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ARCHITECTURE OF A TELEMEDICINE SYSTEM FOR MONITORING SICK HEART REMOTELY

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ABSTRACT

The monitoring of the vital functions of human organism could be in the future facilitated by swallowing micro-sensors or implementing them under the skin. Multi-sensor capsules or micro-cameras that can be swallowed already exist, by which we can transmit images from inside the human body without surgery (with a battery life of 24 hours). This paper presents our first reflection on the development of an application based sensor networks in the field of telemedicine, especially the monitoring the status of cardiac patients remotely. The main objective is to identify constraints and adaptive algorithms for synchronization and sharing resources in applications based sensor networks.

Keywords: *Network Sensors, Telemedicine, electrocardiograph (ECG), ZigBee TinyOS, nesC, Wireless Personal Area Networks (WPANs).*

1. INTRODUCTION

In the last decades, the progress made in the fields of microelectronics, micromechanics and wireless communication technologies have produced a reasonable cost component of a few cubic millimeters in volume. Therefore, micro sensors are a genuine embedded systems.

Nowadays we have witnessed an incredible evolution of wireless sensor networks in various fields such as military, environment monitoring and medicine.

Despite remarkable progress in this field, there are still many problems to solve. Thus, new protocols have been proposed to deal with the control medium access, routing, etc. in sensor networks.

However, some key issues such as synchronization in the acquisition and data access is still research axis in development.

Indeed, the study of an application based sensor networks in medicine and particularly in cardiology will lead us to identify new needs in synchronization and sharing data for which we need to find solutions in the form of architecture, protocols and algorithms [2]. In our research we will rely on wireless sensors to monitor cardiac patients remotely [3].

In this paper we will identify the needs in architecture, protocols, algorithms and tools for developing a solution to monitor the status of cardiac patients at home.
The sensors can be connected together to form a wireless network using communication protocols such as ZigBee and offering programs and embedded networks. The sensors operate at low voltage and therefore this is handled by a specific operating system: TinyOS [3]. It is the system currently most used in applications using sensors.

Finally, the development of lightweight applications in sensor networks are programmed with a language capable of interacting with the operating system TinyOS: NESC. This specific language is close to traditional C, but it is oriented components [3].

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2. CONTRIBUTIONS OF SENSOR NETWORKS IN MEDICINE

2.1. From The Perspective Of Hospitals

2.1.1. Why ?

In hospitals, each patient sees his vital signs monitored continuously, day and night, by a nurse. Therefore, it is better to have tools and wireless devices for taking vital data about a person hospitalized aiming to reduce errors and oversights reporting in the medical record. [4]

2.1.2. Lack of hospital staff

The decline in the number of hospital staff and nurses also leads us to think of ways to overcome this problem, where the use of new technologies that can be an alternative to care and monitoring. Certainly, these sensors do not replace the care staff, but they allow relief work. Thus, nurses may be more prevalent for patients who are just in the usual care [4].

2.1.3. Supervision

Remote monitoring is done through a wireless implantable sensor connected with a system monitoring which records data and then transmits it to a central server for continuous assessment of health status and disease progression. A number of specific diseases can be detected by sensors on the patients [4].

2.2. From The Perspective Of Patients

2.2.1. Why ?

Every citizen becomes more actor of his health. For example, a patient can see the name and dosage of medicines or specific advices that was given by his doctors appearing on his account from his personal computer [4].

2.2.2. Demand of remote monitoring and home care

With sensors, health centers may allow cardiac patients to lead an independent life at home as long as they are able.

It is clear that the fastest healing takes place at the patient's home, this is why doctors want the development of wireless technologies to monitor the evolution of therapy or remote treatment . So it will become adaptable to each person according to his needs.

3. SPECIFICATIONS

3.1. Overview

In this figure we present the general architecture of our system..

