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Remote monitoring of patients of Cardiology Department of the Benin National Teaching University Hospital (CNHU-HKM)

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Abstract. **The remote monitoring system for patients aims to provide better aftercare for them through an easy system scalable and adapted to the socio-economic realities over the world and particularly in the Benin National Teaching Hospital Hubert K. MAGA (CNHU-HKM) as national reference center. To achieve a part of this goal, we have proposed to implement a prototype for patients of cardiology. Its functioning is based on a web application for the exchange of information and data with the system, an electronic device for the acquisition of phonocardiogram (PCG) and two software applications. The first application is responsible of all processing at patients level. The second application, which is for doctors deals with the remote monitoring of the patients' data in real time. The obtained system is highly optimized for cheaper and scalable to all specialties without major component addition. Since the prototype is realized only for cardiac signals, it is extendable other physiological parameters.**

Keywords- ***Republic of Benin, remote monitoring, PCG, GSM / GPRS, GPS***

I. INTRODUCTION

Remote monitoring, a branch of telemedicine technology is important to provide specialists of the National Teaching Hospital Hubert K. MAGA (CNHU-HKM) especially for cardiology all the more as the number of patients with heart disease is considerable and cardiovascular accidents are frequent. Cardiovascular diseases are 1.1% in hospital[a] while the number of beds available (17) for the hospitalization of patients, in the service of Cardiology CNHU-HKM is very low. A flexible remote monitoring system will provide ongoing assistance to these patients while allowing them to continue their daily activities or not. Such flexibility is increasingly made possible in existing systems through integration of wireless and mobile for transmission of patient's data such as electrocardiogram (ECG), heart rate, electroencephalogram (EEG) and others. The phonocardiogram (PCG) is not often used in many achievements although we can draw enough usable information. It is also relatively easy to obtain. This work therefore aims to design a remote monitoring system to monitor the heart case even outside CNHU-HKM order to rescue them in time in an emergency. To do this, the system architecture will be based on the model of Figure 1 and Figure 2 as in unpublished [4]. Patients will be taken into account by this system are those service cardiology and PCG will be the physiological parameter monitor their level.

II. MATERIALS AND METHODS

A. *Transmission means*

We chose the mobile networks in Benin as a means of transmission of data of system. Indeed, the infrastructure mobile networks in Benin are primarily the 2G, 2.5G and 2.75 G. Mobile teledensity is very high, 85.64% in 2011b . Radio coverage of GSM operators is also great. In fact, the departments of Benin in high population density such as Littoral and Ouémé have radio coverage of nearly 100%. In total there is comprehensive coverage of 90.26% of the national territory by all GSM operators at once. On the main roads, they are covered at a rate of almost 100%[b].

B. *System architecture*

We chose architecture as the model of Figure 1 and Figure 2 as in unpublished [4]. This model proposes that the patient has a terminal (Figure1) which will take its physiological parameters. This terminal communicates with GPS (Global Positioning System) for locating the patient. It contacted GSM / GPRS network in case of danger to send SMS alerts and issuing voice call to mobile phones of doctors and first-aid workers. Also, through the GPRS, it transmits data to a reference hospital in real time or in case of danger indicated by a processing module as shown in Figure 2 . These data will be stored on a file server in the reference hospital where there is also a Web server that hosts an application for the processing

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[a] Source : Annuaire 2002-Système de santé de la République du Bénin. Ministère de la Santé Publique (MSP), DPP-SNIGS, 2002.

[b] Source : Annuaire statistique 2011 des télécommunications au Bénin. Autorité Transitoire de Régulation des Postes et Télécommunications (ATRPT), 2012.

and management of information and patient data contained in a database located on a data server. Doctors will be able to view patient data through the web application. First-aid workers will have a Google Earth client to visualize the position of the patient from geographic coordinates to be included in the SMS alert before going to his rescue.

