an oscilloscope, graph paper or any screen. It is important to keep in mind that the ECG shows only electrical activity; it tells us nothing about how well the heart is working mechanically.

Telemedicine can change the current paradigm of care and allow for improved access and improved health outcomes in cost effective ways. ECG remote analysis is under the umbrella of telemedicine. It helps eliminate distance barriers and can improve access to medical services that would often not be consistently available in distant rural communities and it is also used to save lives in critical care and emergency situations. Nowadays, there are several efforts towards the development of systems for the remote monitoring of patients, healthcare industry depends mainly on Information technology to provide best services. And that promise the healthcare area a big change especially in front of the explosion of medical data sources [1] [2], [3].

There are many existing systems that have attempted to simplify ECG data acquisition and analysis. These systems utilize other wireless and IoT (Internet of Things) standards such as Wi-Fi [4], Ethernet [5], [6], Bluetooth [6], ZigBee [7], parallel port [8], USB [9] and even GSM [10], [11]. Although many wireless standards can be used, there are important considerations such as range, throughput, security, ease of implementation and cost. The patient monitoring involves handling of sensitive data. These data should be transmitted securely without any intrusion [2]. The proposed system solves the problem of range, throughput, and security as it utilizes email thus inheriting its large range in this global village and its security advantages. The aspects of ease of implementation and cost are address using the XAMP server, java and Arduino which are free online platforms and very easy to use.
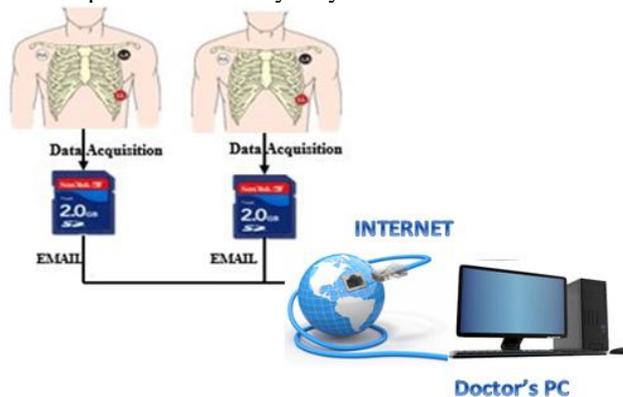

Fig. 1.General overview of the proposed system

The system talked about in this paper acquires the ECG data after placing the electrodes on specific positions on the patient's body, into an SD card which can then be uploaded as an email attachment and sent to the clinic or specialist email for downloading by the software tool into the database. MYSQL database is used here since it's an open source relational database management system. It is also widely used by web application developers, together with PHP and APACHE. MySQL is a three layer model: Application layer, Logical layer and Physical layer [12]. As we can see on Fig. 1, we can have several patients' record sent at the same time, those records are downloaded and stored on the cardiologist PC, because he has the application installed on his PC, downloading any new ECG record, allowing him to watch and compare them any time.

Our system is made up of two main concepts, a hardware section for ECG acquisition and storage, and a software section for ECG record downloading and visualisation. The rest of this paper is organized as follows. In the following section, The system architecture will describe both the Hardware and the software part for the proposed system, then will follow the Experimental tests, results and discussion, with the general conclusion at the end.

II.   SYSTEM ARCHITECTURE

A. Hardware Design

The concept of the system is shown in the block diagram in Fig. 2 The system consist of three modules; the patients' ECG acquisition device, the MYSQL database which is part of the XAMP server, and the software tool for download, plot and analysis of the ECG waveform.
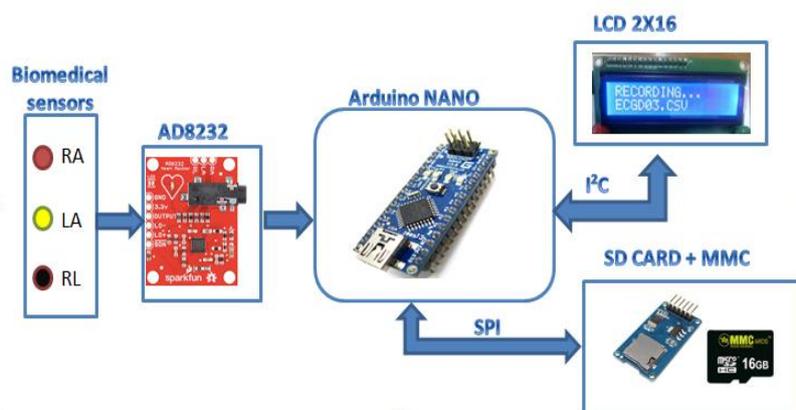

Fig. 2.Block diagram of ECG hardware acquisition module

1) AD8232

The AD8232 SparkFun Single Lead Heart Rate Monitor is a cost-effective board used to measure the electrical activity of the heart [13].

