# ECGalert: A Heart Attack Alerting System

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# ECGalert: A Heart Attack Alerting System

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**Abstract.** This article presents a system for early detection and alerting of the onset of a heart attack. The system consists of a wireless and mobile ECG biosensor, a data center, smartphone and web applications, and a remote 24h health care. The scientific basis of this system is founded on the fact that a heart attack can be detected at least two hours before its onset, and that a timely medical attention can dramatically reduce the risk of death or serious tissue damage.
So far, there are no commercial products matching the goals and functionalities proposed by this system, even though there are a number of proof-of-concept studies, and a number of similar products on the market. For the greater part, these currently offered solutions are specifically intended for conducting stress tests in modern hospitals, or as personal fitness devices. Most of them have limited battery power, do not use algorithms for heart attack detection, and/or require constant supervision by medical personnel.

**Keywords:** heart monitoring system; ECG wearable sensor

## 1 Introduction

The motivation for realization of such a product arises from the latest statistics claiming that more than half of mortalities are caused by cardio vascular diseases. When it comes to matters of the heart, the statistics are dire: Cardiovascular disease is the top cause of death in the United States and around the globe. Americans spend more than $300 billion annually on the costs of heart disease, stroke, and other cardiovascular diseases [17]. Statistics on the mortality rate in EU and wider show that more than 40% of deaths are due to cardiovascular diseases [12]. However, 80% of premature heart disease and stroke is preventable [21]. Additionally, because of dynamic and stressful lifestyle, recently the age limit for incidences of cardiac arrests has shifted from people aged 65 to people aged 40 or older.

It's no wonder, then, that many observers are making alarming predictions about the future of heart health. Unless current trends are halted or reversed, a World Health Organization report noted, over a billion people will die from cardiovascular diseases in the first half of the 21st century.

Within the cardiovascular diseases, a heart attack is a serious medical emergency, which occurs when blood flow (and oxygen supply) stops to a part of the heart. If impaired blood flow to the heart lasts long enough, it triggers a process called an ischemic cascade - the heart cells die (mainly by necrosis followed by apoptosis) and do not grow back. A timely medical attention, however, may save the patient of premature death, and drastically reduce the risk of serious damage to the heart [11]. Interestingly, studies show that *a heart attack may be predicted a couple of hours before its onset by detecting changes in the Electrocardiogram (ECG) of the patient* [10]. This, indeed, is the starting point and the motivation for our innovation.

Traditional EKG/ECG tests are done in a special medical institution with the proper equipment and with professional medical personnel who will read the results and look for patterns and problems with the electrical activity of the patient"s heart. Recently, with the advent of new advanced portable and wireless technologies, the medical institution need not be the only place where ECG tests are conducted [15]. The latest ECG sensors are wireless and easy to wear on the human body, they do not cause any discomfort and can be worn at all times and wherever the patient goes.

We have discussed challenges to develop an mHealth ECG monitoring solution [7] by analyzing the mobile application. Here we give details on realization of a cloud-based system that alerts an onset of a heartattack.

Even though there is much research on the subject of early prediction of heart attacks, to our knowledge there are no commercialized solutions to this problem. In Section 2 we propose an innovative solution for early warning and quick medical attention in case of a heart attack, by introducing a new product (sensor and smartphone application), and a new service (giving medical advice as a service) to patients with heart disease. Section 3 gives related work and Section 4 discusses the value, market potential and innovation impacts, and also compares our approach to the others. Finally, conclusions are given in Section 5.

## 2 ECGalert Solution

In this section we present a functional description and system architecture of the overall system that consists of a wearable ECG sensor, dew server (smartphone) and cloud-based server. The user attaches a sensor on the body and communicates to the smartphone and cloud web application.