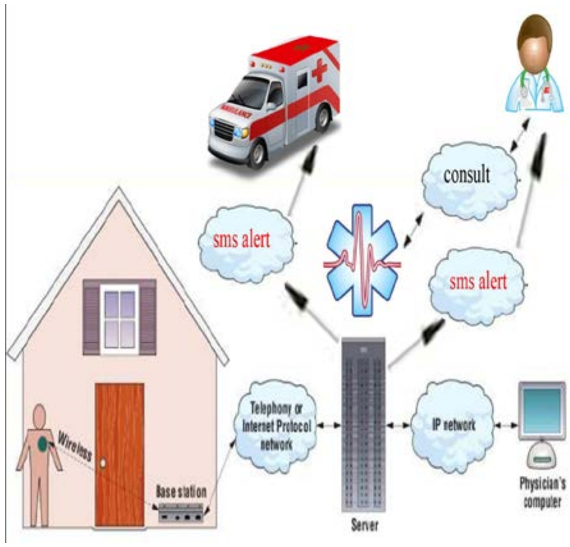

Figure 1: Overview Of The Solution

Starting from the patient's home. The implementation of a sensor network which will collect the physical information and send it to the base station which send in turn the collected data to a server with an application that manage theses information so that the doctor can use them to make decisions and also the patient can fellow the evolution of his state by looking his profile in the application and seeing the medicines and advices to take given only by his doctor.

For the part of server (in the server side), each receiving information it makes the comparison of values from sensors with values recorded as critical:

1. If the values sent by the sensors are normal then they will be stored and sorted by time on the server to be operated by the doctor and the patient.
2. If the values are critical then they will be stored and an SMS containing "measured values, time values and taking the coordinates of the patient" will be sent by the server to the doctor and ambulance.

Finally, the part of the web application will be a platform with authentication for two profiles:

1. A profile that will enable doctors to access and view the status of their patients, to post messages and tips or set an appointment with them.
2. A profile for the patient which will allow him to see the progress of their states,

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doctor's advices and if there is an appointments with doctor.

3.2. Part 1: Sensors Network : State Of Art

3.2.1. Sensor architecture

A sensor is generally composed of a memory, a CPU, a probe and a communication interface (Figure 2).

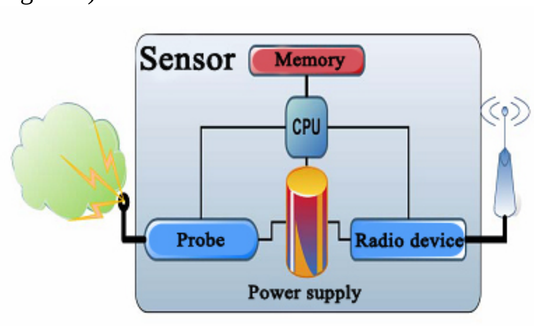

Figure 2: Internal Architecture Of A Sensor

Memory

Obviously there is a need for a RAM memory for storing the measurements of the sensor and the packets received from other nodes. Although the RAM is fast, its main drawback is that it is volatile. Therefore, the program code must be stored in a ROM or more practically in an EEPROM (Electrically Erasable Programmable Read-Only Memory). [5]

CPU Controller

The CPU is the core of a wireless node, it collects data from sensors, treat them and decide the time and the destination to send them and from which nodes should receive data. The node execute many programs such signals treatment, transmission protocols. Is the central unit of a node[5].

Radio device

The implementation of network sensors requires a radio device for exchanging data over a radio channel between nodes. The choice of the radio device need to take into account several characteristics such as energy consumption, the frequency (s), throughput, the ability of power control, receiver sensitivity, the gain, etc. [5].

Probe

This is the real interface with the physical world, it is the device able to observe the physical parameters of the environment. Sensors can be classified into three categories:

- Passive probes and unidirectional: These probes can measure a physical quantity. For example: temperature, light , humidity , vibration , sound ... (Those that will be used).

- Passive probes with narrow beam: these are probes that have a clear direction of measurement. A typical example is a camera that can take measure in one direction.

