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A Self-test to Detect a Heart Attack Using a Mobile Phone and Wearable Sensors

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Abstract

This paper describes a heart attack self-test application for a mobile phone that allows potential victims, without the intervention of a medical specialist, to quickly assess whether they are having a heart attack. Heart attacks can occur anytime and anywhere. Using pervasive technology such as a mobile phone and a small wearable ECG sensor it is possible to collect the user's symptoms and to detect the onset of a heart attack by analysing the ECG recordings. If the application assesses that the user is at risk, it will urge the user to call the emergency services immediately. If the user has a cardiac arrest the application will automatically determine the current location of the user and alert the ambulance services and others to the person's location.

1. Introduction

Cardiovascular disease is the leading cause of mortality in the developed world. It refers to various medical conditions that affect the heart and the blood vessels. These conditions include coronary artery disease, myocardial infarction (heart attack), angina, congestive heart failure, hardening of the arteries, stroke and peripheral vascular disease.

Studies in Australia show that more than two thirds of Australians would not call an ambulance if they thought they were having a heart attack [1]. This is backed up by international studies [2] that indicate that many people hesitate calling the emergency services or going to emergency centres with symptoms of a heart attack. However, after a heart attack it is extremely important to get treatment as quickly as possible, since there is a direct relationship between time-to-treatment and the success of reperfusion (restoration of blood flow to the heart). A heart attack comes with warning signs that are not always recognised by the victim. People often confuse a heart attack with indigestion or heart burn. A study in Germany [3] has shown that sudden cardiac death does not come out of the blue and people often have typical symptoms as long as 2 hours before cardiac death occurs.

Much money and research is spent on making people aware of the warning signs (e.g. [4], [5]). Getting patients to recognise the warning signs is not an easy task. Several web sites offer a set of questions to assess whether a person has heart attack symptoms, but the questions are not integrated in devices that a user carries all the time.

The challenge is to reduce the delay time between the onset of a heart attack and the call to the emergency services ([2], [6]), since early detection and prompt treatment is the key to the success of the clinical outcomes. Another challenge is to reduce the number of false alerts. A pilot study conducted by Aerotel and BroomWell Healthcare in the UK showed that 82% of patients did not need to go to hospital following a test and demonstrated the potential to save 46 millions pounds per year by cutting the unnecessary hospital admissions and visits for chest pain symptoms [7].

To deal with these challenges, fast and accurate diagnostic tools should be at hand allowing the user to be reminded of the warning signs and also performing an on the spot heart attack self-test.

Diagnostic tools exist that detect the onset of a heart attack. They use blood tests [8], implants [9] or sensors [7]. However none of these allow the user to do a self-test with non invasive sensors, or without the assistance of a health professional. A research project closest to our solution is managed by Aerotel and BroomWell Healthcare [7] but they use bulkier sensors and the test has to be conducted by a health professional.

The objective of our research is to use non invasive mobile technology to reduce the diagnostic delay and the number of false alarms. To achieve this goal we developed a self-test application using a small wearable ECG sensor and a mobile phone. The application is able to detect the onset of a heart attack and urges the user to call the emergency services when thresholds are reached, and can even do it automatically if required.

The target group for our application are users that have had a heart attack and are concerned that they will be struck by another one. Their concerns are backed up by the American Heart Association indicating that people who have had a heart attack have a sudden death rate that is 4 to 6 times that of the general population [10]. We also target users that have a known heart condition (e.g. irregular heart beat, angina). These users would only use the ECG heart monitor when they feel the need to monitor their condition.

The heart attack self-test application presented in this paper is integrated in the Personal Health Monitor (PHM) system developed at the University of Technology, Sydney ([11], [12]). The PHM system is capable of monitoring the personal health of its user using a mobile phone and various wireless sensors (see Figure 1). The mobile phone application analyses, in real-time, data wirelessly received from the sensors, such as an electrocardiogram (ECG), blood pressure measurements or accelerometer data. The mobile phone can send this data, in real time, to heart specialists. If a person is in danger (cardiac arrest, fall) and is unable to call an ambulance, the mobile phone will automatically determine the current location of the person using WiFi, GSM Cell-id or GPS and sends automated voice and text messages to their cardiologist and other emergency numbers programmed into it.

