EKG Intelligent Mobile System for Home Users

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Abstract. Medical diagnosis is a fundamental field to detect potential diseases and illness in patients. Nowadays, decision support systems used to detect health problems present several technical advances with respect to the existing systems 20 or 30 years ago. This work is associated to this evolution in diagnostic systems. In this work, a low cost electrocardiography system is developed. The system is able of acquiring patient medical information and send it to a medical center in execution time. This system can be used as an alternative to the current Holter monitors in daily life to record heart activity for 24 hours.

Keywords: EKG mobile · Information fusion · Physical activity monitor · Electrocardiogram · Health sensors

1 Introduction

Due to the advances occurred during last years in mobile technologies, the decreasing price of the terminals, and the ease of access of mobile devices, more and more people have a Smartphone on their daily activities. According to a report from Strategy Analytics [1] the sales of smartphones grew 40% to reach around 990.0 million units sold; this report give us an idea of the great impact of the smartphones in our society [2][3][4]. Smartphones can be explored as technological tools that can help humans in different ways and a critical field where smartphones can be applied is health care.

Nowadays, it is possible to find a variety of "silent" diseases. These diseases don't have symptoms but they are in continuous evolution. Some examples of these diseases are diabetes, hypertension or hypercholesterolemia [5][6], they can lead to important pathologies in the future such as myocardial infarction and stroke, associated with a high mortality among adults.

However, an early diagnosis and a correct treatment and control, can notably help the patients to avoid the consequences of these diseases and to prolong the quality of life [7][8].

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In this sense, the use of mobile devices provides a very useful and versatile tool to prevent and control diseases [10][11]. An example can be our previous work [24], where we pay special attention to the use of multi-agent systems for the detection and monitoring of the patients.

A clear example is the report of “Global Mobile Health Market Report 2010-2015” [9] carried out by expert of research2guidance establishes that in 2015 around 500 million of people in the world will use some application to interact with him/her doctor.

As to Global Mobile Health [9] there are over 4,200 mobile apps in the health sector available in the Apple and Android market places. These kinds of services allow the remote monitoring of the patient by doctors, helping people to control their health status remotely, in their homes.

In this work we present a system for mobile devices that can be used as an alternative to the Holter measurement systems available in medical centers. A Holter monitor is a portable device that measures and records the patient's heart activity EKG (*Elektrokardiogramm*) continuously for 24 to 48 hours [12][13]. The size of a Holter is similar to a compact camera and it has a series of cables connected to electrodes attached to the patient's skin.

A Holter monitor is a device used by the medical staff to observe the activity of the heart during the daily life of the patient. Abnormal heart rhythms and cardiac symptoms may appear and disappear intermittently, which is why physicians may need to evaluate the patient's heartbeat through your daily activities.

The data recorded by the device can be used to check the heartbeat and to establish if it is slow, fast or irregular. The information of an EKG can be used to check whether a certain medicine is working, or to check if a pacemaker is working correctly. This information can help the doctors to improve the patients’ treatment.

A Holter monitor has no risks for the patient and it is painless [14]. The main drawback of these devices is their high price, which makes them unaffordable to the vast majority of patients who may need it. These devices are acquired by medical centers, but due to the high cost, medical centers usually don’t have a sufficient number of available devices to meet the demand. Because of this, there are waiting lists, with the corresponding health risk for patients.

Another drawback with the Holter monitors is that the patient must register accurately all movements and activities carried out throughout the duration of the test. The patients have to register their daily activity, which also means a loss of precision, because some of the annotations cannot fully correspond to reality.

In this work a simple system, low cost and fully integrated with Smartphone is presented to emulate a Holter monitor. The system combines Arduino device with a smartphone to design an advanced and ubiquitous system. Arduino [15] has been used to record the heart rates continuously, using a set of electrodes. The system design scheme is shown in Figure 6. All the hardware used for the prototype is commercially available at a very low cost.

The data acquired by the EKG are displayed in real time in the user’s Smartphone. One of the main advances of the system is its ability to fuse the EKG data with the values of the GPS and accelerometer of the device. This information will serve to monitor the daily activities performed by the user, wearing the device in similar way than a Holter monitor. If the user is at rest, the accelerometer or GPS values will indicate that there is not significant activity [16]. In other case, if the user is walking or performing physical activity, the accelerometers will register this activity.