The ECG acquisition device which is the electronic part is controlled by the Arduino Nano. Electrodes are attached at specific positions of the patient's body, under the principle of silver/silver chloride sensors. These AgCl electrodes acquire the ECG signal which is of very low voltage (below 0.8V). The principle of silver/silver chloride sensors operation is the conversion of ion current at the surface of human tissues to electron current to be delivered through the lead wire to the instrument to read. An important part of the operation is electrolyte gel which is applied between the electrode and tissues. That signal low voltage is amplified and partially filtered by the AD8232 Heart Rate Monitor (HRM). The AD8232 and SD card adapter module containing the SD card is interfaced alongside the AD8232 to the Arduino Nano. DS3231 Real Time Clock (RTC) is also interfaced with the Arduino to give the real time when the ECG signal is actually gotten. Fig. 2 shows the block diagram of the acquisition module.

The data saved in the SD card are two files: a comma separated value (.csv) file containing the actual ECG and a text file (.txt file) which contains the patients' weight, temperature, and the time the data is acquired. The sampling frequency is also stored in this file.

2) leads

Electrodes are applied to the skin to measure voltage changes in the cells between the elecrodes [14]. Those electrodes where placed according to the three-wire patient cable placement which represents the first Einthoven bipolar lead as represented on Fig. 3 [15].

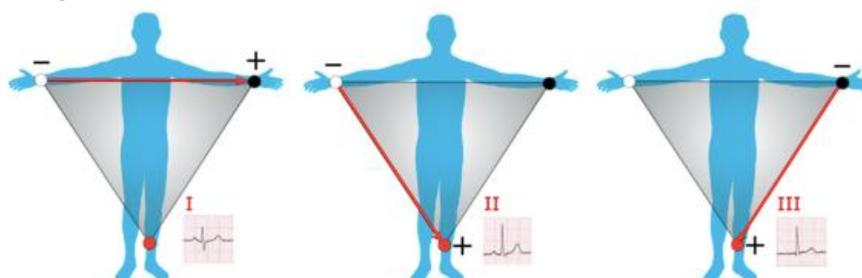Fig. 3.Different configurations for Leads I, II and III are called the limb leads sampling [15]

Lead I is the voltage between the (positive) left arm (LA) electrode and right arm (RA) electrode:

$$I = LA - RA \qquad (1)$$

Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode:

$$II = LL - RA \qquad (2)$$

Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode:

$$III = LL - LA \qquad (3)$$

3) Arduino board

We used for this paper the Arduino Nano [16] is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x) or ATmega168 (Arduino Nano 2.x). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. Arduino Nano board's default clock is 16MHz. Using the 128 prescaler value gives a sampling frequency of 125 kHz for 10bits [17]. Timing in ECG is a very essential factor. The real time the ECG is taken from the patient, is recorded and saved as txt file in the SD card.

4) RTOS

Given that SD card latency considered for a buffer of 512 Bytes when writing in our SD card is about 1ms, we should understand the need of a parallel computing, when aquiring data since we have to store them, as they are collected . FreeRTOS was used as a real-time operating system (RTOS) to set timers, handle events and tasks, and to avoid wasting SD Card latency [18], the **Error! Reference source not found.** shows an illustration of the hardware environment running with all the components interconnected. A scheduler is at the heart of every RTOS, as it provides the algorithms to select the tasks for execution. Three of the more common scheduling algorithms are [19]
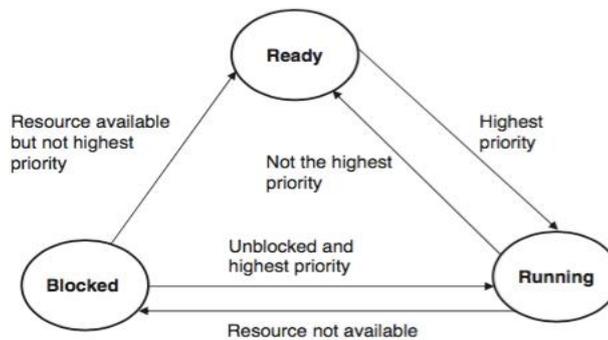

Fig. 4. RTOS scheme for implementation

B. Software Design

Voltage changes obtained on the previous section are amplified and could be visually displayed on an oscilloscope and graph paper as usual, but we will instead save our own onto the SD card and transfert them to a database, so that they could be plotted.