### 2.1 Functional Description

The system presented in [7] consists of attaching a small portable wireless ECG biosensor on the patient's body and installing an application on the patient's smartphone that receives ECG signals from the sensor, passes them to the data center, which in turn, processes them and determines if there's any abnormal heart activity. The system is also connected to a web application on the cloud

(cloud computing) that communicates with doctors who are in charge of providing a 24h remote medical care as a service. In case of a detected onset of a heart attack, doctors are notified by the system and may call the patient with instructions and medical advice. Additionally, 24h medical care service centers are notified by the system to send an ambulance on the location given by the patient's smartphone. This timely medical attention may save a patient's life.

Even though there is much research on the subject of early prediction of heart attacks, still there is no commercialized solution to this problem. Wie propose an innovative solution for early warning and quick medical attention in case of a heart attack, by introducing a new product (sensor and smartphone application), and a new service (giving medical advice as a service) to patients with heart disease.

### 2.2 System Architecture

A wearable ECG sensor that is attached to the patient body transmits signals to the patient's smartphone (or mobile device) and then it transmits the signal to the cloud-based data center.

The overall architecture and organization of the processing modules is presented in Fig. 1.

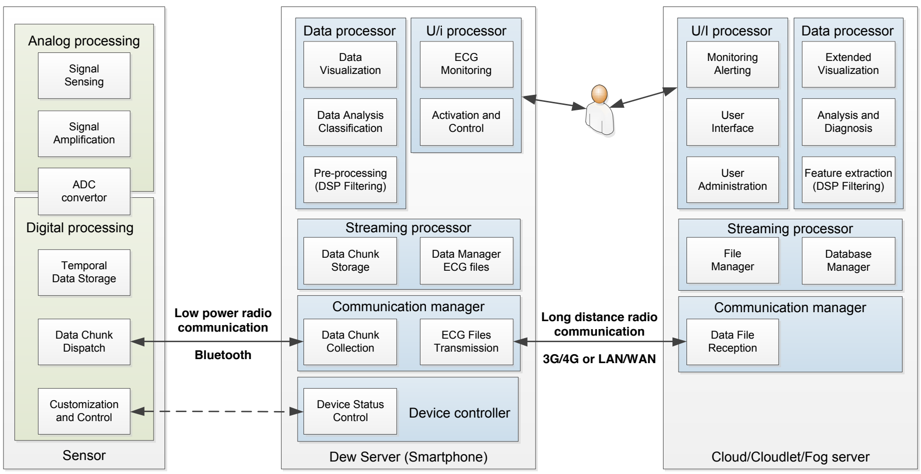


**Fig. 1.** System architecture and module organization

The sensor functions are based on two parts: the analog and digital processing. The analog part senses micro electrical signals on the human skin, amplifies them, and realizes analog to digital conversion. The digital part consists of temporal data sample storage in small buffers, their organization in small data chunks and then their dispatching via a Bluetooth channel. In addition the sensor realizes several customization and control functions, such as Bluetooth pairing and connection, and customization of several parameters including sampling frequency, time synchronization, etc.

The nearby smartphone receives the measured and dispatched data chunks via Bluetooth channel. Then, it stores them in temporal buffers and creates files for permanent storage on the local internal storage media. In case of internet connection, the files are transmitted to the higher level servers for further processing. In addition, the smartphone, realizes data processing by applying an efficient DSP filter and data analysis with QRS detection and heart rate determination. Besides this, it uses a UI interface to communicate with the user and realizes data visualization and ECG monitoring.

The cloud realizes data collection and processing features via a more complex data analysis for diagnosis and monitoring purposes. In addition, the web application needs user administration, and user interface to communicate with doctors and end-users.

The identified system modules are presented in Fig. 1. The smartphone is based on organization of the following five modules: device controller, communication manager, streaming processor, data processor and U/I processor. The cloud does not realize device control since all data is pushed by the smartphone and the only communication that might happen is alerting via standard voice telecommunication system. The other four modules (communication manager, streaming processor, U/I processor and Data processor) include extensive processing, and database storage.