C. Technical choices for achieving

1) The patient's terminal (hardware)

The patient's terminal is composed of two modules: a module A for the acquisition of the required physiological parameter and a module B for processing. We designed a module A can recover the heart sounds of a patient and send it in real time to module B. This device relatively simple to perform has permitted with low cost to follow the PCG of patients and anticipate many dangers. Do not have great ways to develop the Bluetooth; we used a wire support for sending data to the module B. Indeed, we have used a double horn extended by a short length of tubing in which is inserted the microphone capsule. Functioning principle is following: heartbeats received by the membrane of horn are transmitted to a sound sensor (the microphone capsule) through a sound waveguide (small tubing) in the form of sound. The sensor then converts the recovered sound as electrical signal. This electrical signal is then sent to the module B in real-time for its processing. On module B is installed processing application. It therefore has two parts: hardware and software part. For its realization, we used a notebook. For desired functionality, we would have connected a GSM / GPRS modem and GPS receiver via its USB ports. The designed module A sends the acquired signal in electric form to sound card of module B through a jack. Processing application communicates with the GSM / GPRS modem with AT commands of the ETSI GSM 07.07. The commands used are those emission and control calling and sending SMS.

2) The software

The software part of the patient's terminal is made of operating system and the processing application. Installed on the module B, all operations of the application (communication with the internal components of the module B and data processing) are in real time. We provided it of conditioning algorithms based on reliable and recent digital signal processing tools. Regarding the application of remote monitoring, it must be installed on a standard PC and will function to display real-time patient data it receives from the FTP server. It will also provide an opportunity for automatic diagnosis. To meet this need, we chose MATLAB of MathWorks, Inc. This is an interactive program used for scientific computing the numerical solution of many mathematical problems or applied. In addition, it has significant graphic and signal processing potential. It allows you to easily communicate with the hardware, retrieve real-time data from an external device or internal to a computer. It implements communication modules with remote servers including Web and FTP servers. To do so, it is widely used in industry as in academia.

3) The Web application

Technical tools chosen for the realization of the application are practically the most used in the web because of their effectiveness and for most, their GPL. It is basically HTML5, CSS3, PHP5.3, SQL, MySQL, JavaScript and WampServer (test server).

4) Automatic processing of biosignal

To achieve this system, we proposed to make the automatic diagnosis of cardiac arrhythmias. For this, the signal received by the module B undergoes a series of preprocessing to extract the PCG signal. Then from the latter is automatically deducted the heart rate. Finally we always automatically make the diagnosis of arrhythmias.

a) Acquisition of the signal

The signal sent by the module A is recovered by the module B processing application at a frequency of 9600 samples per second. Indeed, the driver for the sound card under Microsoft Windows platforms allows sampling between 6000 and 96000 samples per second. This frequency of 9600 samples per second, according to Shannon's theorem[c] provides a signal containing one since the PCG heart sounds S1 and S2 are in the low frequency range with a maximum frequency of 500Hz as in [6]. To ensure real-time aspect, we propose to capture the signal for short periods of 10 seconds. Indeed, to estimate the heart rate must be at least 12 R peaks in ECG. This corresponds approximately to a path length of 10 seconds for a normal subject. The estimated rate would be even more accurate than the analysis time is great; however there must be a compromise between this and the real time.

b) Signal filtering

To keep only a maximum signal frequency of 500Hz characterizing a PCG, we chose a band pass filter cutoff frequency 60Hz and 500Hz. The cutoff frequency of 60Hz eliminates additive noise that originates from the mains power supply module B. The filter used here is a Butterworth filter of order N = 6 since it is an anti-aliasing filter. PCG signal obtained in this step must be sent to a server at CNHU- HKM in real time or when an abnormality is detected. This transmission is done through the GSM / GPRS network. Because this type of network does not offer large capacity data transmission (a theoretical speed of 117 kbit / s for GPRS), it is necessary to compress without huge losses the signal before sending. Indeed, if each sample of the signal is coded "n" bits, for 9600 samples / s, 9600 × n bits will be transmitted per second (9.375 × n kbit / s 1 kbit being equal 1024 bits). Such sounds are coded on 8 or 16 bit WAV format from Microsoft. To minimize the amount of data to send, we chose to encode the signal of 8 bits (it already contains all the information of the signal), which gives a total of 75 kbit / s to transmit if the signal is not compressed.

