Remote Monitoring Solution for Cardiovascular Diseases based on Internet of Things and PLX-DAQ Add-in

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***Abstract*—Access to health remains a real problem in Africa especially for the follow up of patients with chronic diseases. Many cases of heart attack deaths are still recorded before victims can access treatment. This is due to several factors, namely the insufficient number of cardiologists, the inaccessibility of hospitals with adequate infrastructure, the carelessness and ignorance of people about their health. In response to these limitations, internet of Things, thanks to its remarkable technological contribution, allow to follow from afar and easily patient's condition. In this paper, we offer a ubiquitous surveillance solution distance from patients with cardiovascular disease in order to minimize or eliminate the risk of heart attacks. The proposed solution is based on a micro-service architecture and consists of two essential parts that are data acquisition and data transfer. It will allow the patient to access their physical data and submit them in real time to the doctor through a dedicated medical application. The doctor will then be able to analyse the data obtained and return a prescription to the patient in case of abnormality .We used the microcontroller Arduino esp8066, the heart Rate Monitor AD8232 ECG (electrocardiogram) to measure the electrical activity of the heart that can be traced as an ECG, a pulse-eater, a photoresistor LDR and an potentiometer to regulate and modify the current flow in the circuit. We also used add-in PLX-DAQ for data acquisition and Jira software for data transfer to the doctor. Our solution is inexpensive and allows people not yet suffering from cardiovascular disease to prevent it.**

***Keywords*—Cardiovascular diseases; microcontroller arduino; esp8086; AD8232; Plx-DAQ; IoT; ECG**

I. Introduction

According to the World Health Organization, cardiovascular diseases are a group of troubles affecting the heart and blood vessels, with the most common being heart attacks and strokes. These diseases are and expected to remain the leading cause of death with a mortality rate of 31% worldwide [1] [2]. By 2030, almost 23.3 million people will die from cardiovascular disease (mainly heart disease and cerebrovascular accident) [3].

The cardiovascular morbidity and mortality burden is increasing worldwide, reaching even younger subjects in both developing and developed countries. The work of Kantako et al. reveals that, on a sample of 666 hospitalized patients, 301 were suffering from cardiovascular diseases. Considering Table I below, these authors show that cardiovascular diseases can reach subjects as soon as 15 years old [4].

The Kantako et al. studies proposed Table II, to show that cardiac insufficiency was the most frequent reason for hospitalization with 41.9% of cardiovascular diseases.

To prevent most cardiovascular diseases, behavioral risk factors such as smoking, unhealthy diet, obesity, physical inactivity, alcoholism and many others must be strategically addressed. Lifestyle change and physical effort would be one of the World Health Organization's recommendations for the prevention of cardiovascular disease [1]. Unfortunately, the precarious living conditions of populations in developing countries do not allow for easy prevention of cardiovascular diseases. Studies have shown that the symptoms of a heart attack, even a severe one, do not appear until two hours after the event. Hence the need to monitor cardiac activity and therefore to have an appropriate and low-cost sensor solution to prevent cardiovascular disease.

Usually, people with cardiovascular disease live at home and go to the doctor when they feel sick. This is because the disease manifests itself when it is at a very advanced stage, and the damage is irreversible. Most of these patients die before receiving any treatment [5]. It becomes urgent to adapt to the current sociological changes, incorporating the digital revolution that improves the way patients interact with health institutions [6]. Patients of all ages will be able to be monitored without the need to travel.