The smartphone actually realizes data collection, preprocessing, storing, and transmitting to the higher level servers. The cloud realizes data reception and extensive data processing. This belongs to a specific architecture described for cloud-based processing of streaming IoT sensors [4]. This is why the smartphone is a realization of a dew server in the dew computing scenario, where the processing is brought close to the user, by enabling an independent and collaborative server. Since the system uses a wearable and wireless sensor, the dew server needs also to be a moveable device close to the user using a low power radio connection (Bluetooth) to the sensor and long distance radio communication, such as 3G/4G communication to the mobile operator or LAN/WAN wireless connection.

### 2.3 ECG Data Processing

A typical ECG consists of a QRS complex (with identified Q, R and S points) and P and T waves (Fig. 2). The data path and processing of ECG data is organized as presented in Fig. 3. The preprocessing and feature extraction is realized in two paths. The first path uses a DSP bandpass filter (5-20Hz) to eliminate the noise and reduce feature space, and the other just to eliminate the noise by a DSP bandpass filter (0.5Hz-30Hz). As DSP filters we use an improved pipelined wavelet implementation for filtering ECG signals [13].

The first feature extraction phase is the QRS detection algorithm to detect the R peaks on the signal with reduced feature space. The R peak within the

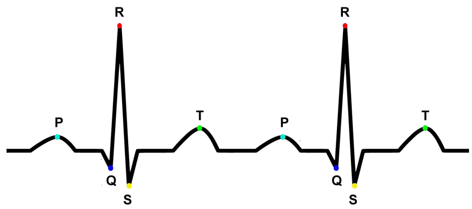


**Fig. 2.** A typical PQRST waveform of an ECG.

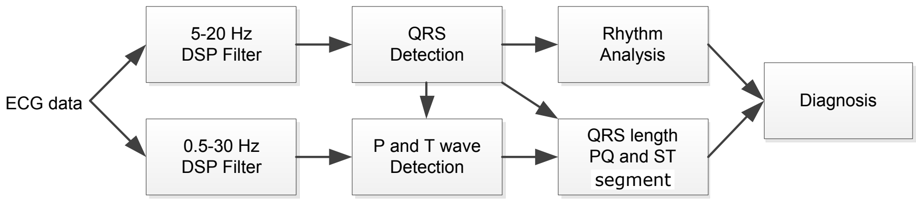


**Fig. 3.** Organization of the software

QRS complex is detected by an adaptive differential technique to compare the slope and adapt its magnitude to the signal energy, using a partial pattern matching algorithm [6] The second phase of the feature extraction follows a detected R peak with detection of the other characteristic waves, such as P and T are determined by appropriate analysis on the signal with eliminated noise.

Once the characteristic peaks are determined, the results from this feature extraction phase are forwarded to morphological processing to determine the QRS length, PQ and ST segments and other morphological features. In parallel, the rhythm is analyzed for the occurrence of the R peaks to determine regularity of the heart rate and rhythm.

Both the morphological and heart rate analysis are used to establish the diagnosis and support the monitoring and alerting system. This phase will diagnose arrhythmia and finishes with determination of a set of heart malfunction diagnoses and eventually an onset of heart attack. A heart attack can be detected by ST segment elevation in the morphological analysis of the ECG [1].

This system will not result with detecting of all possible diagnoses, due to the limitation of the used wearable sensor to detect only one ECG channel that exposes most characteristic features. To establish a more elaborated diagnosis, one needs more channels and analyze 3D heart positioning by more precise detecting the source of the identified problems. Note that by using two wearable sensors and principles of the physics, one can reconstruct 12 lead ECG [20].

## 3 Related work

For our proposed solution, there are numerous clinical trials and scientific studies published in the form of proof-of-concept [2]. In this section we overview latest

ECG sensors, patents describing monitoring systems and similar commercial products.

We have analyzed the State-of-the-art of Cloud Solutions Based on ECG Sensors [5]. including analysis of related patents, existing mobile solutions and cloud-based architectures, including, cloudlet, fog and dew computing approaches.

