



public health care and health education. Advancements in mobile and wireless health care solutions contribute to different aspects of our lives ranging from diagnosis to treatment of various health problems such as cardiovascular diseases in [9]. If any abnormalities are found, the patient will be notified through an audible alarm and first aid techniques will be shown to the patient in the phone's display [10]. Android applications are also part of the diverse groups of products that can provide health care solutions. These applications have also been adapted as references for developing Bluetooth applications in the Android platform. Reference [11] proposed that telemedicine can be applied to a greater extent in cardiology wherein ECG serves as a primary tool. Patient vital signs, such as ECG, heart rate, respiratory rate, temperature, and peripheral capillary oxygen saturation values, are captured and entered into the database. Then, the data are uploaded to a web-based server, which sends them to doctor phones with Android technology. Clifton et al. explained that several technologies that promise to significantly improve patient care are currently available or are being developed [12]. Vital sign recordings can be enhanced by automated transmission of the measured parameters to an electronic patient record. Therefore, these technologies should be carefully executed because poor-quality deployment can lead to bad patient care.

### III. METHODOLOGY



Fig. 1. Complete m-Cardiac system architecture

The proposed m-cardiac system is shown in Fig. 1. The system consists of ECG electrodes with an embedded Arduino microcontroller placed in a belt under the chest and belly of a patient. The RN-XV WiFly module is used as the communication medium to transmit ECG data to mobile phones. Real-time ECG data are displayed by using a mobile application. The application then sends the data via WLAN or GPRS to a patient medical profile (PMP), i.e., a personalized cloud-based health data center. The huge amount of health data is processed by using a specific algorithm tool. This tool performs real-time classification of vital signs based on data mining techniques.

We work with a three-lead ECG sensor in our prototype. Noise, interference, and non-rest conditions of the patient can contaminate signals. This condition implies that focus should be placed on extreme ECG signals. We used Lead II (Fig. 2)

in the proposed ECG monitoring system because the voltage from the right arm to the left leg provides the strongest signal as it moves across the heart. Electrode placement on the human body is shown in Fig. 3.

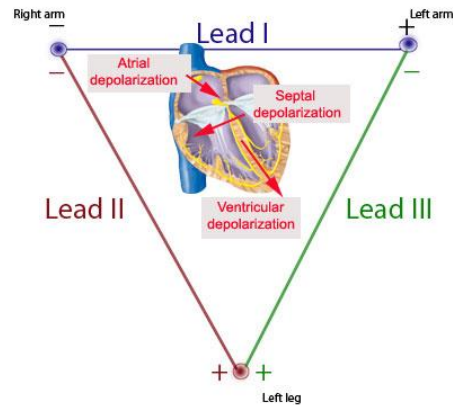


Fig. 2. ECG leads as explained in McGill Physiology Virtual Laboratory [10]

The block diagram of the proposed wireless ECG monitoring system is shown in Fig. 4. The system consists of the following: i) ECG electrodes, ii) microcontroller Arduino, iii) e-health kit, iv) the RN-XV WiFly module, v) smartphone, and vi) database.

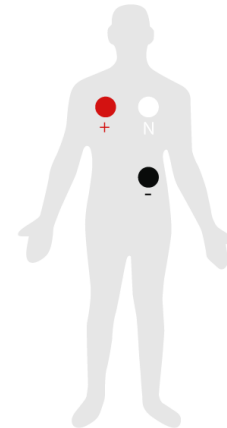


Fig. 3. Electrode placement as suggested in Libelium Comunicaciones Distribuidas [11]

#### A. Hardware System

The hardware system has a significant role in the operation of the proposed ECG monitoring system. We will provide a brief introduction to the sensor and the microcontroller in this section.

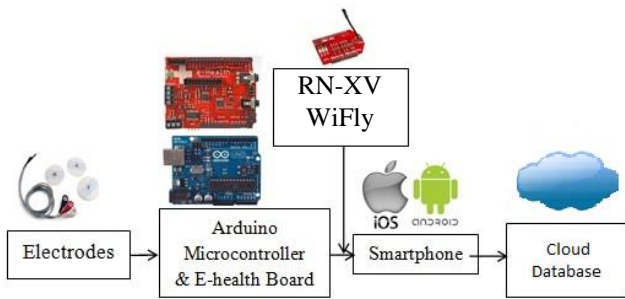


Fig. 4. Architecture of the proposed system

Arduino UNO is the main component used in the proposed system. It processes signals sent by the biosensors. This microcontroller board is based on ATmega328 and consists of 14 digital pin entries (input) and 6 analog productions (output), a 16 MHz ceramic resonator, a USB connection, a power jack, an In-Circuit Serial Programming header, and a reset button. Arduino UNO possesses the necessary features required to support the microcontroller by connecting it to a computer through a USB cable. The RN-XV WiFly is used to establish communication between the microcontroller and the smartphone. This module functions as a Wi-Fi antenna for transmitting data from the Arduino to the smartphone, as shown in Fig. 8.