- Active probes: an example is, sonar or radar or some types of seismic probes that produce waves and detect their reflections and then decides based on the received power (or other parameters such as the phase or modulation that the frequency has undergo). [5]

Power supply

The power supply is a crucial component of the system. There are essentially two aspects: energy storage and power generation. Energy storage is accomplished by using batteries, which are characterized by their low storage capacity. They can be either non-chargeable or chargeable (requires a recovery). Many methods can be used for the recovery, for example, photocells, pressure variation, the variation of the temperature, air flow, vibration, etc. [5].

3.2.2. Architecture of our network sensors

The location of the sensors will be the location of ECG electrodes in order to have accurate data [6].

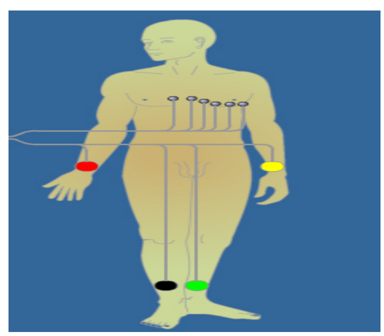

Figure 3: The location of the ECG electrodes

Red and Yellow electrodes are stuck to the posterior surface of the forearm, above the wrist, respectively to the right and left arms.

Black and Green electrodes are stuck on the anterior side of tibia os, above the ankle, respectively to the right and left legs. [6]

To better determine the location of other electrodes, we will be based on the following figure:

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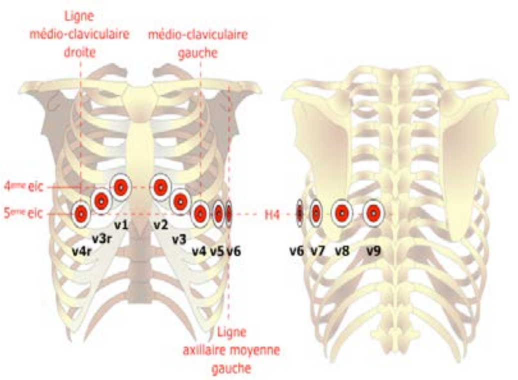

Figure 4: The position of the ECG electrodes(Upper)

We will put sensors in the locations we have just seen for the ECG electrodes, without forgetting the sink and base station sensor.

Sink: is a particular node of the network. It is responsible for collecting data from different nodes. It must always be active since the arrival of information is random. This is why his energy should be unlimited. In a large sensor network where the charge is a little higher, we can find two or more Sink to lighten the load [5].

Base station or data processing center: is the node to which the data collected are sent by the sink. Its role is to gather data from nodes and process them to extract useful information. The process center can be far from the Sink, then the data must be transferred through another "Wi-Fi" network [5] **.**

3.3. Part 2 : Http And SMS Server

An HTTP server will be implement to receive data from the base station, to compare them with four critical values that require intervention, to decide whether to store them in the database or send an SMS to the ambulance and the responsible doctor.

4. TOOLS

Regarding the networking of sensors, we will use the TinyOS operating system.

This is an open source operating system for wireless sensors designed by the American University of Berkeley. Its design has been fully implemented in nesC, component-oriented language that is syntactically closer to the language most known: C.

For programming the sensors, NesC will be needed. NesC language (network embedded system C) is a dialect of C-based components. NesC is oriented to meet the requirements of embedded systems. In addition, it supports a programming model that aggregates the administration of communications, causing competition tasks and events as well as the ability to react to these events.

NesC also makes an optimization program compilation, detecting possible careers that data can produce concurrent modifications to the same state, within the process of executing the application. A career data occurs when more than one son can simultaneously access the same memory section (memory concurrency between threads), and when at least one of the accesses is a "write"[4].

For routing information between sensors, the ZigBee protocol will be used for that purpose. It is a high-level protocol to communicate little radios, low consumption, based on the IEEE 802.15.4 standard for network personal dimension (Wireless Personal Area Networks: WPANs). This technology aims to work in short-range communication such as Bluetooth technology already offers, while being cheaper and easier[5].