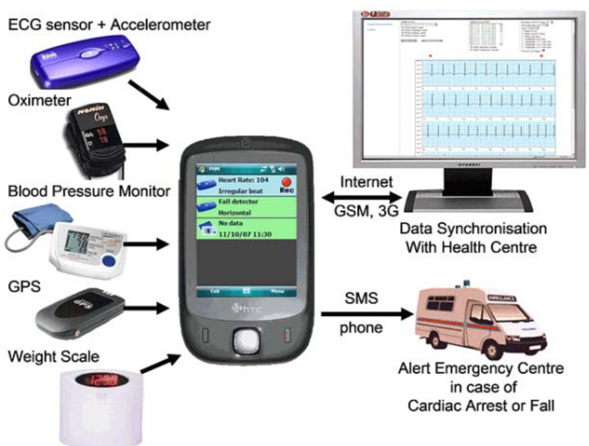

Fig. 1. Personal Health Monitor System.

This paper focuses on the heart attack self-test application and is organised as follows:

Section 2 outlines the requirements for the self-test application. Section 3 describes the heart attack self-test application as it is currently implemented on a mobile phone. Section 4 concludes the paper with a discussion.

2. Requirements

Time is a crucial factor for heart attack patients. If proper medical treatment is performed within 60 minutes of the event, the chances of surviving improve dramatically and the likelihood of serious damage to heart tissue decreases.

If a person decides to do the self-test, it usually means s/he feels something. The first priority is to ask whether the person has heart attack related symptoms and analyse the answers. If the symptoms clearly indicate that the person is having a heart attack there is no reason to delay the call to the emergency services. For example, if the user feels pressure in the chest, pain spreading to their left arm, is sweaty and looks extremely pale, the application will immediately urge the person to call the emergency services. Making an additional ECG recording would simply delay the process by several minutes.

Automating the call to the emergency services avoids the possibility of dialling incorrect numbers but more importantly, can reduce the hesitation many people might have when calling an ambulance, and hoping that the pain will pass. Talking to an emergency operator could convince the user that urgent treatment is needed.

The accuracy versus time ratio of the diagnosis needs to be optimised. For instance, for the analysis of an ECG, the length of the ECG recording should be minimized but long enough to be able to make an accurate decision.

Time is also a factor when deciding how many sensors are used in diagnosing a heart attack. Besides the ECG sensor other sensors (e.g. blood pressure, glucose monitor) will only be used when the emergency level is low.

Ease of use is important since most people will be stressed or feeling very uncomfortable, so a quick assessment with minimal interaction is crucial.

All instructions need to be easy to understand. The text displayed on the screen should be large, and the application needs to play (repeatedly) the questions and instructions aloud so that the person does not need to read what is displayed on the screen. The interface should take into account that the person might have bad eye sight or be trembling. Answering a question should be as easy as pushing a button on a touch screen.

The sensors have to be simple to operate allowing a person to take a measurement. It is important to optimise the accuracy and ease-of-use ratio for sensors. A 12-lead ECG sensor would be the most accurate to diagnose a heart attack. But attaching the various cables and placing the electrodes correctly can be difficult without external help from a medical professional. In contrast, a 2-electrode, 1-lead ECG sensor is easy to attach by a person, but offers less accuracy and information when compared to a 12-lead ECG sensor.

A heart attack can happen anytime, anywhere. Therefore the user must be able to do the self-test wherever and whenever symptoms occur. This has an impact on the technology that can be used. The sensors should be small and non intrusive so that people are willing to carry them all the time. A mobile phone is a logical choice device for the self-test application since most people carry one.

It is important to know some personal details about the user, such as their age, gender or preferred language, in order to adjust the way the application interacts with the person. Medical conditions, such as prior heart attacks, angina or allergy to certain medicines are important in assessing the probability of a heart attack and to provide the correct feedback to the user (e.g. do not prescribe an aspirin to a person if s/he is allergic to it).