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[c] This theorem states that the maximum frequency that can be found in a sampled signal at the frequency Fe is equal to Fe / 2.

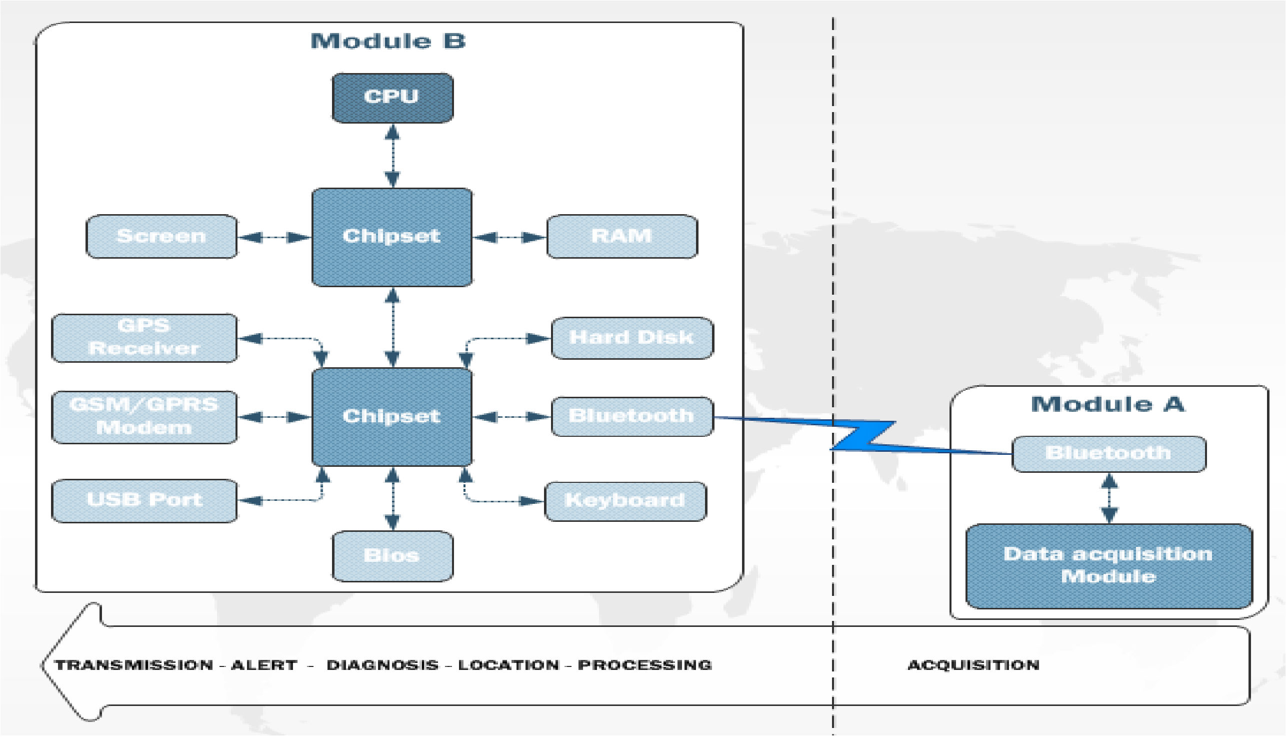

Figure 1. Block diagram of the patient's terminal.