So far, many studies have proposed how to develop a remote ECG monitoring system, in theory. Unfortunately, none of these ideas are fully implemented in the way that we propose. For instance, most of the solutions on the market [19, 14, 16], perform continuous recording of vital signs (ECG, heart rate, respiration rate, body temperature), consequently the battery lifetime is short. Other solutions are based on constant monitoring by a medical expert [14].

The competing solutions on the market only partially accomplish the goals and functionalities that are subject of this project proposal. Predominately, similar state-of-the-art solutions are intended for easier conducting of stress tests[14], for prioritizing medical care in hospitals[19], or even for personal fitness[16]. The existing solutions are limited to monitoring of vital parameters and signaling on simple preprogrammed thresholds. This basic data processing is insufficient for detecting the onset of a heart attack.

For instance, the sensor Shimmer3 ECG[19] provides a continuous recording of vital signs, but does not process the data and has no system for early warning. Similarly, NeuroSky[14] provides a recording of vital signs but is more intended for conducting stress tests in hospitals. QardioCore[16] is a multi-sensor platform that besides ECG, measures body temperature, the level of activity, and other vital signs, and thus presents a more complete picture of the patient's health. Nonetheless, the data is only presented, and not processed at all. ZIO XT Patch[8] is a sensor in the form of a replaceable patch where the battery lasts for up to 14 days and sends data to a clinical software iRhythm, where medical professionals set a diagnosis and therapy. While this is a good starting point, no warning in case of emergencies, however, is offered with ZIO XT Patch. Savvy [18] is a commercially available solution and is used for realization of the ECGalert project.

On the same note, many scientific studies deal with wireless, mobile, and remote ECG biosensors. One such comprehensive study[2] examined 120 different ECG biosensors from several aspects. The authors conclude that this area is a hot research topic, and that innovative, applicative solutions may seize a unique market chance.

The end-user benefit is the reduced mortality rate due to early alerting of potential heart attack, and prolonged patient life. The benefit of the medical experts that will actively participate is in the possibility to react faster and be more successful in the treatment of the patients, and in financial incentives with the monthly fee subscription for providing a medical care on the basis of early alerting. This is a kind of a 'win-win' situation where both the care providers and clients will benefit of the proposed system.

The development of wireless sensors that can communicate with personal electronic devices is still at an early phase of development. In Macedonia there are no suppliers of such an equipment yet. It is, therefore, an excellent market position/opportunity to use sophisticated technology (sensors in combination with personal smart devices) to early alert of potential medical risks, as well as to provide a medical care as a service (web application on cloud). This, coupled with the chance to emerge first on the market significantly increases the probability of success of the project.

Although much research exists on this topic, none of it resulted with a definite commercialized solution. Partial, incomplete, or un-implemnted solutions include the design of a wireless ECG system for continuous recording and communication with clinical alarm station [3], the procedure for self-test to detect a heart attack using mobile phone and wearable sensors [10], and an overview of mobile phone sensing systems [9].

## 4 Discussion

This section discusses the product value, market potential, foreseen impacts, and compares our proposed solution with the others available commercialized products.

### 4.1 Value and Market Potential

The value for customers is in developing a system that will alert early of a potential medical emergency (heart attack). Interestingly, it has been scientifically proven that heart attacks can be detected at least two hours prior to their onset, by patterns in the heart's electrocardiogram[11], and that a quick medical attention significantly reduces the dangers of tissue degeneration and possible death[10]. Recently, small, wireless and wearable ECG biosensors have emerged on the market that can keep track of the patient's heart output and other vital parameters. In this context, our system makes use of newly available technologies and advances their application. We propose a solution for early alerting of heart abnormal function, doctor's access to the patient's history and recent ECGs, and a quick medical treatment.