Thanks to all this information, we will have a collection of values about the patient's heart rhythm and that activities performed. This information is received and processed in real time on the Smartphone, and it is sent to the doctor in charge of monitoring the patient.

Additionally, the proposed system will incorporate models to predict possible heart problems, through the comparison of the processed data with a collection of statistical data. The system not only records the sensor values, it will also process them in real time for detecting anomalies and send alerts to medical centers.

2 Literature Review

This section presents the state of the art of existing Holter systems, electrocardiograms readers systems and systems used to monitor daily physical activity of users.

First, we start reviewing the Holter monitor systems that can be found on the market. The vast majority of these devices are intended to provide services in medical centers and hospitals and not to the general public. The main reason is that the prices of these devices are very high. Besides, medical professionals are qualified to use them, because managing these devices requires technical knowledge and previous experience about their management.

The Dutch company Philips sells professional Holters devices, specifically the model DigiTrak XT Holter Recorder (Figure 1) which is priced at about $15,000.

Fig. 1. Philips DigiTrak XT Holter Recorder

The Phillips Holter monitor is one of the lightest devices on the market; it has an integrated display to provide information to the user. It has 12 referrals for heart rate measurement, pacemaker detector sensitivity settings, and can make a recording for up to 7 days on a single AAA battery. Another example of commercial systems like this is the BMS1200 of biomedical systems. The price is around € 20,000, and has very similar characteristics the Philips device.

There are many commercial examples of Holter monitors, they are very similar in price and features, and they are aimed at doctors and centers handled by qualified professionals.

Apart from this, it is possible to find more alternatives for a domestic use but equally effective and integrated with smartphones. The Israeli company SHL Telemedicine offers a product called SmartHeart. This device is a household electrocardiogram that connects wirelessly to any SmartPhone and is able to record the user's ECKG and later sending the information to a doctor in order to make an analysis of the data.

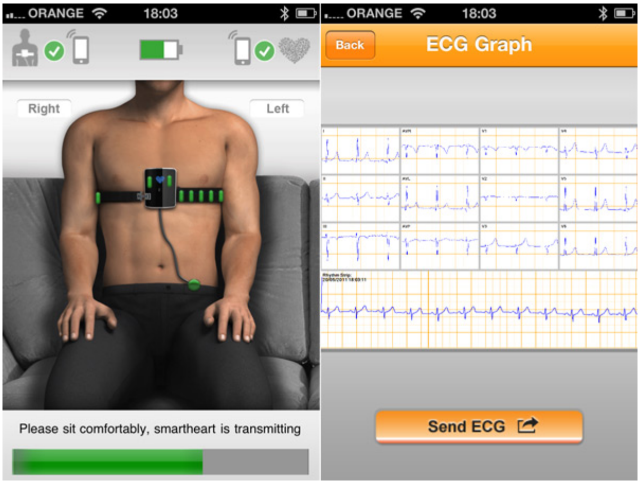

Fig. 2. SmartHeart app

This device simplifies the process of obtaining an EKG, especially compared to the Holter monitors used in medical centers. It's very simple to use since it only consists of an elastic band, it is placed on the chest and that the electrodes are integrated to the monitor that will record and send data to the Smartphone. The application interface is also very simple to use, since the user simple has to connect the device and link it via Bluetooth as illustrated in Figure 2.

This system has a cost of around $ 500, is less than the price Holter devices but still high for most users. Also note that this monitor only records heart activity over a period of 30 seconds, while the Holter devices can monitor a person from 24h onwards.

The American company AliveCor has developed the AliveCor Heart Monitor, a sheath for Smartphones able to record the EKG through a single channel in the rear, Figure 3.

This device is integrated within the cover of a smartphone, and its price is $ 200 lower than other systems making it accessible to the public. It was created by Dr. David Albert, a cardiologist with over thirty years of experience. His main goal was to create an accessible EKG to everyone. The manufacturing cost in China per device is less than $ 15, which represents a very affordable price.