The American Heart Association [13] recommends having easy access to important phone numbers in case of mild to moderate symptoms that do not require the emergency services. The correct phone number to dial varies depending on the time and day. It is therefore important to add contextual information such as date and time. This allows the application to dial automatically the correct number at the day/time the self-test is conducted. Knowing the location is useful if the user has a cardiac arrest, as this will guide emergency services to the right location.

3. The heart attack self-test application

We used these requirements as input for the design of our self-test application. Our objective is therefore to develop a user friendly application able to give quick and accurate feedback to the user anytime, anywhere and without intervention of a medical professional.

The user initiates the self-test from the main menu (Figure 2, right) and is requested to answer 'Yes' or 'No' to several simple questions. The questions are designed to quickly assess whether the user is experiencing what could be the onset of a heart attack. Based on these replies and the personal data and medical history stored in the PHM system, the application determines the degree of risk of a heart attack. If the risk is high, the application will urge the user to call the emergency services immediately (Figure 3). The emergency number is automatically dialled when the user agrees.

If the answers indicate that the user is at a low risk, or the user declined calling the emergency services, the application will ask the user to carry out two ECG recordings. The application will analyse these ECG signals for heart attack signs. If they are found, the user will be once again urged to call the emergency services.

Fig. 2. PHM monitor and the self-test integrated into the PHM application.

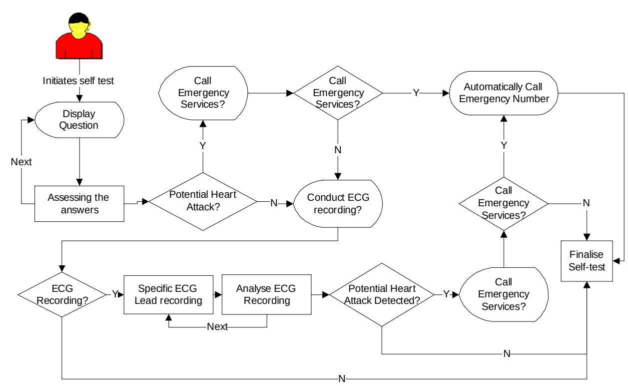

Fig. 3. Flow chart for heart attack self-test

If the self-test application does not detect an abnormality in the ECG signal, the application will finalise the test based on the personal user information available in the PHM system. For example, it advices the user to wear the ECG monitor for that day so that the person is continuously monitored in case of a cardiac arrest.

The following sections describe parts of the process and how they are implemented on the mobile phone.

3.1. Questioning the User

When the individual initiates the self-test a series of questions are asked to identify the possible occurrence of a heart attack. The questions (see table 1) are a compilation of typical heart attack related symptoms as described in [4] and [5]. Symptoms can be different for women and men but the questions asked address both genders.

Table 1. Heart attack related Questions.

1.	Do you feel discomfort around your chest? This can be a feeling of tightness, pressure or squeezing in your chest.
2.	Do you feel pain spreading to your shoulders, shoulder-blades, neck or arms?
3.	Are you having indigestion (gas-like pain) or heartburn?
4.	Do you feel nauseous? Did you vomit?
5.	Do you feel dizzy, weak or anxious?
6.	Are you sweaty or short of breath?
7.	Do you look tired, pale?
8.	Do you feel any typical sensations? For example, feelings of overwhelming doom?

Figure 4 shows how the questions are presented to the user on a mobile device. A recorded voice will repeatedly phrase the question so that he person does not need to read from the screen. If the person is too unwell and not able to use the phone a family member or any person nearby can assist answering the questions.

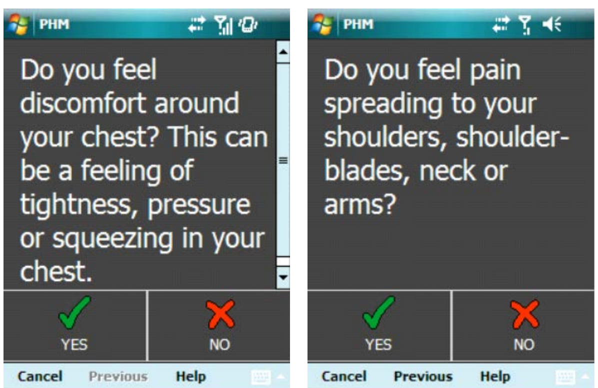

Fig. 4. Screenshot of questions being asked.