TABLE I. Distribution of Cardiovascular Mortality by Age Group [4]

Age Range	**Numbers**		**Number**	**Specific mortality**
	Deaths	Percentage		
[15 – 29]	3	17.65	38	7.89%
[30 – 44]	4	23.52	54	7.40%
[45 – 59]	3	17.65	87	3.44%
[60 – 74]	4	23.52	83	4.76%
75 et plus]	3	15.65	39	7.69%
Total	**17**	**100**	**301**	**31.18%**

TABLE II. REPARTITION OF PATIENTS WITH RISK FACTORS [4]

Reason of hospitalization	Numbers	Percentage
Hypertensive flare-up	96	31.9
Chest Pain	6	2.0
Heart insufficiency	126	41.9
Rhythm trouble	13	4.3
Stroke	58	19.3
Other	2	0.7
Total	**301**	**100.0**

Using Internet of Things technologies, the physical condition of patients can be monitored in a customary way and in real time wherever they are. The acquired data can be sent to remote doctors at low cost [7] [8]. These technologies can also be used to prevent these diseases.

The aim of this paper is to propose a solution that will allow subjects from 15 years old, to be followed by a doctor at a distance if they already have a cardiovascular disease, or to follow their physiological parameters to prevent any cardiovascular pathology.

In this work, the technologies of the Internet of Things are used to realize a solution dedicated to the recovery of certain physiological parameters of the person, in particular the heart rate and the number of pulsations. The data collected via a data acquisition software will be transmitted to the doctor via a dedicated platform.

The rest of this paper will proceed as follows. Related work will be discussed in Section II and Section III will illustrate the system under three aspects namely: the architecture of the proposed system, data acquisition, data transmission. In Section IV we will present the results and a discussion with a presentation of a prototype of the proposed system. Section V presents the conclusions and perspectives.

II. RELATED WORK

All related work on smart health systems integrating the internet of Things unanimously demonstrate the efficiency and time savings in patient care. The internet of Things has become an important technology for health monitoring systems. In professional medical centers, ECG data collection is done using twelve electrodes due to their good performance in short-term calibration. Unfortunately, these devices are not laptops and patients are often forced to visit medical centers for regular checks-up. Which could be tedious and very expensive for patients [9].

Tamana Shawn et al. designed a system to frequently monitor the electrocardiogram signal collected from the patient’s body using the wearable sensors and the data is stored in the database of data that can be viewed by authorized personnel [7]. This solution has been implemented so that seniors can receive accurate care without having to make frequent trips to hospitals. When a malformation is detected, an automatic email is sent to users and doctors to analyse the critical condition of patients and provide emergency health assistance.

Hasan et al. proposed an ECG monitoring system that consists of an AD8382 ECG sensor to read patient data, an Arduino Uno, an ESP8266 Wi-Fi module, and the Blynk IoT app. The proposed ECG allows the physician to monitor the patient remotely via the Blynk IoT app installed on the patient's smartphone. The monitoring process can be performed anytime and anywhere without the need to physically come to the hospital [10].

Deli and AL. proposed a platform for disease prediction cardiovascular. This platform uses an IRI compatible ECG telemetry system that acquires the signal ECG, processes it and alerts the doctor in case of emergency. Their contribution incorporates a monitoring system based on lot for ECG signal analysis. The statistical characteristics of the raw ECG signal are calculated. They have analysed the ECG signal using the QRS detection algorithm of Pan lampkins to obtain the dynamic characteristics of the ECG signal to capture the characteristics of heart rate variability. The statistical characteristics and dynamics are then applied to the classification process to classify cardiac arrhythmias. This solution allows users to check their heart condition by acquiring the ECG signal, even when they are at home. The size of the system is reduced, and requires less maintenance and operational costs [11].

A wearable health monitoring system combined with the Internet of Things (IoT) is a promising alternative to conventional health systems according to author Wu and colleagues. They proposed a small, flexible, and wearable real-time electrocardiograph (ECG) monitoring system embedded on a T-shirt. This system uses a biopotential analogy front-end chip (AFE), AD8232, to collect ECG data from subjects. The collected ECG data is transmitted via Bluetooth low energy (BLE) to an end device for real-time display. Their solution incorporates a PC graphical user interface (GUI) and smartphone application designed for real-time viewing. The power consumption of the proposed portable ECG monitoring system can be as low as 5.2 mW. Their portable system is Powered by a 240 mAh rechargeable battery and can operate for over 110 hours continuously. To extend the battery life, a flexible solar energy sensor is also integrated into this system [12].