Fig. 3. EKG sheath for Smartphones

This monitor fits into the back side of a smartphone, and provides capacities to record, view, store and transfer wirelessly, the rhythms of the single EKG channel with the AliveECG application. It is not necessary a link between the Smartphone and the heart monitor. The heart rate data is recorded and can be of any length. It can be stored in the smartphone and in a cloud. The system provides a report in PDF format to be reviewed, analyzed and printed through the website AliveCor, which meets the HIPAA (Health Insurance Portability and Accountability) requirements.

Another open source alternative is found in the American College of South Carolina, Dr. Chris Rorden's research group has developed a prototype EKG open source system based on Arduino controller and a bluetooth system [17] shown in Figure 4.

An interesting feature of the ADS129n chip used in this project is that it provides 24 bits of precision. This allows that a single hardware design will be used for different applications. In contrast, a 16-bit design has to be adjusted for small and slow signals from the scalp to perform a rapid test or EEG signals generated by relatively large superficial muscles in EMG test. The chip also contains a number of more sophisticated data filtering to EKG acquisition. The recent ADS1299 chip provides better accuracy, but requires higher energy power.

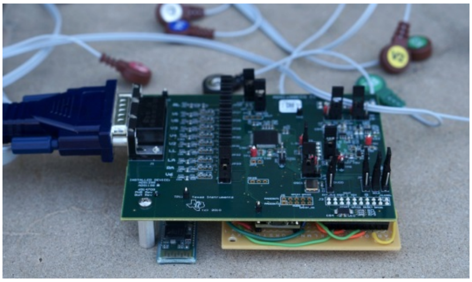

Fig. 4. Prototype of South Carolina's college

The documentation, source code and hardware schemes of the project are available on the website of the university. Although the system still does not have a medical validation, the test results can provide a degree of accuracy similar to that of professional medical devices.

Regarding the activity meters that exist in the market, we can highlight the Fitbit Flex bracelets (Figure 5) from company Fitbit [21]. This is a watch to measure your daily activity: steps, calories burned, the walking distance and even the quality of your sleep.

Fig. 5. Fitbit Flex bracelets

This kind of bracelets takes a series of accelerometers and altimeter to monitor the activity values.

3 Proposed System

This paper proposes a system composed of an Open Source Arduino electrocardiogram to merge the data of an EKG with the values of the sensors of Smartphone and monitor the physical activity of a patient shown in Figure 6. The obtained data will be analyzed by an intelligent algorithm that will be able to detect heart episodes and trigger a series of actions, such as contacting with a doctor.

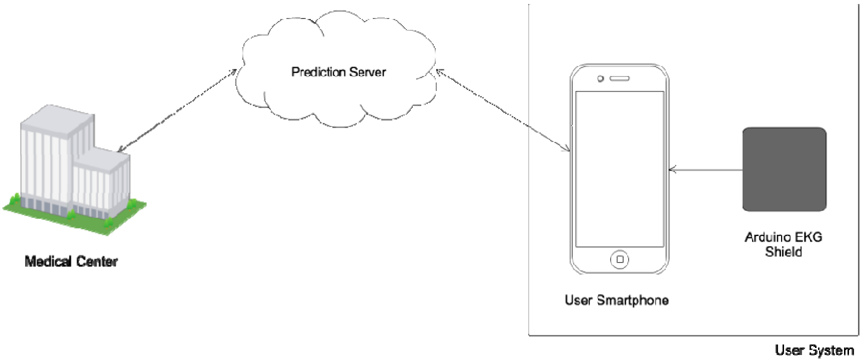

Fig. 6. Scheme of the proposed system

3.1 Low Cost EKG

As previously mentioned, the components of the prototype are based on Arduino technology because this technology is hardware and software free and it allow easily integrating a wide range of chip components and sensors. The prototype consists of 2 plates Ardunio (one Board and Shield) and electrodes compatible with the electronics.

Arduino Bluetooth: This is a kind of Arduino Board, it is responsible to interpret and process the information from the Shield plate and send the information via a bluetooth to the Smartphone user.

Olimex Arduino Shield SHIELD-EKG-EMG: The board receives the information from the electrodes and encode, Figure 7. The prototype and the example code, can be found in https://www.olimex.com/Products/Duino/Shields/SHIELD-EKG-EMG/open-source-hardware.