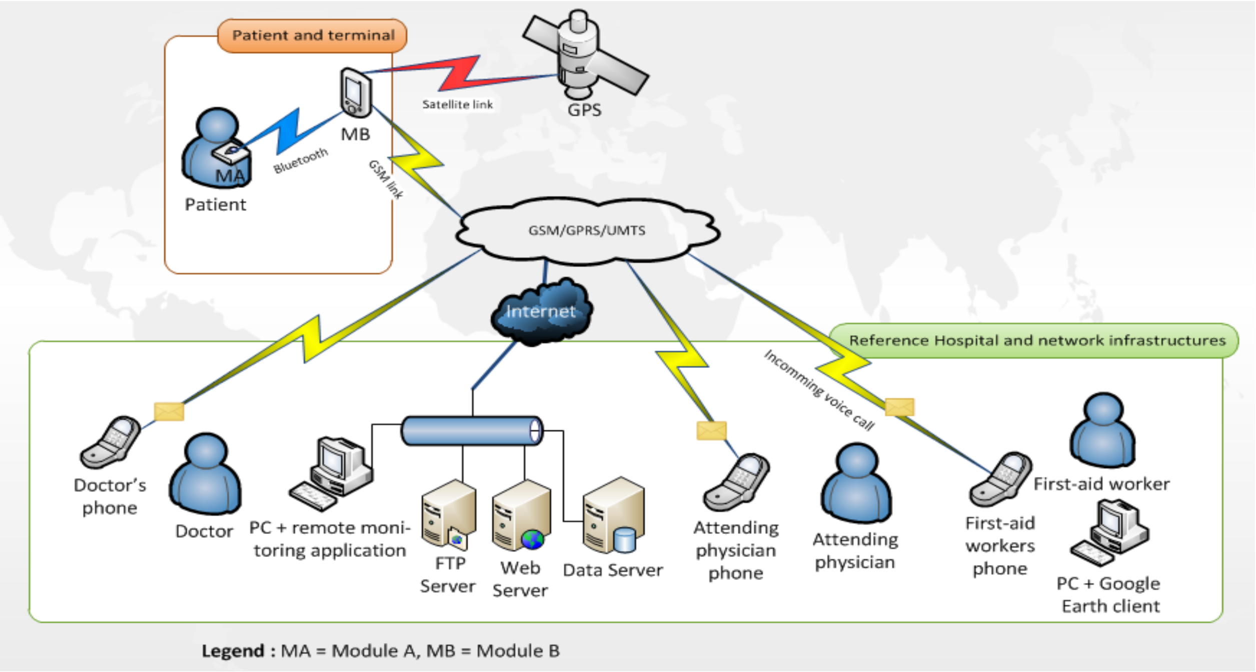

Figure 2. Architecture of patient's remote monitoring system.

c) Compression of the signal by the wavelet transform

The wavelet transform provides a high temporal resolution for the high frequency components and a good frequency resolution for the low frequency components. And while it remains appropriate for the analysis of heart sounds [2]. The application we are interested in here is the wavelet transform MultiResolution Analysis (MRA). It is this property of the multiresolution decomposition we have chosen to use for the signal compression. Wavelet family of Daubechies is most appropriate for the PCG signal processing [2]. With this wavelet, the level 4 approximation signal has the same morphology as the original PCG signal. S1 and S2 waves are present and pathology is not deleted. Indeed, since the signal is then analyzed by doctors, should not undergo morphological changes. At this level of decomposition we have a good compression ratio ($1/2^4$). That is to say, the size of the signal will be divided by 16. Moreover, it is one of the reasons why we chose a sampling frequency initial (9600) multiple of 16. In addition, conditions are often high frequency and the level of decomposition is high, more high frequent are attenuated. This explains the fact that the disease is hardly attenuated at level 4 unlike at level 5. The level 4 approximation signal will be chosen to represent the original signal with a size 16 times smaller. We will have to pass 4.6875 kbit per second instead of 75 kbit. This amount of data can be easily transmitted through the GPRS network.

d) Deduction of the heart rate

The signal obtained after compression is used for the deduction of the heart rate. Since PCG is normally between -1 and 1, we normalized the signal (x) using the formula x (t) = x (t) / max (x (t)). The observation time signal shows that it is marked by strong amplitude peaks that do not appear to be directly related to heart rate. If we assume that the noise distribution is Gaussian, we know that the probability of having amplitudes greater than 3σ is close to zero and that such amplitudes are not significant[d]. We therefore chose to limit the amplitude of the signal at 3.σ where σ is the standard deviation or effective value of the normalized signal. We then detected signal envelope; thereof is obtained similarly to the amplitude demodulation of the signal by rectification and low-pass filtering. At this point, if the heart was still periodic signal, it was hoped, through autocorrelation, make clear the period heartbeat. However, sporadic events such as hazardous disturbance of module A membrane can occur and give a different look to the casing, thus biasing the results to be obtained by direct correlation. To do this, we wrote a special algorithm for the deduction of heart rate from the envelope, described as follows:

- Thresholding the envelope: literatures propose a threshold of 15% of the maximum signal value. Let x be the signal, we have: threshold = 0.15 × max (x (t)). Values below this threshold are set to 0 and the other set to 1. Let x_1 be the signal obtained at this stage.
- Detecting the end of the S1 and S2 waves: the binary signal x_1 is derived to the right and then retains its opposite: $x_2(t) = x_1(t) - x_1(t+1)$. Negative values of x_2 are set to zero.
- The phenomena of double waves S1 and S2 may occur. The minimum duration of systole is approximately 100ms. To avoid counting twice the same wave split when two successive peaks are separated by a period of less than 100ms, the second peak is set to 0.
- The maximum duration of diastole is about 1400ms. If you notice that two successive peaks are separated by longer than 1400ms, the heartbeat deduction is canceled to avoid a false estimate.
- If the number of peaks is not obtained between 7 and 75 for a period of 10s (which roughly corresponds to a rate of between 21bpm and 225bpm), the deduction is also canceled.
- If the deduction is not canceled, we proceed to the determination of the duration between two waves S1 or S2 two successive waves. It calculates the standard deviation σ and the mean μ of these times. It eliminates all times are not included in the interval [μ - σ, σ μ +] then recalculates the average periods used. Thus, the values of the average spread too will be ignored. Finally we multiply the inverse of this duration by 60 to get the heart rate.

e) Automatic diagnosis

In the absence of any disease, heart rhythm is regular[e] and its frequency is between 60bpm and 100bpm (beats per minute) during the day and between 40bpm and 80bpm night. Outside these limits, there may be arrhythmia, which must be a comprehensive study to identify any underlying pathology. However, any irregularity is not pathological: in fact, the autonomic nervous system, exercising permanent control, can greatly accelerate in response to a particular context: a period of stress or effort, for example. It is therefore essential to take into account the patient's activity prior to diagnosis. In this work, we based the diagnosis on the case of an adult patient at rest. If an event of stress or emotion alters heart rate, an alert is necessary considering its medical history of heart disease. To ensure the accuracy of the diagnosis, several successive values of heart rate were collected. If the deviation between these values exceeds 10bpm (roughly corresponding to a variation of the RR interval of 100ms[f]) at that time no diagnosis is made. It is assumed that sporadic events have occurred when taking these values. On the other hand, if the standard deviation is less than or equal to 10bpm, we can make a correct diagnosis. To do this, we calculate the

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[d] Property of the Gaussian (normal distribution)

[e] But not strictly constant, ideal standard deviation of the distribution of the RR interval is approximately 100ms

[f] Interval between two successive R peaks of ECG

average of these different successive values of heart rate and we compared it to the threshold of bradycardia and tachycardia previously set to make a diagnosis. Is called bradycardia when the heart rate is too slow (less than 60bpm), and tachycardia when it is too fast (more than 100bpm).

III. RESULTS AND DISCUSSION

A. The patient's terminal

Module A (Figure 3) of the patient's terminal we performed using a stethoscope with a microphone capsule automatically recovers the heartbeat. The module B of terminal is composed of two parts: hardware and software. The equipment consists of a set of components with specific functions necessary for the performance of the role of the terminal patient. In addition the software part controls the various hardware components. Since the hardware structure is complex and has almost a microcomputer configuration, the model will be given to manufacturers for its realization. That we implemented consists of a notebook (HDD 16GB, RAM 2 GB, Intel Atom 1 heart two 1.6 GHz processors), a GPS receiver (Geonaute KeyMaze 300 version 1.0 .8 Model GH-610A) and a GSM / GPRS modem (brand: LG, Class B). In addition, the software part consists of two components: the operating system (Windows 7 Ultimate), drivers (GPS receiver and GSM / GPRS) and processing application. It is the latter that we have designed. The Human Machine Interface (HMI) of application processing obtained from the Matlab codes written is called "Cardio Plus Patient" (Figure 4). The application of remote monitoring was found at the doctors and allow them to view patient's data in real time wherever they are. We called it "Cardio Plus Médecin" (Figure 5).