The idea is to sell such sensors, which will be connected with a smartphone application and a system for early alerting of abnormal heart function. The business model is based on selling the smartphone application together with the sensor, whereas the 24hour medical care, based on the application's early alerting of abnormal heart function, will be charged on a monthly subscription basis. The main customers are patients with cardiovascular diseases, under the risk of heart attack.

The main partners are clinics and ambulances for cardio-vascular diseases. This system is based on an active participation of the medical professionals, not only in their recommending of the product to patients, but also in giving medical expertise at regular intervals, or intervening in the case of an alert of abnormal heart function - services for which the patients will be charged a monthly fee.

From informal discussions with patients, we have concluded that our proposed system is of interest to a wider circle of clients, especially keeping in mind the fact that in recent years the dynamic lifestyle and stress have shifted the age limit for incidences of heart attack from people of 65 years of age to people of 40 years of age or older.

### 4.2 Foreseen Impacts

The proposed innovation will contribute in the area of applying ICT solutions for medical care as a service, based on remote sensors. Here we address two important areas: the use of wearable sensors in combination with smart personal devices for health monitoring, and timely action in case of an emergency.

The designed system does not affect or harm the environment. Smartphones are electrical devices used daily by everyone in society, and the sensors do not pose any environmental threat. The development of smartphone application and web application in the cloud also do not harm the environment.

Implementation of this system will have a significant impact in lowering the mortality rate of patients with cardiovascular diseases, and in prolonging their life. Therefore, it will have positive social and societal implications. Estimates show that at least 80% of all heart disease and stroke could have been prevented.

It is known that heart attacks can be detected at least two hours prior to their onset[11], but at the moment ECG devices are fixed, stationary equipment confined in medical facilities. Latest state-of-the-art advances in technology enable the production of portable, mobile and wireless sensors, which are worn by patients as a sticker patch.

### 4.3 Comparison to the other solutions

Our idea is to translate these results in an efficient IT solution. Making use of the fact that the ECG sensors and smartphones are more sophisticated in recent years, we intend to use the personal network established by the smartphone to accept these ECGs and transfer them to the data center. A specialized web service will process the data and alert on abnormal heart function. The doctor will have the opportunity to see the patient's medical history and recent ECGs, establish a proper diagnosis and react accordingly.

Differences to other competing products are:

1. Instead of continuous recording and sending ECG data, the sensor works in time intervals (20, 30 or 60min) and thus considerably saves battery life;
2. Instead of a complex smartphone application, the smartphone receives sensor data via a personal network and sends data to data center via Internet;
3. Instead of continuous monitoring, the doctor on duty monitors on regular time intervals and on alerts send by the alerting system;
4. Instead of using a stationary equipment in the medical institution, diagnosis of cardiovascular diseases can be done remotely, using the sensors and the system for early alerting;

5. Instead of a specialized device with sensor and communicator to the data center, our solution uses sensor accessed by the personal network and mobile smartphone to access WiFi and the data center.

## 5 Conclusion

Our approach goes beyond this by a product innovation in that a constant medical attention is not necessary. ECG data is sent periodically via a smartphone to a data center, prolonging in this manner, the sensor's battery life. In addition, we introduce an application, based on specially developed algorithms, which analyzes the QRS signals from the ECG and determines if there is abnormality. Therefore, there is no need of a constant monitoring by a medical expert, but only in the case of emergency.

In this paper, we presented the system architecture and organization of the software modules, along with details on data processing of the signals. We have realized a prototype solution and are currently in a process of testing and improving the solution, that will be elaborated in a future work.

Precisely this idea of a response only in case of an emergency is a service innovation. In such a case, the doctor on duty would be able to remotely get a visual of the ECG diagram, call the patient and if necessary call an ambulance. To enable this remote health care system with a doctor on duty who will intervene in the event of an emergency, patients will be charged a low monthly fee not exceeding that of other standard communal utilities, such as fixed-phone line, or Internet subscription, or selected TV channel subscription by a cable operator.

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