Mishra et al. proposed and implemented a smart healthcare application using an IoT system. They used an AD8232 heart rate sensor interfaced with Arduino UNO and connected to the Cloud. Their system uses an ESP8266 wireless LAN module for data transfer [13].

Xu has proposed an Internet of Things-assisted electrocardiogram (ECG) monitoring framework with secure data transmission. The proposed solution aims to contribute to the continuous monitoring of cardiovascular health. The author analysed the ECG signal intensity for automatic classification. For the implementation of the solution, he used ECG sensors, Arduino microcontroller, Android phones, Bluetooth and a cloud server. The work also proposed Lightweight Secure IoT (LS-IoT) and Lightweight Access Control (LAC) for secure data transmission [14]. The authors do not specify the security levels of the cloud that stores the data collected by the proposed system.

Chao LI and al. monitor multiple parameters that may not be limited to single parameters physiological. These non-physiological parameters are considered because they provide information contextual services. This can facilitate remote analysis or support for contextual services. Their solution involves a ubiquitous system that can send patients' physical signs to remote medical applications in real time. Compared to single parameter monitoring systems, multi-parameter systems can provide more accurate and richer information to remote experts [5]. The solution proposed by Chao does not provide follow-up for subjects already suffering from cardiovascular disease. The doctor cannot plan the follow-up with the patients.

The work presented in this literature review, although very interesting and edifying, has some limitations. Some authors have worked on heart activity monitoring using the Internet of Things. For this purpose, they used in most cases the unique AD8232 sensor for heart rate monitoring and the Arduino microcontroller. These solutions allow patients to be followed by their respective doctors in real time via a dedicated platform. Other work has focused on multi-parameter monitoring systems. The results of these approaches offered more accuracy and help to make the best decisions on the condition of the subjects. On the other hand, the proposed works do not specify the level of security of the cloud in which the data acquired via sensors are stored. The proposed solutions are dedicated either to subjects in senior age or suffering from a cardiovascular disease.

The literature also reveals that cardiovascular diseases affect a layer of young people from the age of 15 years and that the mortality rate is higher for the age intervals of [15-29], [30-44] and [75-plus] See Table I of this paper. The mortality rate from cardiovascular disease is expected to increase by 2030 according to the WHO. This paper proposes a real-time monitoring (multi-parameter) and management system for patients of all ages with cardiovascular disease. In order to prevent the explosion of the mortality rate due to cardiovascular diseases, the proposed monitoring system will also allow people not yet affected by cardiovascular disease to monitor their activity and participate in the reduction of the mortality rate of cardiovascular diseases. The proposed monitoring system is designed at very low cost and the acquired data is stored on a platform based on the plans made by the physician.

III. Internet of Things (IoT) based Heart Activity Monitoring System Architecture

Detecting a heart attack encompasses several purposes. It is above all a question of making an appropriate diagnosis, so that the patient who suffers a heart attack receives treatment as soon as possible. The monitoring of cardiac activity from the ECG module makes it possible to prevent a heart attack, but also to guide subjects to improve their lifestyle to safeguard their health. To monitor the patient's cardiac activity, our solution uses heart rate sensors and the pulse sensor.

A. Proposed System Architecture

Our architecture (Fig. 1) includes two essential phases, which are data acquisition, and data transfer. This architecture is designed on the general model of IoT applications composed of the detection layer, the transport layer and the application layer. Fig. 1 shows the architecture of the Internet of Things-based remote heart activity monitoring system for heart disease patients.