B. Test results

Fig. 4 and Fig. 5 show two screenshots made on module B and doctor's PC 87 seconds after "Cardio Plus Patient" and "Cardio Plus Médecin" applications were launched. Indeed, after placing module A on a test patient, applications have been configured. The operating system installed on the module B assigned to the GPS receiver and GSM/GPRS modem respectively ports COM4 and COM5. This has been set in the application "Cardio Plus Patient" with transmission speeds of 4800 bits/s for the GPS receiver and 9600 bit/s for GSM modem. Real-time mode has been activated. The identity of the patient has been informed application and finally automatic detection mode has been activated. More on "Cardio Plus Médecin", the identifier of the patient was also informed. It must be unique for each patient. Some comments were noted. The patient's position, heart rate RC and the patient's condition displayed by Cardio Plus Patient are the same as those displayed by Cardio Plus Médecin. The current heart rate displayed (RC = 69bpm) differs from that shown for the patient state (RC = 63bpm) because the latter is derived from the average of several successive heartbeat current values. PCG plots are the same on both applications. The first line (green) is the PCG itself and the second is at the end of S1 and S2 waves. The route PCG is noisy but it did not stop clearly observe waves S1 and S2 and deduce automatically the corresponding true heartbeat. Indeed, the state PCG noisy or not does not depend on the application or module A but the way it was put down. From these results, we can conclude that overall the one hand, the function of real-time remote monitoring system is functioning properly and secondly, the heart rate, the patient's health and position have been properly given by applications. To verify the proper functioning of the early warning system, we conducted a simulation. The principle is as follows: the patient is in good health but the heart rate detected is biased purpose. Indeed, after the automatic determination of heart rate in the source code we have written for the application, we increase this value automatically 60. And final heart rate obtained is necessarily reduced to a case of tachycardia. About 90 seconds after pressing the button "Démarrer", in an interval of 10 seconds, each mobile received an alert SMS indicating the identity of the patient, his health, his heart rate and its geographic coordinates. After about 5 seconds, the mobile of first-aid workers received a voice call. After release, pre-recorded voice message has been served requiring the assistance of the patient. Meanwhile "Cardio Plus Patient" is displayed in the Status field of the Patient the detected anomaly as well as the patient's heart rhythm. This rhythm is exactly the same as written in the SMS alert. Thus, in an interval of about 20 seconds after detecting danger, doctors and aid workers are warned. First-aid workers have to visualize the patient's position from coordinates received to go rescue him.

C. Discussion

The real-time analysis of PCG signals and automatic fault diagnosis based on these signals are nowadays research areas of major importance. Most of the research we consulted such as in [5] proposes algorithms for automatic processing of cardiac signals. These algorithms require sufficient processing resources to be used in real-time processing. In this work, we have modified the existing algorithms so that they can be effectively used in real time. System presented in [1] and also the most remote monitoring of cardiac patients are based on the automatic ECG arrhythmia while it is also feasible with the PCG (as we have demonstrated with this system) relatively cheaper to obtain. Most systems already implemented as in [7] and as in [3] do not have automatic alert mode in case of danger, but rather a viewing distance Real time biomedical data. Those who have an alert mode as in [1] only offer the automatic call for help. About the system we have implemented, it has two modes warning in case of danger: a voice call and number alert SMS. Probability no warning reaches its destination is then very understated. In addition, our system also provides real-time visualization of biomedical data. The implementation of the system does not require the installation of new telecommunications networks because the system is based on existing mobile networks for communication and data transmission.

