IOT System for Self-diagnosis of Heart Diseases Using Mathematical Evaluation of Cardiac Dynamics Based on Probability Theory

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Abstract. Cardiovascular diseases are one of the most frequent worldwide death causes, this owing to a late detection of that illnesses, however, the majority of people do not carry out proper cardiovascular health check-ups due to a lack of time or resources. For that reason, we propose an IoT services oriented system which throughout patient’s mobile device and heart rate monitor, using an analysis methodology based on the probability theory, allows the patient to take preventive check-ups in his own anytime, and lets him know when it is necessary to consult medical services, all of that supported in a proved and reliable diagnosis. Finally, we show a system implementation test, the results and the future work derived from this research.

Keywords: Data analysis · Cardiovascular health · Heart Self-diagnosis · Internet of things · Probability theory

1 Introduction

Cardiovascular Diseases (CVD) have been one of the main death causes worldwide, according to American Heart Association in 2013 the CVD reports an amount of 17.3 million of 54 million total deaths in the world or 31.5% of all global deaths [5]. With the aim of reducing this percentage, medicine has to be oriented to prevention and real time monitoring, however, attend to medical checks can demand too much time and money and for that reason patients tend to skip those checks.

Therefore, we have developed a tool that allows patients to know an approximate state of his cardiovascular health, our goal is to provide the patient with tools to carry out cardiovascular analysis on his own through devices that he owns in his home or that can be easily accessed. The tool consists in a mobile application for android smartphones which has the capacity of collecting data from a generic Bluetooth Low Energy (BLE) heart rate measurement device, and send that data to a server, in order to be stored and analyzed, for giving as result the diagnosis of the patient.

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2 Related Work

There are several research projects and work proposals with the aim of determine mechanisms that allow patients to be monitored [17], by capturing their vital signs. Currently there are two main ways to make an individual heart rate control (i) using apps installed in smartphones or (ii) using heart rate sensors which are included in devices such as watches, wristbands or sports bands [9]. Some of the vital signs that are monitoring with this approach are blood glucose level [14], blood pressure [2], heart rate [4] and electrical activity of the heart (ECG) [8]. Early researches and works as [7] have been developed to monitoring and find critical changes in the vital signs values of a patient, if an abnormal behavior is detected the device sends an alert.

Other medical notification systems are shown in [3, 10, 15], where selected different persons can receive a SMS notification when a patient presents any arrhythmia signs, those systems use ECG sensors and uses different methods and algorithms, as R-wave Detection, Discrete Wavelet Transform (DWT) and Support Vector Machine (SVM), in order to perform data analysis and detect arrhythmias. Most of the works with ECG sensors presents some difficulties with ambiguity in locating the electrodes of the sensors, unfixed lead-wires and thick substance of wireless cardiograph. It is important to say that the works are not only oriented to heart rate diseases patients, some developments like [16] are oriented also to sports people who had the requirement of control their heart behavior during training.

Those kind of works show the potential of mobile devices in telemedicine, being one of the fastest ways to send the notifications with relevant data as IDs, locations and other details. Nevertheless, with the current technology and the advances in medical science and IoT devices, it is possible to aim for techniques that allows to give anticipated alerts when the system finds signs of a disease, and before the critical changes occur, having a higher probability of giving a proper treatment for the patient disease, works as [11] show that the applications itself cannot make preventive diagnoses to the patient but needs the intervention of a specialist or doctor, for that reason our work is not only oriented to monitoring but diagnosis too, approach of this is shown in [1] that describes an IoT based patient monitoring system and diagnostic prediction tool for the stroke affected elderly people, this system collects data from blood pressure with pulse rate and glucose level in blood sensors, the prediction model is developed using the classifications algorithms in machine learning. The weakness is that even the system is wearable users must activate the system pushing a start button, so continuous automatized monitoring is not presented.

3 System Description

The system has two parts, the first part is the architecture which describe all the components and the way that they communicate to each other, the second part is the data analysis, each part will be explained in the following sections.
3.1 Architecture

The system has five components, these components interact with one another in different ways and allow the system to collect and show information to the user, as seen in the Fig. 1. The heart rate measurements are collected by the sensor that the user wears, then the information is read by an android device and sent to a server where the data is processed and stored in a database. The communication between the android device and the server is done through internet and brings the user the advantage of wearing the device in any place and still collecting and storing data.

Each component has specific functions and has characteristics that supports the communication between each other, those specifications are:

**Heart Rate Sensor.** The heart rate sensor works with BLE, this sensor expose services that are consumed by other devices that supports this technology, the exposed services are called (GATT) Services Generic Attribute Profile which establishes in detail how to exchange all data over a BLE connection, each service has a unique id that makes it different of others, those service unique ids are described in the Bluetooth GATT Services Specification [6].

**Android Device with Heart Rate Diagnosis App.** An app for android devices was developed to create a bridge between the heart rate sensor and the Representational State Transfer (REST) API, the android device must be compatible with BLE because the app uses the cell phone’s Bluetooth to connect to the service exposed by the sensor. When the connection is established the heart rate sensor begins to send the measurements that are read by the app and are showed to the user (See Fig. 2), then they are send to the server where they are stored with the corresponding date.