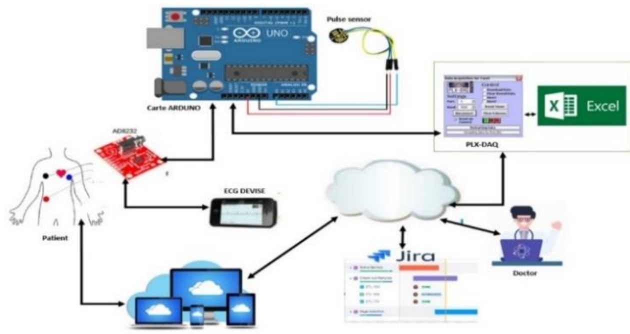

Fig. 1. System Architecture.

1) Components of the architecture: The proposed architecture is composed of sensors (AD8232 module, pulse sensor, potentiometer, LDR photoresistor), an Arduino board, PLX-DAQ, the ECG signal display screen and the Jira platform.

a) AD8232 ECG sensor: The AD8232 ECG module shown in Fig. 2 separates nine connections from the IC commonly referred to as "pins" to connect wires or header pins. It is used to determine the heart rate (heart rate or HR).

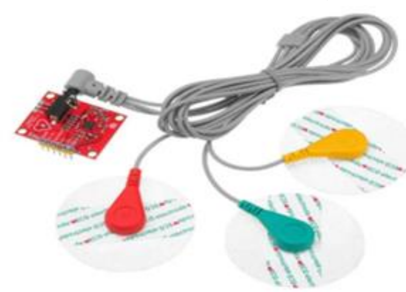

Fig. 2. AD8232 ECG.

As shown in Fig. 3, we have connected five of the nine pins of the ECG module to the Arduino Uno microcontroller. The five pins are labeled GND, 3.3v, OUTPUT, LO- and LO+. This connection collects signals from the human body which can be displayed on the screen as an ECG signal via the Arduino IDE.

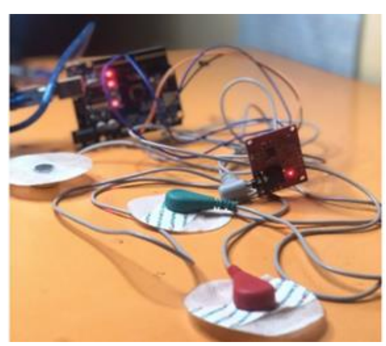

Fig. 3. Connected the Pins of the ECG Module to the Arduino.

b) Electrocardiography ECG: Electrocardiography (ECG) is the analysis of the electrical activity of the heart over a period. It is used to determine the heart rate, the regularity of the heartbeats, the size and position of the cavities, the existence of a possible heart attack.

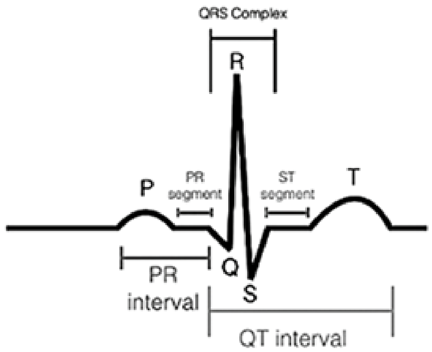

Fig. 4. ECG Signal.

The normal ECG signal is shown in Fig. 4. The ECG signal contains five characteristic peaks and valleys called P, Q, R, S, and T. The intervals of the ECG signal are the PR interval, the QT interval, and the QRS [15]. Fig. 4 illustrates a normal ECG signal

c) Pulse sensor: It is connected directly on the Arduino board using the Signal VCC and GND pins. The operating voltage of this sensor is +5V or +3.3V. Once the sensor is connected to the Arduino board, the code entered in the Arduino IDE and uploaded back to the board will activate the pulse sensor.

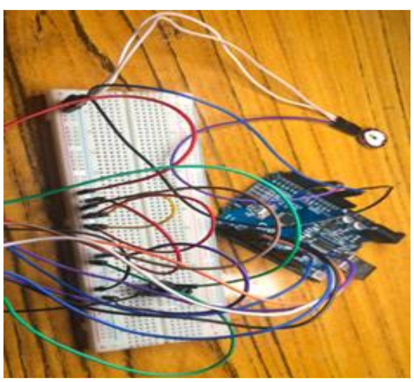

Fig. 5. Prototype Connection of the Pulse Sensor.