Protocol	**Zigbee**	**Bluetooth**	**Wifi**
IEEE	802.15.4	802.15.1	802.11a/b/g
memory requirements	4-32 Kb	250 Kb+	1 Mb+
autonomy	Years	days	hours
Nodes's number	65 000+	7	32
transfer rate	250 Kb/s	1 Mb/s	11-54-108 Mb/s
Range	300 m	10-100 m	300 m

Table 1: Comparison of protocols: Zigbee, Bluetooth and WiFi [6]

Of course before we start working with real sensors in our research we will use a sensor network simulator to study the effectiveness of our network and its configuration.

The TOSSIM simulator

Is a powerful tool that has been developed and proposed to simulate the behavior of sensors. It is often used with a graphical user interface (TinyViz) for a better understanding and visualization of the network state. The use of these two programs is immediate since TinyOS is operational[5].

TinyViz

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TinyViz tool is a graphical application that allows us to have an overview of our network without having to deploy sensors in nature. Economy of effort and preservation of equipment are possible with this tool. The application allows an analysis step by step in activating the available modes[5].

For the server side, we will use the MySQL DBMS, the JEE programming(struts 2, hibernate 3, MVC 2, JavaMail and DisplayTag) of our web pages.

5. OUR NETWORK TOPOLOGY

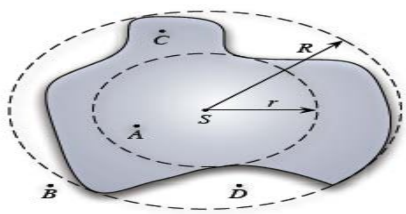


Figure 5: Transmission Area Of A Standard Sensor Equipped With An Unidirectional Antenna

Nodes can communicate only gradually, by local diffusion limited to the transmission's radius of the sensor. Consider a node S shown in the center of figure 5. We specify r and R, two radius of different lengths, with the following properties: (1) $0 \leq r \leq R$ et (2) $SS(r) \subseteq SS(R)^2$. r represents the radius of the sphere to which the transmission rate is uniform, and within which, all nodes at a distance less than r positively receives the messages sent by S (e. g, the node A in figure 5).The second radius R is the distance for which the transmission may not be uniform. No node separated from another by a distance of at least R cannot receive transmissions from the latter (eg node B in the same figure). Therefore, nodes separated by a distance between r and R may, or may not, receive messages sent to one or the other (nodes C and D with respect to S in previous figure). More formally, we propose a model of the actual behavior of transmissions: the probability of receiving a message sent by a node from a distance d is given by the following equation:

$$\mathbb{P}[\text{réception}|d] = \begin{cases} 1 & \text{si } d < r \\ P_{min} + \sqrt{\frac{R-d}{R-r}} \cdot \left(5 - \frac{R-d}{R-r}\right) \cdot \frac{1-P_{min}}{4} & \text{si } r < d < R \\ 0 & \text{si } d > R \end{cases}$$

In this equation, Pmin represents the lower limit likely to receive a message at a distance equal to R. A graphical representation of the evolution of the probability function of the distance separating the transmitter in question to a potential receptor is given in figure 6, with the following parameters: r=3, R= 5 and Pmin =0.3.

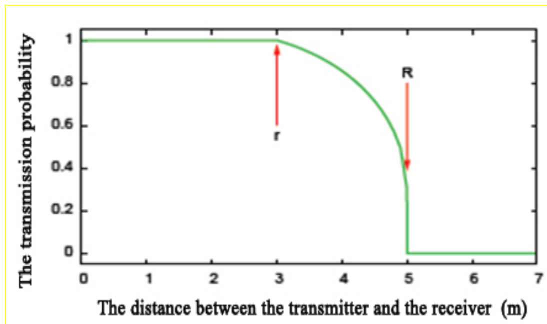
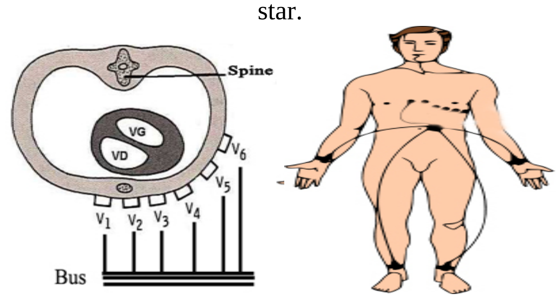


Figure 6: Probability Of A Successful Transmission Function Of The Distance Between The Two Sensors.