![Diagram of the system architecture](image-url)
REST API. It performs all the (CRUD) Create, Read, Update and Delete operations on the database, besides it contains all the diagnosis logic in order to make all the data analysis results available, the endpoints defined in the REST API are:

- **login**: Makes the user access with his id and password.
- **getMeasurements**: Obtains all the patients measurements, if the request has an id parameter the specific user measurements associated with the given id.
- **postMeasurement**: Stores in the database the measurements collected from one user.
- **getPatients**: Obtains all the patients data, if the request contains an id parameter the result only contains the specific patient data associated with the given id.
- **postPatient**: It registers a patient and stores his basic information.
- **getDiagnosis**: Reads the diagnoses that are associated with the patient that performs the consult.
- **postDiagnosis**: It stores the diagnosis results when the user selects the option in the app.
- **makeDiagnosis**: Performs the data analysis with the measurements recollected in the last 21 h and returns the diagnosis results.

Fig. 2. App heart rate measurement screen, on the left figure the connection is not established, once the Bluetooth is on and the device is selected the app shows the actual measurement to the user and the amount of measurements read as seen in the figure of the right.
DB server. The database stores all user’s basic information, the measurements collected and the diagnosis that the user performs, the information only can be accessed by the REST API and the user can see it through the app or the web client.

3.2 Data Analysis

One of the most important part in the system is the data analysis which allow the user to know a preventive diagnosis of his cardiovascular health, in the REST API the cardiac measurements already stored in the database are analyzed with the use of a method based on the theory of probability.

The methodology proposed in [12] is used to analyze the data of the heart rate of cardiac measurements of a patient in a minimum of 21 h, and to establish if a patient is in heart disease status, healthy or is in progress towards heart disease, this methodology was tested in [13].

The methodology determined that, as in dynamic systems, characteristic spaces can be established to determine characteristic behaviors in healthy and sick patients, in order to be applied to particular cases and to be able to set conclusive results regarding their cardiac health, with the cardiac measurements ranges of 5 beats per minute is defined and the probability of the patient being in one of these ranges is calculated, in the same way the probability that the patient presents a number n of beats in one hour is calculated, establishing ranges of 250 beats. According to the results, the following criteria admits to determine a patient’s cardiac health status:

1. If a patient’s heartbeat data appears in more than 17 heart rate ranges, his condition is normal, but if a patient appears in 14 or less heart rate ranges his condition is characteristic of heart disease, if he is in the middle, it is said that the criteria it is not conclusive.

2. The parameters a and b are applied simultaneously.
   a. Difference between the ranges of the two frequency values with greater probability greater or equal to 15 is characteristic of disease.
   b. The maximum probability of the number of beats with value equal or less than 0.217 or greater than or equal to 0.304 is characteristic of disease.

According to parameters a and b, it is vested that:

- If only the a parameter is presented, then, there is disease.
- If the a and b parameter are presented, then, there is disease.
- If only the b parameter is presented, then, there is progress towards heart disease.
- If only the b parameter is presented and the number of beats in one hour less than 3000 or greater than 6250, then, there is disease.

3. The sum of the two most frequent probabilities in sick Holters is characteristic of disease when it presents higher values than 0.319 in the following cases:

- When parameters a and b are also characteristic of disease.
- When the parameter b is characteristic of disease.
– When parameter b is characteristic of disease and a number less than 3,000 or greater than 6,250 beats is presented in one hour

In that order the possible responses of the REST API are:

– For the first analysis:
  • Characteristic of normality.
  • Characteristic of heart disease.
  • Inconclusive.
– For the second analysis:
  • Characteristic of heart disease by (first or second) criteria.
  • Characteristic of disease in evolution by third test
  • Health.
– For the third analysis:
  • Characteristic of disease by (first, second or third) test
  • Health
  • Inconclusive

4 Case of Study

The case of study for this investigation consists in the implementation of the system with a healthy patient. The implementation begins when the user download and install the App, then the user must put on the heart rate sensor and launch the App, then the patient makes the app register and login, finally he selects the sensor connected in the App and the App begins to collect the data, the patient has to wear the sensor for 21 h (as recommended in [12]) while performs his normal daily activities. In this case the heart rate was monitored during this time, when the test finish there were 75603 registers of measurements stored in the database, each one has the exact date and the value of the measurement.

When the user has enough data to perform the analysis he goes to the diagnosis screen where he can execute the diagnosis generator process (see Fig. 3) and see the results of that process. In this case as expected at the beginning of the test the result of the diagnosis conclude that the user was completely healthy.
5 Conclusions

The design of this system, which includes a reliable, analysis component that works over the data collected using mobile devices and IoT technologies, as well as wearable devices which communicate with the system through reliable protocols as BLE, come out as an alternative to the traditional diagnoses, made with professional medical equipment.

Using our approach, the patient has the possibility of having a check-up of his cardiovascular health when he wants to, and carry out it as frequently as he needs, even without having the necessity of leave his home, in that way, the only equipment needed to have a diagnosis is composed of an android mobile device and a Bluetooth heart rate monitor, getting as a result, the patients current cardiovascular health state and recommendations if needed, based on a variety of criteria which use data analytics and probability theory. Our future work will be oriented to make authorized test of the system with cardiovascular patients in a hospital.

Fig. 3. Diagnosis screen, in the left figure the user has not performed the diagnosis and in the right one the user has performed the diagnosis, which allows him to see the results and record them if he wants.
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References