Fig. 5 shows a prototype connection of the pulse sensor that we have made.

d) Arduino Uno: The Arduino Uno in Fig. 6 is a board based on the 16 MHz ATmega328P microchip. It has 14 digital I/O pins, six analog pins, and an ICSP In-Circuit Serial Programming header. It can supply up to 5 V to the components that connect to it. The Arduino Uno board is relatively large and has the disadvantage of using a USB connector to interface with computers [16].

2) Functioning of the architecture: When the patient connects to the AD8232 ECG sensor and pulse sensor, the signals are picked up by the Arduino board and displayed on the screen as a curve. Thanks to the PLX-DA software, a macro that only runs on Excel, the data is retrieved and stored on an Excel sheet. The patient can then save them and transfer them to the doctor via the Jira platform. The doctor receives the results, analyzes and provides feedback on the results to the patient. The patient sends his results according to the planning made by the doctor in the Jira platform.

Fig. 6. Arduino Uno.

B. Data Acquisition with PLX-DAQ

The data acquisition part is mainly composed of sensors worn by the patients or connected to them, as shown by the architecture of the proposed system illustrated in Fig. 1. These sensors will collect the signals and transmit them to the microcontroller. The parameters to be monitored in this solution are the heart rate and the pulsation.

Data management plans typically include sections on data collection, data storage and backup, data security, data retention, data sharing and reuse [17]. It is in the sense that we used the add in PLX-DAQ confer Fig. 7, for Microsoft Excel in order to acquire up to 26 channels of data from any microcontroller. Easy spreadsheet analysis of data collected in real time will be done.

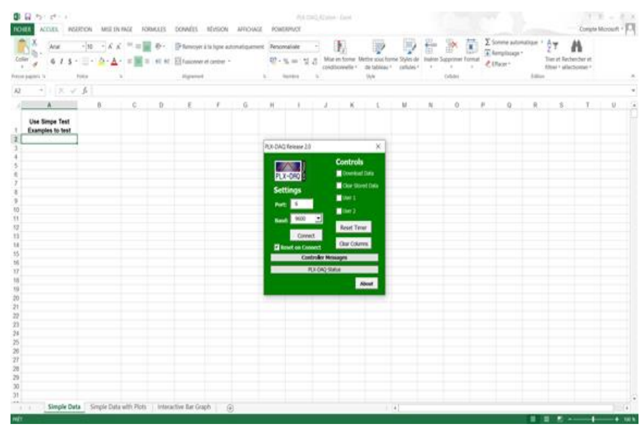

Fig. 7. PLX-DAQ.

C. Transmission of Data Collected from the Patient to the Doctor

After collecting the data from PLX-DAQ, the patient will send it to his doctor via the Jira platform so that it can be analyzed. Indeed, the dedicated Jira platform will make work fluid and facilitate exchanges between the patient and the doctor through a single interface.

IV. Use Case Diagram System

To properly express the needs of this backend and to identify the functionalities of each actor, we used the UML (Unified Modeling Language) formalism of use cases. These were developed by Ivar Jacobson long before the appearance of UML. Nevertheless, they have been integrated into this modeling language to represent the functionalities of the system from the user's point of view.

As shown in Fig. 8, these use cases allow us to structure and articulate the interactions between the actors.