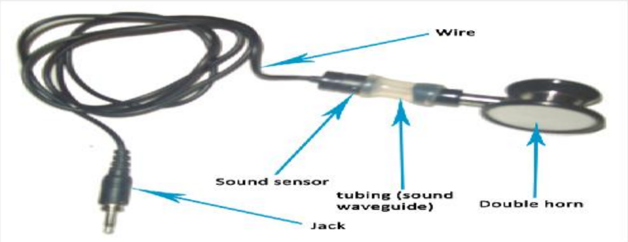
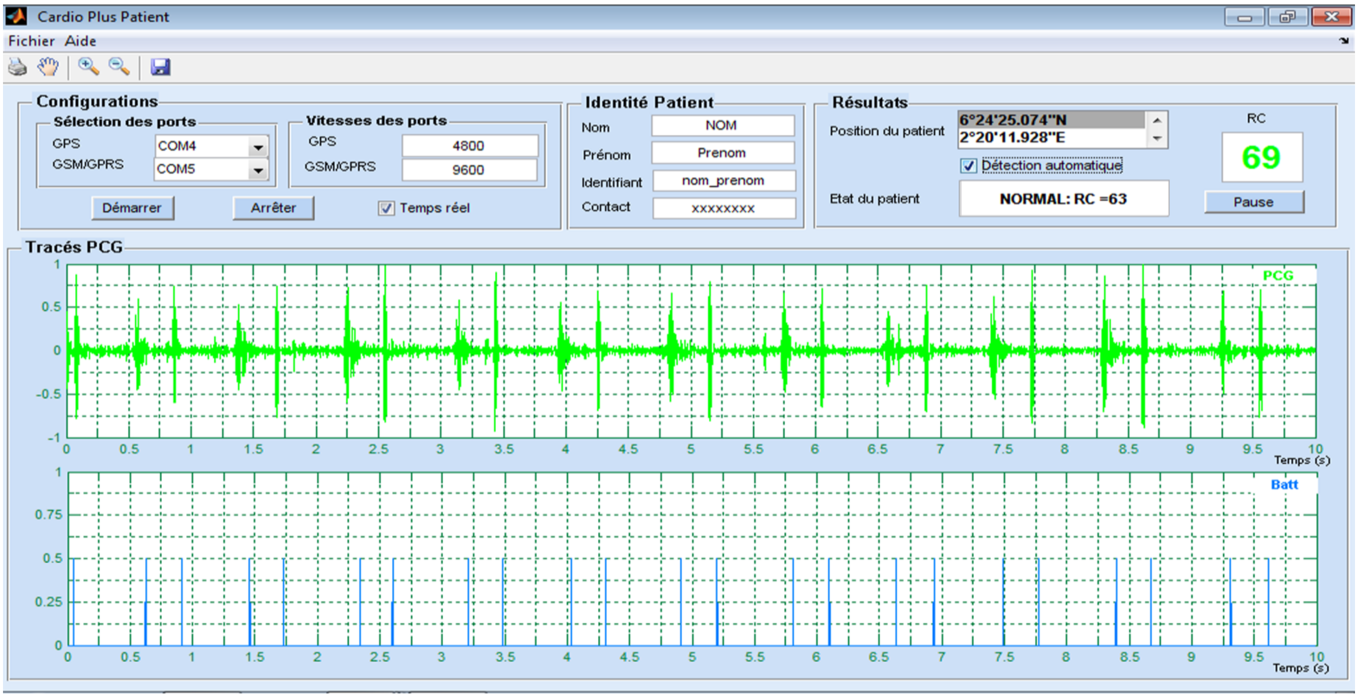