The current version of the decision algorithm is basic. If one or more questions are answered positively, the application will urge the person to call the emergency services. Further research is needed to fine-tune the decision algorithm to reduce false alarms but currently we have a "better save than sorry" approach. Further research needs to be conducted to refine the set of questions, adapt them to the user's condition and take into account extra contextual information (e.g. we can get an indication that the user was very active before the test using the accelerometer data).

Another example: There are similarities between angina and a heart attack where the location and the severity of the pain can be similar [14]. Angina is usually related to exercise, stress or indigestion and lasts less than 20 minutes, while a heart attack lasts longer and may come and go. Both have symptoms of shortness of breath and dizziness, but sweating, nausea, and vomiting are not experienced with angina. Angina is relieved with rest and/or nitro-glycerine, but this is not the case for heart attack. Therefore the decision algorithm used distinguishes between angina and a heart attack, and in the case of angina; the advice is to rest, take nitro-glycerine as prescribed, and continue monitoring.

3.2. Calling the Emergency Services

The application will automatically dial a pre-programmed number after 20 seconds. The user is given the option to cancel the call, but the idea behind automatic calling is to persuade the user to act. Studies in the UK have shown that "*the delay between the time of onset of symptoms and the time at which the patient comes under medical attention is a major determinant of prognosis in acute MI; the largest single component of the delay is that taken by the patient deciding to summon help*." [15]

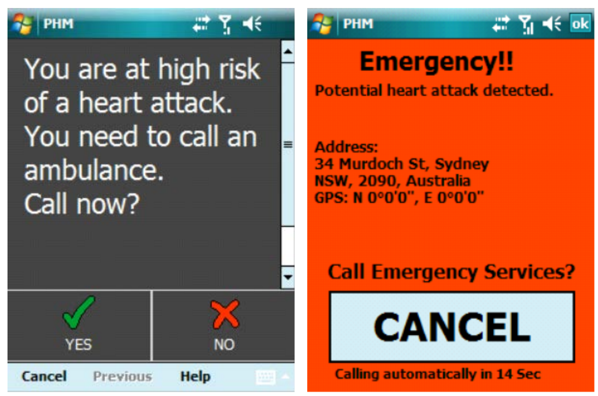

Fig. 5. Automatic call to the emergency services.

Ingafield [16] identified reasons why patients with chest pain delayed seeking hospital medical care and when they do or don't use an ambulance. One of the observations is that patients see their general practitioner (GP) first which on average resulted in a delay of 30 min. This is confirmed by another study [17] which concludes that most patients who contact non-ambulance services are seen by general practitioners. Therefore we decided that the application should call the emergency services number first, in case of a high risk episode.

3.3. ECG recording

If the answers suggest no immediate emergency, the application will ask the user to take two ECG recordings that the application will analyse for signs of a myocardial infarction (MI). During a typical acute MI the ECG evolves through three stages [18]:

1. T wave peaking followed by T wave inversion,
2. ST segment elevation,
3. Appearance of new Q waves.

Using the 2-electrodes, 1-lead ECG sensor the application instructs step-by-step where to place the 4 electrodes on the body and how to attach and operate the ECG monitor. We take 2 separate ECG recordings (Figure 6, left and right) which results in 2 different views of the heart and gives a higher chance of detecting MI.

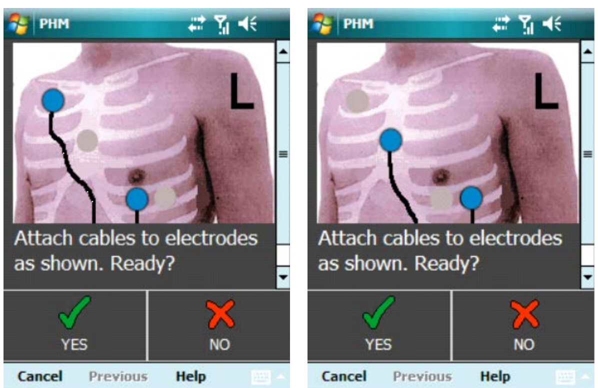

Fig. 6. Obtaining two different ECG recordings

The user will be instructed not to move during the recording to reduce motion artefacts. The application records for 2 minutes and then analyses the ECG recording for changes in the ST segment. Figure 7 shows an example of a normal heart beat (Fig.7, left) and a heartbeat that shows ST elevation (Fig. 7, right) possibly indicating a myocardial infarction. MI can often be seen on an ECG by a flat, down sloping, or depressed ST segments or an ST segment elevation.