For this we will try to adapt a topology that decrease the distance between the transmitter sensor and the receiver for limiting the areas of packet collisions. Thus, our topology is composed of two sub topologies, the first bus and the second star.



Bus topology **Star topology**

Figure 7: Our Topology

Regarding the bus topology, the sensor V6 will send the value captured to the V5 sensor which in turn sends the value received from the V6 and the value captured by itself, and so on until reaching the V1 sensor which contain all values captured by the six sensors.

In the star topology, the sensor V1, the sensor in

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the left hand, the sensor in the right hand, the sensor in the left foot and the right foot send the values caught to the central Sink sensor that will send all the results to the workstation.

The workstation will transform the measures taken by the sensors into a signal similar to that of the ECG based on the Fourier series:

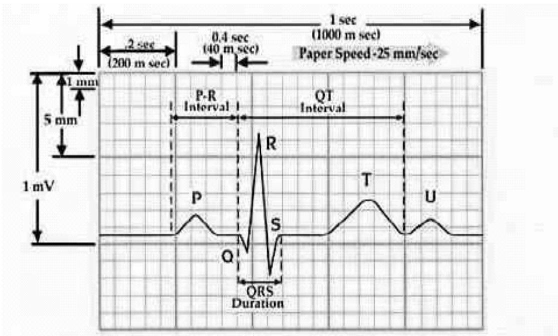

Figure 8: ECG signal

Any periodic functions which satisfy dirichlet's condition can be expressed as a series of scaled magnitudes of sin and cos terms of frequencies which occur as a multiple of fundamental frequency.

$$f(x) = (a_o/2) + \sum_{n=1}^{\infty} a_n \cos(n\pi x / l) + \sum_{n=1}^{\infty} b_n \sin(n\pi x / l),$$

$$a_o = (1/1) \int_T f(x)\,dx \qquad , T = 2l \qquad \rightarrow (1)$$

$$a_n = (1/l) \int_T f(x) \cos(n\pi x/l)\,dx \quad ,n=1,2,3.... \rightarrow (2)$$

$$b_n = (1/l) \int_T f(x) \sin(n\pi x/l)\,dx \quad , n = 1,2,3... \rightarrow (3)$$

ECG signal is periodic with fundamental frequency determined by the heartbeat. It also satisfies the dirichlet's conditions:

- Single valued and finite in the given interval
- Absolutely integrable
- Finite number of maxima and minima between finite intervals
- It has finite number of discontinuities

Hence Fourier series can be used for representing ECG signal.

CALCULATIONS:

If we observe figure 8, we may notice that a single period of a ECG signal is a mixture of triangular and sinusoidal wave forms. Each significant feature of ECG signal can be represented by shifted and scaled versions one of these waveforms as shown below.

- QRS, Q and S portions of ECG signal can be represented by triangular waveforms
- P, T and U portions can be represented by triangular waveforms

Once we generate each of these portions, they can be added finally to get the ECG signal.
Let's take QRS waveform as the centre one and all shiftings takes place with respect to this part of the signal.