### B. Software System

For the software system, we use Arduino for programming and Tera Term to configure the RN-XV WiFly module. The connection properties of Tera Term are shown in Fig. 7. Before connecting the smartphone to the RN-XV WiFly module (Fig. 8), the module should be configured first. Tera Term is used to set up the IP address of the module to perform this process.

An Xbee USB adapter is connected to the RN-XV WiFly module to produce a serial connection during configuration. Configurations for Android (Fig. 4) and iOS (Fig. 5) are performed independently.

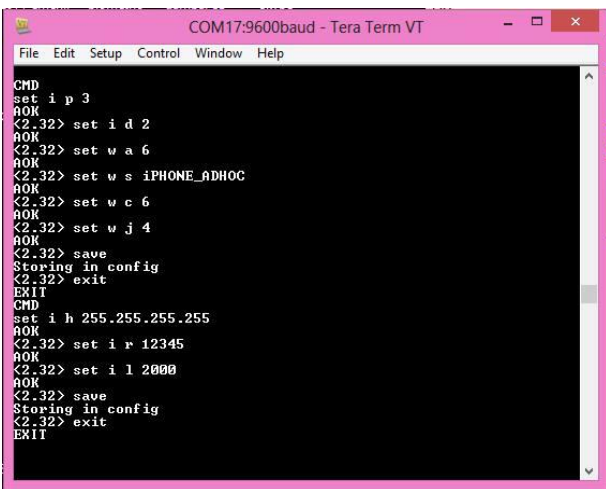


Fig. 5. iOS configuration on the RN-XV WiFly module

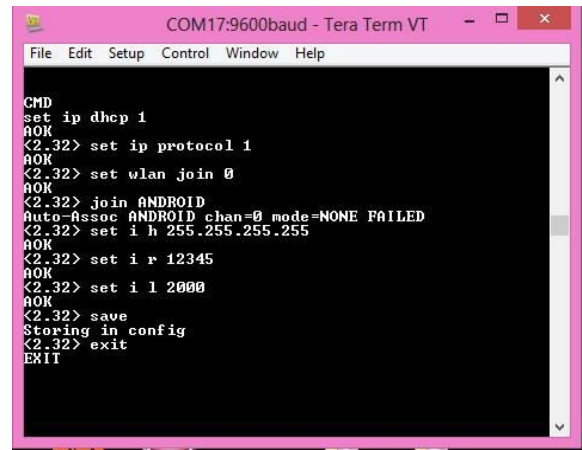


Fig. 6. Android configuration on the RN-XV WiFly module

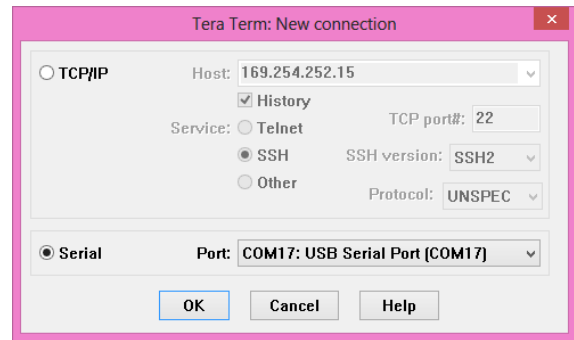


Fig. 7. Tera Term connection properties

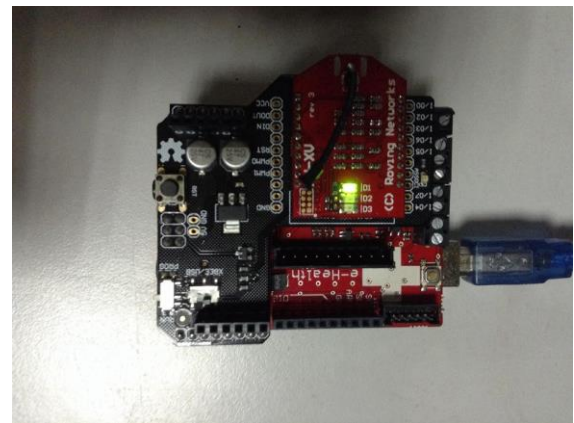


Fig. 8. The RN-XV WiFly module connected to a smartphone

## IV. RESULTS AND DISCUSSION

This chapter, which presents the results, is divided into two parts: (1) the serial monitor for the desktop and (2) data transmitted to smartphones. The output is initially tested on the serial monitor (Fig. 9) to ensure that the sensor is fully operational before being displayed on a smartphone. The smartphone processes sensor data. Raw data are then converted into ECG signals via Gaussian process regression to