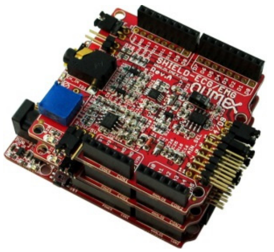

Fig. 7. Olimex Arduino SHIELD-EKG-EMG

Electrodes SHIELD-EKG-EMG-PA: they will be connected to the patient (Figure 8).

Fig. 8. Electrodes for EKG shield

The firmware of the Arduino executes the source code to read the data of the EKG. We used the Arduino programming language with Mstimer2 TimerOne and libraries provided by the manufacturer.

The functionality of the firmware is to obtain the values of the attached sensors in the shield and provides the information thought bluethooth connection.

In the Figure 9 is seen the graphics obtained by using the values obtained by the electrodes.

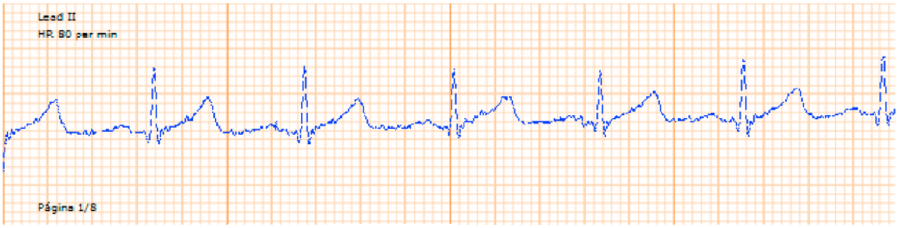

Fig. 9. EKG graphics

3.2 Algorithms for Detecting Cardiac Events

Currently many algorithms have been proposed for the detection of cardiac events. However, the recognition of the heart rate is still unsatisfactory due to unreliable extraction features in the analysis of the characteristic signal. It is possible to find advanced works in this area that allows learning patterns on electrocardiograms to predict pathologies.

In this work, the EKG introduces more noise than a professional EKG, and the calculation of P, QRS and T waves is more complicated. Thus, instead of calculating the length of each ware, the system calculates the maximum point or each wave P, QRS and T that can be easily observed in Figure 10.

First the R-wave is detected. The process to detect the R-wave peak is simple. The system looks for a sequence of values higher than a threshold tr according to the work [23], then the maximum value is selected. To find the minimum value of the P wave, the system follows the same procedure; the threshold is set tp and minimum value in the interval Ip prior to the wave time tr is calculated. Similarly the proceeds with the p-wave, s and t.

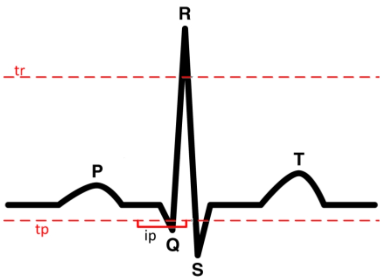

Fig. 10. EKG wave diagram

To detect anomalies, some basic rules were introduced based on the type of problem detected. Specifically, we have analyzed: sinus tachycardia up to 150 beats, sinus arrhythmia beats variation depending on the breathing apparatus is observed easily, SA nodal blocking a pause in a multiple of p-p interval, sinus pause is not a pause interval is multiple of p. This type of pathologies is analyzed using a set of rules according to a given definition. Apart from this pathology, it is possible to find many other pathologies so that it is necessary to introduce new rules.

One alert is sent automatically if a wave is not detected. Usually, it will be a symptom of a serious disease or malfunction of the system.

3.3 Sensors to Monitorize Daily Life

In this paper we use the sensors available in a Smartphone to merge this data with the information obtained from the EKG system weared by the user. Specifically, to obtain these values the system accesses to the values of the accelerometer and GPS.

The accelerometers can be used to detect the physical activity and detect if the person is walking, standing. Also, in outdoors environments, the GPS can determine the route of the patients and the walking speed. The detection step with the accelerometer is performed according to this work [18].