How do we generate periodic QRS portion of ECG signal

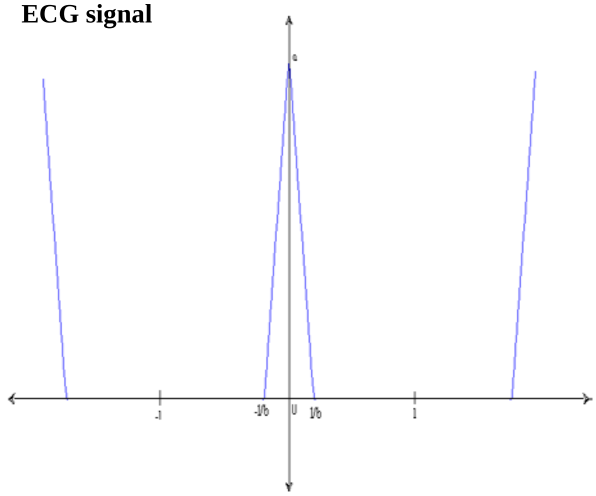

Figure 9: Generating QRS waveform

From equation (1), we have

$$f(x) = (-bax/l) + a \qquad 0 < x < (l/b)$$
$$= (bax/l) + a \qquad (-l/b) < x < 0$$

$$a_o = (1/1) \int_T f(x)\,dx$$
$$= (a/b) * (2 - b)$$

$$a_n = (1/1) \int_T f(x) \cos(n\pi x / l)\,dx$$
$$= (2ba / (n^2\pi^2)) * (1 - \cos(n\pi/b))$$

$$b_n = (1/1) \int_T f(x) \sin(n\pi x / l)\,dx$$

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= 0 (because the waveform is a even function)

$$f(x) = (a_o/2) + \sum_{n=1}^{\infty} a_n \cos(n\pi x / l)$$

How do we generate periodic p-wave portion of ECG signal

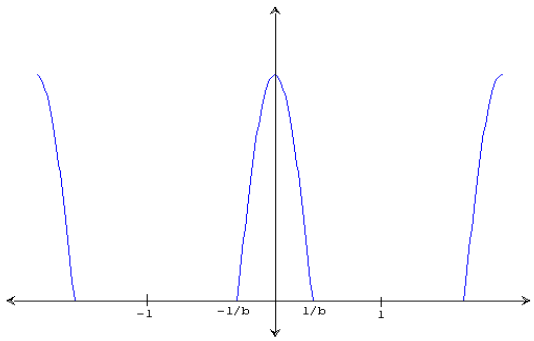

Figure 10: Generation of p-wave

$$f(x) = \cos((\pi bx)/(2l)) \quad (-l/b) < x < (l/b)$$

$$a_o = (1/l) \int_T \cos((\pi bx)/(2l))\, dx$$
$$= (a/(2b))(2-b)$$

$$a_n = (1/l) \int_T \cos((\pi bx)/(2l)) \cos(n\pi x / l)\, dx$$
$$= (((2ba)/(i^2\pi^2))(1-\cos((n\pi)/b))) \cos((n\pi x)/l)$$

$$b_n = (1/l) \int_T \cos((\pi bx)/(2l)) \sin(n\pi x / l)\, dx$$
$$= 0 \text{ (because the waveform is a even function)}$$

$$f(x) = (a_o/2) + \sum_{n=1}^{\infty} a_n \cos(n\pi x / l)$$

Finally, we need to transform these calculations to a program, that will generate a signal as the following type:

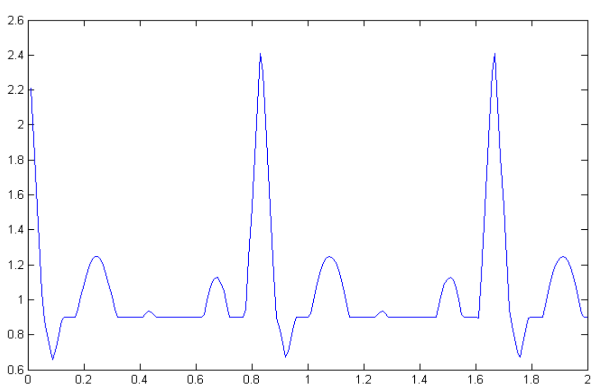

Figure 11: Final signal

This record will be stored on a web server in the medical record of the patient, and can be easily seen by the patient and by the responsible doctor.

6. MEDICAL PLATFORM

Our platform is dedicated for the medical field, the target population is limited to the medical staff namely doctors, nurse, and patients.