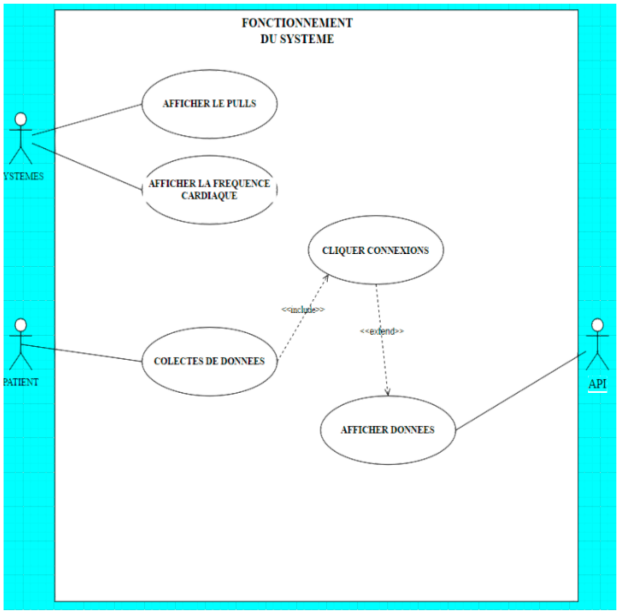

Fig. 8. The use Case of System.

We illustrate below the description of the two main use cases.

A. *Description of the use Case to Display it Heart Rate*

The Table III shows the description of the use case to display it heart rate.

TABLE III. Description of the use Case to Display it Heart Rate

Title	Show Data
Actor	Patient, System, API
Purpose	Display the patient's heart rate
Preconditions	Have a card and install Arduino IDE and the LFCSP box, having a computer, having AD8232 or Pulse sensor sensors,
Nominal scenario	1 - The patient places the sensor on him and connects to Arduino 2 - The patient executes the code already uploaded on the Arduino environment 3 - The system will display the frequency heart on an electrogram
Alternate Scenario	1-The sensor is not properly connected to the patient 2-Server unavailable 3-Error in entering the code

B. *Description of the Data Collection use Case*

The Table IV shows the description of the use case of data collection.

TABLE IV. Description of the Data Collection use Case

Title	Collect data
Actor	Patient, Micro-service
Purpose	Collect patient data
Preconditions	Have a card and install Arduino IDE and the LFCSP box, having a computer, having AD8232 or Pulse sensor sensors,
Nominal scenario	1 – The patient connects to PLX-DAQ 2 – The patient presses connect 3 – PLX-DAQ automatically displays the data collected 4-The patient saves the results file
Alternate Scenario	1-The data is not displayed because the sensors are incorrectly connected

V. Results and Discussion

As mentioned above, the implementation of our solution involves two main processes which are the acquisition of the ECG signal and that of the pulse, then the transfer of data.

The ECG signal is detected using the prototype implementation shown in Fig. 9. The AD8232 ECG sensor is connected to the Arduino microprocessor.

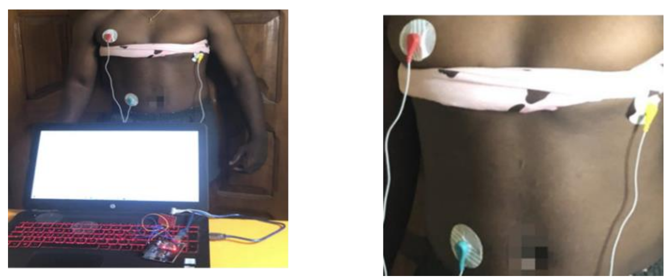

Fig. 9. The AD8232 ECG Sensor.

With the use of the serial port, the system obtains the analog values after uploading the code to the Arduino board. The sensors are connected to a 24-year-old young man. The sensors will retrieve the data and transmit it via the microcontroller once the system is activated. The following Fig. 10 show the codes that will allow communication between different peripherals, the collection and display of information from the AD8232 ECG sensor and the pulse sensor.

The code in Fig. 10 specifically shows the connection of the AD8232 ECG and Pulse sensors. It also considers the connection between the Arduino IDE and PLX-DAQ for data acquisition. This code allows to generate the ECG signal as shown in Fig. 11.