eliminate noise. This algorithm will be further improved to generate ECG signal more accurately. The final ECG signal is shown on the smartphone based on Fig. 10 and Fig. 11. In Fig. 10, due to low sampling rate, the ECG signal appears inaccurately.

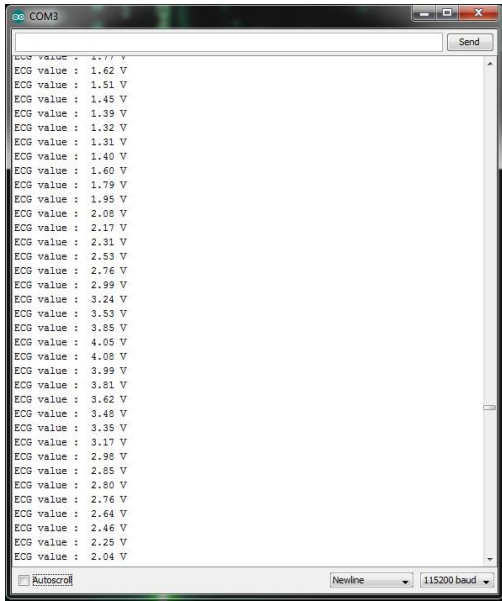


Fig. 9. ECG signals verified by using the serial monitor Arduino



Fig. 10. Output on an iOS smartphone



Fig. 11. Output on an Android smartphone

Users also have the option to store data in text form in PMP, as shown Fig. 12. Doctors can replot ECG data for a particular period that requires attention.

ECG value : 2.44 V	ECG value : 2.20 V
ECG value : 2.02 V	ECG value : 2.64 V
ECG value : 1.65 V	ECG value : 2.87 V
ECG value : 1.43 V	ECG value : 2.80 V
ECG value : 1.37 V	ECG value : 2.46 V
ECG value : 1.50 V	ECG value : 2.06 V
ECG value : 1.78 V	ECG value : 1.66 V
ECG value : 2.17 V	ECG value : 1.41 V
ECG value : 2.60 V	ECG value : 1.33 V
ECG value : 2.88 V	ECG value : 1.44 V
ECG value : 2.86 V	ECG value : 1.73 V
ECG value : 2.55 V	ECG value : 2.13 V
ECG value : 2.13 V	ECG value : 2.58 V
ECG value : 1.75 V	ECG value : 2.89 V
ECG value : 1.47 V	ECG value : 2.88 V
ECG value : 1.36 V	ECG value : 2.57 V
ECG value : 1.44 V	ECG value : 2.16 V
ECG value : 1.69 V	ECG value : 1.75 V
ECG value : 2.07 V	ECG value : 1.48 V
ECG value : 2.52 V	ECG value : 1.37 V
ECG value : 2.86 V	ECG value : 1.45 V
ECG value : 2.91 V	ECG value : 1.74 V
ECG value : 2.66 V	ECG value : 2.11 V
ECG value : 2.24 V	ECG value : 2.57 V
ECG value : 1.83 V	ECG value : 2.92 V
ECG value : 1.52 V	ECG value : 2.97 V
ECG value : 1.39 V	ECG value : 2.72 V
ECG value : 1.43 V	ECG value : 2.29 V

Fig. 12. ECG data stored in a cloud database

## V. CONCLUSION

An m-cardiac wireless ECG monitoring system that uses smartphones has been developed. We have constructed a working prototype that focuses on ECG sensors. In addition, the features of the ultra-low RN-XV WiFly module as a communication medium between microcontrollers and smartphones have been described. This system helps reduce the number of times that lithium batteries should be recharged. ECG data that have been saved in the database can be retrieved by doctors for future reference. The target users for our application are patients who have suffered from a heart attack or at high risk of suffering from a heart attack. We have learned from discussions with cardiologists that these patients are worried that a heart attack may occur/reoccur, and thus, are willing to wear a monitoring device that can help reassure them of their safety. Intrusiveness is not an issue for these highly motivated patients.

## ACKNOWLEDGMENT

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