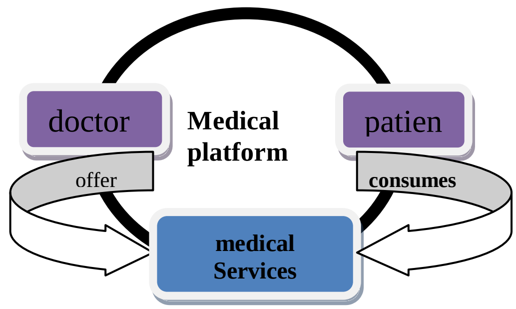

Figure 12: Our platform

The platform aims to computerize the medical process, or more precisely the medical services through a web interface reserved for doctors with access permissions granted by an administrator. Any doctor approved by the administrator can:

- Register patients and manage freely, i.e respectful of transactions modification, deletion and display of information.
- Establish a medical record for each patient recorded, the record contain all medical visits, analyzes, treatment recommended by the doctor, and other information that qualifies the doctor to be important.
- The doctor should also be able to communicate with patients via a correspondence or notification.
- The medical record include the management of medical documents (Analysis, ECG, X-ray, ultrasound ... etc), all prescriptions and treatments recommended by the doctor, and he traces the medical state of the patient.

The patient does not have the permissions to register himself in the platform, only the doctor can add him, and every patient registered by a doctor can take advantage of the medical services available in his electronic medical account. He can see his analysis, and treatments provided by the doctor. The platform also offers a channel of communication

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between the patient and his doctor via the notification system.

Every doctor has the right to register himself in the application by providing personal information. The account will be operational after its activation by the administrator. The administrator has the full right to manage doctors and their different operations such as adding, modifying and deleting information.

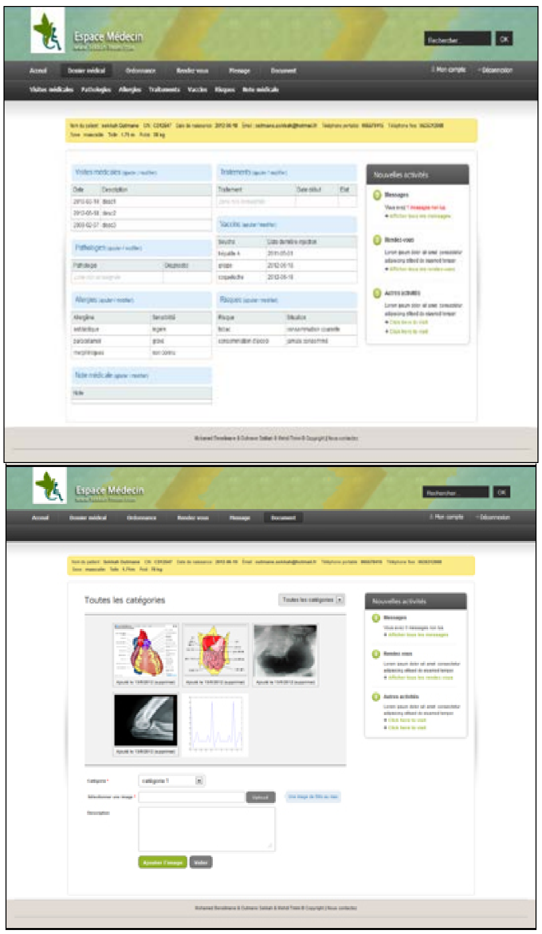

Figure 13: Our platform's interface

7. CONCLUSION

To conclude, the field of the telemedicine and the computing for medicine develops continually , such solution will certainly facilitate tasks to the doctors and in the other hand it will help patient to beneficiate from cure remotely

Our work consists of mixing between different areas and concepts of computer and network:
- wireless sensor networks,
- JEE Web programming,
- Design pattern,
- Database to manage our data,
- Data archiving
- SMS Server for sending SMS
-...

All this aims to have a complete solution to follow and monitor cardiac patients remotely.

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