The code in Fig. 12 only relates to the activation of the pulse sensor. It will allow the led connected to Pin 13 to turn on and off each heartbeat.

```
ECG
int AD8232 = A0;
int PulseSensor = A1;


void setup() {
// initialize the serial communication:
Serial.begin(9600);
pinMode(10, INPUT);
pinMode(11, INPUT);
Serial.println(F("CLEARDATA"));
Serial.println(F("LABEL,Temps,FAP,FCR"));
}
void loop() {

  int ValeurMesuree = analogRead(AD8232);
  delay (4);
  int FCR = analogRead(PulseSensor);
  Serial.print(("DATA,TIME,"));
  Serial.print(ValeurMesuree);
  Serial.print(F(","));
  Serial.println(FCR);
  delay(250);
}
```

Fig. 10. Uploading the Code to the Arduino.

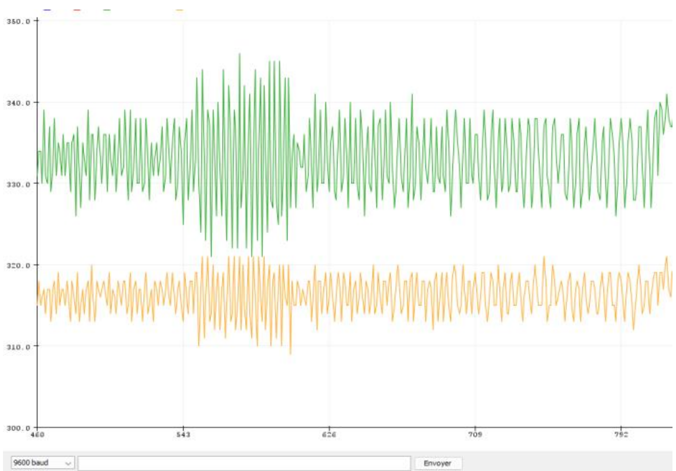

Fig. 11. The Electrocardiogram in Green and its Derivative in Orange.

```
pulse_sensor
//code copied from arduino.cc
int pulsePin = A0;
int blinkPin = 13;

// Volatile Variables,
volatile int BPM;
volatile int Signal;
volatile int IBI = 600;
volatile boolean Pulse = false;
volatile boolean QS = false;

static boolean serialVisual = true;

volatile int rate[10];
volatile unsigned long sampleCounter = 0;
volatile unsigned long lastBeatTime = 0;
volatile int P = 512;
volatile int T = 512;
volatile int thresh = 525;
volatile int amp = 100;
volatile boolean firstBeat = true;
volatile boolean secondBeat = false;

void setup()
{
  pinMode(blinkPin,OUTPUT);
  Serial.begin(115200);
  interruptSetup();
```

Fig. 12. The Codes to Activate the Pulse Sensor.

It should be noted that the normal heart rate of an adult at rest varies between 70 and 250 beats per minute. In children aged 7 to 15, it is between 70 and 115 beats per minute. Fig. 13 and 14 display the pulse sensor results (Fig. 13) and the Pulse plot results (Fig. 14), respectively.

```
COM7

15:20:16.246 -> MS Heart-Beat Found BPM: 54
15:20:16.900 ->  Heart-Beat Found BPM: 56
15:20:18.771 ->  Heart-Beat Found BPM: 52
15:20:33.208 ->  Heart-Beat Found BPM: 73
15:20:36.700 ->  Heart-Beat Found BPM: 163
15:20:37.073 ->  Heart-Beat Found BPM: 163
15:20:37.305 ->  Heart-Beat Found BPM: 168
15:20:37.864 ->  Heart-Beat Found BPM: 161
15:20:38.143 ->  Heart-Beat Found BPM: 163
15:20:38.421 ->  Heart-Beat Found BPM: 169
15:20:38.748 ->  Heart-Beat Found BPM: 169
15:20:39.029 ->  Heart-Beat Found BPM: 175
15:20:39.263 ->  Heart-Beat Found BPM: 181
15:20:39.870 ->  Heart-Beat Found BPM: 170
15:20:43.036 ->  Heart-Beat Found BPM: 205
15:20:43.270 ->  Heart-Beat Found BPM: 208
15:20:43.550 ->  Heart-Beat Found BPM: 207
15:20:43.878 ->  Heart-Beat Found BPM: 205
15:20:44.205 ->  Heart-Beat Found BPM: 204
15:20:44.439 ->  Heart-Beat Found BPM: 207
15:20:44.718 ->  Heart-Beat Found BPM: 210
```

Fig. 13. The Pulse Sensor Results.