1) Database

The database is implemented using the MYSQL Data Base Management Systems (DBMS) [12]. It comprises of 03 main tables: SignUp table which stores the credentials of the specialists accounts; Patients table where the patients personal information like name, age, sex are stored; and at last ECG Signal table, which stores the actual ECG data alongside the date of acquisition and also the patients temperature and weight. Fig. 5 shows the database design using MySQL Workbench.
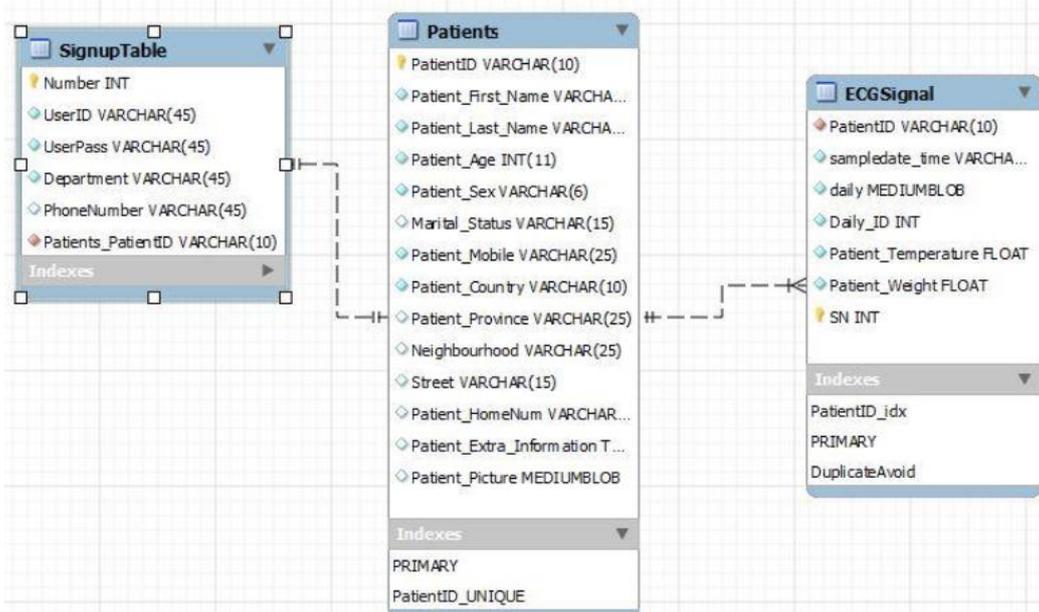

Fig. 5. Database design

2) Email

We have used Email service as a transmission protocol specifically Post Office Protocol, POP3 [20] for receiving the email and Simple Mail Transfer Protocol, SMTP for sending emails. POP3 is a standard mail protocol used to retrieve emails from an email server. However when used through Java, it ticks the digital signature of the email thus avoiding re-download of the same email and its associated attachment.

Since email services is the technology used, it thus implies the system inherits the security aspects of the email services. An example of such security is logging in into the email using a specific Username and password. Other special encryptions can be done to improve the security of the patients ECG data. The API used in this project is JavaMail.

3) Java

The last module of this system is a dedicated software application. Tools and different APIs used for developing the desktop application are provided through Java Development Kit (JDK). To develop the desktop application, NetBeans development environment has been used. JavaFX with FXML were used for designing the various screens of the software tool.

This software tool is built using Java language. The tool enables the auto downloading of the email attachment and stores the appropriate data into the hospital's database. A login screen enables a specialist to login into his account then if a new signup is required, there is a possibility of signup. The software enables adding, updating and deleting patients' information from the database. The ECG data in the database is also plotted and the specialist can get the the patients' heart rate. We will present the software implementation in term of UML Use Case Diagram, as presented on Fig. 6 a which is actually the main component of the system, it illustrates the specialist (Cardiologist) account subject, with the Specialist User as actor. From Fig. 6, the specialist can do four different sub activities:

- Login and Sign up: to log in the system, create an account, or even delete an existing account to keep some visibility on who is using the system, presented on Fig. 6 a .
- Manage patients: Alter some data on the patient, and manual updates, like names, weight, temperature. The manage patients abstract use case is specialized by Add new patients, Update existing patient account and Remove Existing Patient, presented on Fig. 6. b.
- ECG analysis: to view the different ECG data of a patient and compare with previous. The ECG analysis abstract use case is specialized by ECG plot, Heart Rate computation, Displacement between points and zooming capabilities, presented on Fig. 6.c.
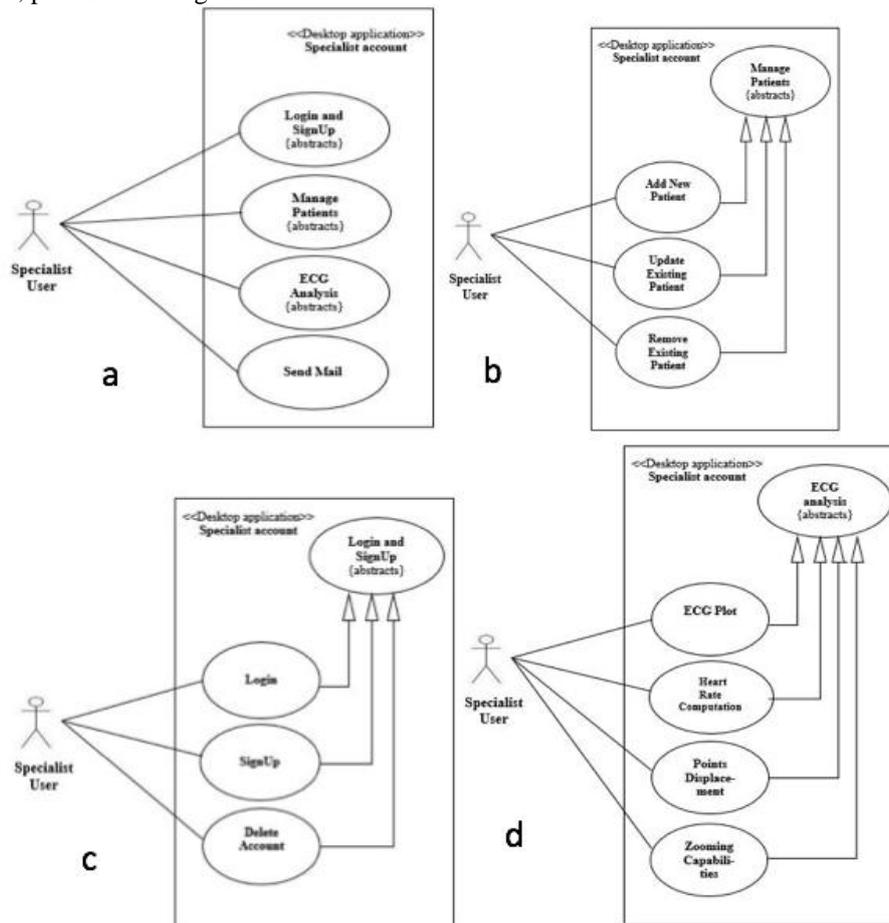

Fig. 6.   a) Use Case diagram for ECG Software Tool, b) Manage Patients use case for Software tool,c) SignUp and Login use case for Software tool, d) ECG analysis use case for Software tool.

- Send mail: for ECG data forwarding some patient's record to another specialist, may be for further analysis, presented on Fig. 6.d.

III. EXPERIMENTAL TESTS, RESULTS AND DISCUSSION

The first part is the electronic circuit built around the AVR atmega328 on the board Nano of the Arduino project which is cheaper than PIC microcontrollers used in [9] [8], to acquire heart's electrical activity through the Single Lead board of SparkFun with the AD8232 [18] instead of traditional AD620, and INA118 [9], where a (RTOS) Real Time Operating Systems is embedded, for sampling accurately at 1024 microsecond time interval as datalogger that is about 970 Sa/s (Sample per second), accurately better than [9] which is 310Hz. Those digital data are saved in an SD card, which are then uploaded via email as attachment, and sent to the clinic care email address. Those records are automatically downloaded for storage in the health care's database. The second part of this system is creating a monitoring server that collects those recordings form the database for plotting, giving room for easy heart rate calculation. MySQL Database Management System (DBMS) used for the patient's ECG data management. A dedicated application software was developed using JAVA language for that purpose. This application provides access for the auto downloading, data retrieval, data plotting for analysis and gives the possibility for the specialist to compute displacements between points and also to get the Heart rate's value on the plotted ECG.