We implemented the algorithm developed by P. Langley et al [19] since they achieved the best accuracy for distinguishing ischemic and non-ischemic ST changes in an ambulatory ECG monitor. For the first implementation of our algorithm we focus on ST segment changes since this gives an indication of an onset of MI. The details and performance of the ST algorithm will be published in a forthcoming paper. When the algorithm detects ischemic events the user will be urged to call the emergency services.

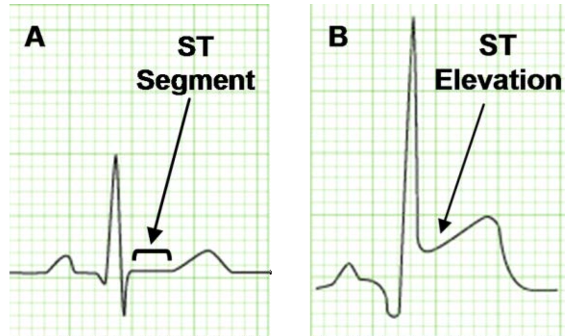

Fig. 7. A normal heart beat (left) and a heart beat during a myocardial infarction (right)

3.4. Finalise Self-test

If the emergency services are called, the application will give advice to the victim and bystanders while waiting for the ambulance to arrive. Advice is displayed and played in a recorded message.

The emergency operator might be on the phone providing additional advice that should be followed.

If no heart attack symptoms are found, the application advises the user to wear the ECG monitor for the rest of the day so that the person is continuously monitored by the Personal Health Monitor. The results of the self-test are automatically upload to the health-centre website and can be directly inspected by a health professional. Uploading the ECG recordings to a healthcare centre is important since there are limits to what can be analysed on the mobile phone. The expertise of medical staff is needed to complement the analysis. A health professional can contact the person directly on the mobile phone if irregularities are seen that need immediate treatment.

4. Discussion

The objective of our self-test application is to reduce the delay time between the onset of a heart attack and the call to the emergency services. Two factors contribute to this delay time. These are the failure to recognise typical heart attack symptoms and the failure to act [20].

Our self-test solves these issues by using pervasive technology: a mobile phone and a small wearable ECG sensor that can be easily carried by the person. By asking a set of questions, the person will realise what they experience may be a heart attack. The application also analyses two ECG recordings on the mobile phone for heart attack signs to confirm this. Therefore, the application can quickly assess the user's condition and provide appropriate advice without the intervention of a medical professional. It also guides the user and (potential) bystanders in getting the right help by automating the call.

We record and analyse an ECG in real-time on the mobile phone using a 2 electrode, 1-lead heart monitor developed by Alive technologies [21]. Our algorithm is able to detect heart rhythm abnormalities such as ventricular tachycardia/fibrillation (cardiac arrest) [22] and changes in the ST-segment. We are currently validating whether a 2-electrode heart monitor provides sufficient quality signal for detecting ST segment variations. If this is not the case we can easily switch to a more sophisticated ECG sensor such as the 12-lead ECG sensor developed by Corscience [23]. The downside is that it is a less portable ECG sensor and it will be more difficult for users to attach the electrodes.

The self-test application is never going to provide 100% accuracy. However, we aim at reducing the false positives (i.e. user has a heart attack and it is not identified) and also bring down the false negatives (i.e. user has not had a heart attack but the system sees it as a heart attack). We hope to achieve this goal by using a combination of questions and ECG recordings. We are conducting trials with the Personal Health Monitor system at the Royal North Shore Hospital in Sydney and we are investigating the possibility of trialling our self-test application with the same hospital to find out whether it reduces the delay time and therefore improves the outcome for heart attack victims.

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