Figure 3. Photograph of module A of patient's terminal



GPS COM4

GSM/GPRS COM5

GPS 4800

GSM/GPRS 9600

☑ Temps réel

Nom NOM

Prénom Prenom

Identifiant nom_prenom

Contact xxxxxxxx

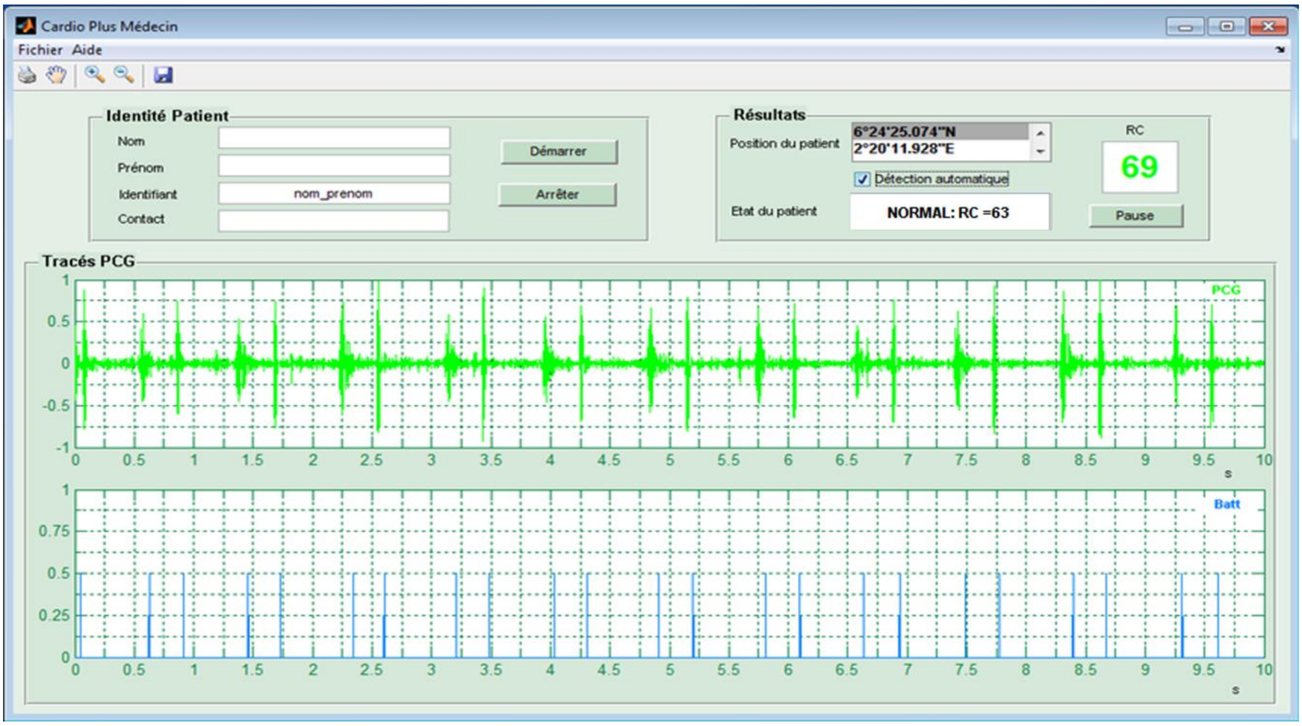
Position du patient 6°24'25.074"N 2°20'11.928"E

☑ Détection automatique

Etat du patient NORMAL: RC =63

RC 69

Figure 4. *Cardio Plus Patient*.



Nom

Prénom

Identifiant nom_prenom

Contact

Position du patient 6°24'25.074"N 2°20'11.928"E

☑ Détection automatique

Etat du patient NORMAL: RC =63

RC 69

Figure 5. Cardio Plus Médecin.

IV. CONCLUSION

The implementation of a remote monitoring system for cardiology service was the purpose of this study. To achieve this, we based on the remote monitoring model of Figure 1 and Figure 2 as in unpublished [4]. The designed system uses the cardiac signals (PCG). To do this, we conducted extensive processing of these signals. The diagnosis is based on automatic arrhythmia, an automatic alarm system is triggered when a patient at risk. Alerts consist of the issuance of voice calls and sending multiple SMS via the GSM network. Also, the patient's biomedical data are transmitted in real time or in case of danger through the GPRS network. It is clear from this work a system for the further processing of cardiac signals, remote monitoring of these signals, the real-time location of patients and early warning system. However, it would be useful to communicate the modules A and B by the Bluetooth to make the system more flexible at patient level.

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