Fig. 7.Experimental setup

After connecting electrodes on the patient's body, as device is powered on, the LCD screen will display the names of files new files created, then after five seconds data will start being logged in the SD card. The system on the   the ECG data and other required data are stored in the two files which are manually uploaded and sent via email. Our dedicated application tool downloads these files and saves the accordingly in the MySQL database. The cardioligist can choose to view the saved ECG data as a plot through the software tool, or can choose to either add a new patient or remove an existing patient from the database. Patients information can also be updated if need be. The software tool enables a send mail options such that the specialist can react accordingly to the viewed ECG signal. The tool gives the specialist the possibility to compute the Heart Rate and displacements between points thus the required time intervals can be gotten(like the PR or QRS intervals).The application has zooming functionality, which improves the usability of the app.

The ECG data shown on Fig. 8.c is a real life ECG gotten after placing the electrodes on the patient's body for 8s. Those data were sent via Email, then downloaded into the database. Screen shots of some frames of the desktop application are shonw in Fig. 8, presenting in: a) the Login Screen, b) the form Adding new patient screen, in c) the Main screen displaying patient's ECG on lead I as (1), at last in d) then Send Mail Screen to forward some patient's record.
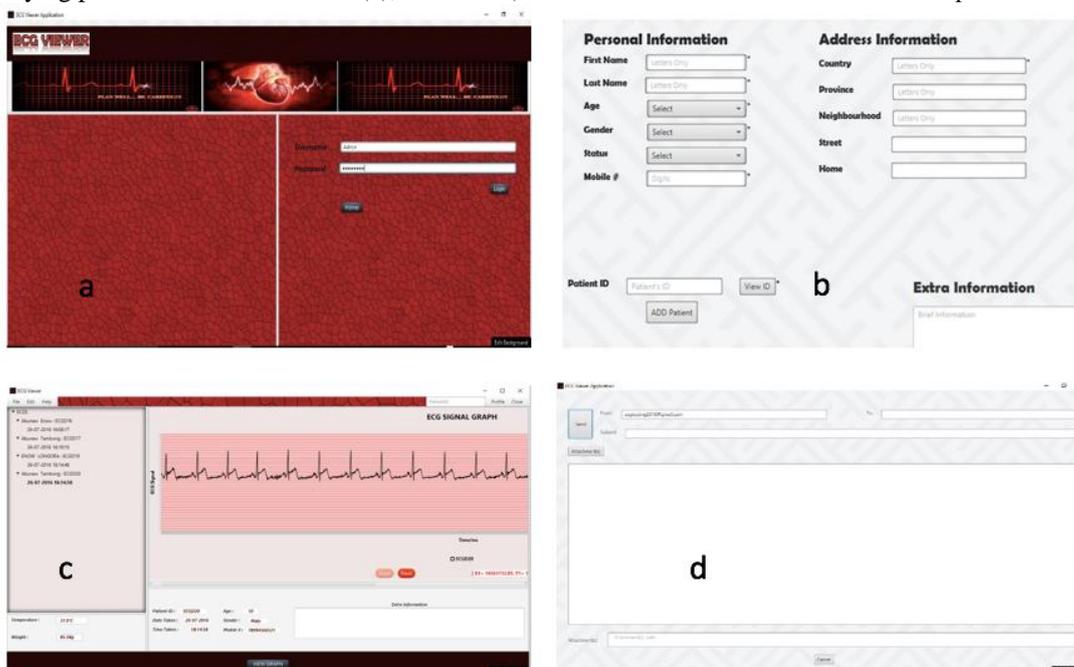

Fig. 8.a) Login Screen, b) Add new patient screen, c) Main screen displaying patient's ECG, d) Send Mail Screen.

IV. CONCLUSION

We have demonstrated a very low cost ECG acquisition dual design with a prescision of 970 Sa/s, able to sense, to transmit and keep ECG records in a SD card, upon forwarding those records to a dedicated Health center's Email address, The remote hospital's PC configured as server, in charge of downloading those specific data and store them in a MySQL database. Those data are then plotted by the desktop application. Iby so doing, ECG signals can be interpreted remotely by specialists in the absence of the patient. This paper is inline with the new trend of E-health development. Some features to be included are module for irregularities detection in the heart rhythms, automatic alert to the doctor in case of emergency. It is also important to make the the device transfer its data via Bluetooth or Wi-Fi to facilitate ECG plotting on smart devices.

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