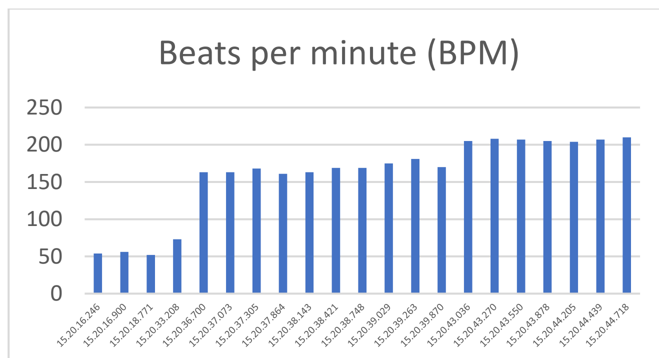

Fig. 14. The Pulse Sensor Results.

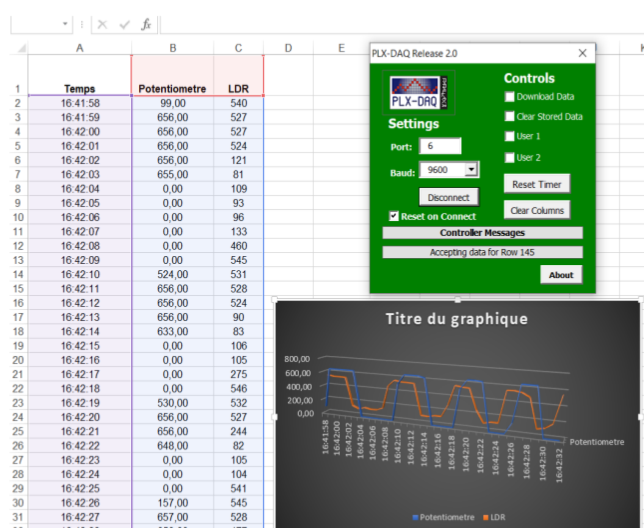

Fig. 15. Potentiometer and LDR of the Subject.

Electrical components such as the potentiometer and the LDR have been connected to the proposed system. Their data can be retrieved using data acquisition software. PLX-DAQ. La Fig. 15 shows the acquisition of the data emitted from the IDE on Arduino using the PLX-DAQ.

VI. Conclusion

The damage caused by cardiovascular diseases remains spectacular. These diseases are the first cause of death in the world and reach all age groups from the 15 years old. The urgent need to minimize the mortality rate caused by these diseases consists in using the Internet of Things, in order to connect the physical world to the virtual world.

This paper proposes a cardiac activity monitoring system based on the Internet of Things and integrating the PLX-DAQ add-on module. For the design and implementation of the system, low-cost equipment's have been used. They are a computer, sensors (pulse, ECG AD8232), electrical components (potentiometer and LDR), the Arduino microcontroller for the recovery and display of information on the heart rate as well as the pulse of the subject, the JIRA software which allowed to establish the connection to facilitate the exchange of data between the actors of the system, the PLX-DAQ for the collection of these data. The results of the analysis of the data collected via the Arduino board allow the user to follow his health status and monitor his performance. In addition, the subject no longer needs to travel to health centers to be monitored. This represents a saving of time and money. The Jira platform allows the physician to plan the submission periods of the data acquired via PLX-DAQ.

In perspective, the solution will be improved by integrating more sensors to collect physiological data (temperature, blood sugar, etc.) from the subject. For emergency management, the aim will be to integrate environmental parameters to facilitate patient location in case of emergency. The security of the transferred data and the handling of the connected object will be addressed.

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