These values are useful to determine the activity performed by the user and to merge them with the values of the EKG. The system can determine if those values are normal or if there is a real problem instead. For this purpose, a case-based reasoning system is designed to determine if the situation is abnormal or not. A CBR system is chosen because the capacities for learning and adaptation as well as for the active participation of medical experts in the supervised evaluation and learning of the system. The proposed reasoning system makes use of past experiences to propose new solutions. CBR systems execute a CBR cycle composed of 4 stages: retrieve (to recover past experiences), reuse (to obtain a new solution based on the retrieved past experiences), revise (to evaluate the obtained solution) and retain (to learn from the new experience). The CBR system proposed in this paper recovers a set of variables for a group of patients. This dataset is used as an input for the reuse phase of the CBR system. The reuse phase incorporates new classification techniques during the reuse phase, not previously used for this kind of problems, in order to generate a classification for the new patient. The system defines a time series composed of 30 measures, each measure ei contains the elements showed in the table 1.

Table 1. EKG waves and times

Wave	Time
Pi	Milliseconds from the last value pi-1
Qi	Milliseconds from the last value qi-1
Ri	Milliseconds from the last value ri-1
Si	Milliseconds from the last value si-1
Ti	Milliseconds from the last value ti-1
Dpqi	Milliseconds between the maximum value of the p wave and minimum value of q wave.
Dqri	Milliseconds between the minimum value of the q wave and maximum value of r wave.
Drsi	Milliseconds between the maximum value of the r wave and minimum value of s wave.
Dsti	Milliseconds between the minimum value of the s wave and maximum value of t wave.

In addition, the case also introduced 5 measures associated with the accelerometers and GPS of the smartphone. Each measure s_i and v_i contains information about steps per second and speed. Measurements are taken homogeneously and distributed throughout the 30 measurements in the electrocardiogram.

State information has been added to indicate whether this case is a normal case or a pathology. Thus, the case is defined as follows.

$$c = \{e_1,...e_{30}, s_1,..., s_5, v_1,..., v_5, state\}$$

Once a new case is received, the CBR cycle of the system is applied. The CBR cycle is composed of four stages: retrieve, reuse, review and retain phases. During the retrieve phase the most similar case to the current case is retrieved by applying Manhattan distance. Cases with a distance less than the predefined threshold u1 are recovered, as a percentage of the difference between two heart beats. The retrieve phase only considers variables shown in Table 1. Then cases are filtered as the speed and steps, the system selects the cases with a distance lower than the threshold u2 as a percentage determined experimentally. When the system is not able to retrieve cases, then an alert is sent to the health center. Otherwise, the system uses the retrieved cases to build a J48 decision tree, and uses the decision tree to calculate the probability of belonging to a disease class or to a normal class. The interpretation of the tree is considered relevant if the kappa index is above 0.8 otherwise is ignored and always sends the alert. The alert will be sent if the probability of disease is greater than 0.2 to avoid false negatives.

The review and retain phases are performed online with the cases with a detected pathology while other cases are reviewed offline. The system send to the doctor the data associated with EKG and physical activity, due to some variations in the heart rate can be associated to some physical activity.

The initial cases of the CBR where created from the data available at the hospital and the state was defined by the medical staff that participated in the experiments.

4 Results

A mobile application for smartphones was developed to monitor the EKG in real time.

Some characteristics of the graphical user interface are as follows:

Previously to star using the system, the user has to configure the device to introduce IP address of the remote server to send the data, as shown in Figure 11.a. The second screenshot, shown in Figure 11.b, indicates the time from the EKG was started, and the last image show the EKG of the user.

The system has been tested with simulated data according to 100 sequences belonging to 4 pathologies and a normal state. The system has not been tested with real patients in daily life situations because it is in early stages and it is only a prototype. The successful rate of the first state of the algorithm was analyzed, and the system is able to discriminate between disease and normal behavior by 94% in a sequence, taking 10 consecutives sequences, all pathologies were detected.

Fig. 11. a) Screenshot of previously version. b) Screenshot of EKG graphic

The functionality of the monitoring physical activity was also analyzed. The system helps the doctor to determine for example if the hearth rate is associated with a physical activity, improving the results and helping to detect a normal behavior with hearth rate 60-100 beats with a sinus tachycardia to 150 beats. However, this section is necessary to check more detail.

Although the work is in an early stage, it was proven that the hardware provides good enough data to analyze the EKG and this information can be used to make a clinical analysis. However, the hardware introduces a meaningful quantity of noise if we compare it with commercial existing devices. As further work it is needed to includes new pathologies and analyze alternatives such as [19] for the detection of pathologies. It will be necessary to introduce a public database as [20] to analyze the system performance.

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