BBAware - A Context-Aware Mobile and Wearable Architecture for Monitoring Beta-Blocked Cardiac Patients

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Abstract. *Beta-blockade drugs are still in use as treatment option to lower heart rate, to improve cardiac function, and to reduce cardiovascular events. Patients who use beta-blockers usually surpass a therapeutic test full of collateral effects to adapt their organisms. Furthermore, these patients with a baseline heart rate above 70 beats per minute have a significantly higher risk of all cardiovascular events. Context-aware healthcare field arises as an alternative to monitor patients constantly. This paper introduces the Beta-Blocked Aware (BBAware) project, a pervasive solution, that uses the concepts of ubiquitous healthcare in order to help patients under beta-blockade treatments.*

1. Introduction

Ischemic heart disease was the first cause of death in the world, between 2000 and 2012 [WHO 2014]. Several efforts have been made to decrease this rate in different areas.

A particular research area on cardiologic medicine is the study of beta-blockers after myocardial infarction [Freemantle et al. 1999]. Beta-blockers are a class of drugs that are among the current treatment options to lower heart rate, improve cardiac function, and reduce cardiovascular events in postmyocardial infarction patients and in heart failure patients [Mathers and Loncar 2006, Kjekshus 1986].

One of the main determinant of a cardiac problem is the heart rate [Andrews et al. 1993]. As beta-blockers decrease heart rate, in the beginning of the treatment patients should undergo a period of the treatment that will evaluate and balance the medication dose. This period is called therapeutic test and usually causes the patient tiredness, dizziness, and sometimes fainting [de Melo 2011]. These collateral effects could be prevented or minimized if the patient could be alerted if his/her heart rate is out of range.

Furthermore, some studies support the idea that patients with a baseline heart rate above 70 beats per minute (bpm) have a significantly higher risk of all cardiovascular events as compared to those with heart rate below 70 bpm. Heart rate reduction decreases the risk of coronary events in Coronary Artery Disease (CAD) patients with heart rate above 70 bpm [Diaz et al. 2005, Fox et al. 2008, Mathers and Loncar 2006]. Therefore, a continuous way to measure the patient heart rate and guarantee that his/her heart rate does not surpass this limit will help this kind of treatment.

Nowadays, patient monitoring by doctors is held in sporadic consultations where heart rate is measured. Perhaps, at this time, the patient heart rate is between the safety limits. However, on other time of daily life, the value of heart rate may surpass the safety limits. Hence, if there was a way to monitor a patient, to guarantee that his/her heart rate is between the limits at most of the time, it would help patients and doctors. This thought leads to the research question: ”How context-aware, mobile and wearable computing can help beta-blocked patients monitoring?”.

With the evolution of smartphones and wearable devices, heart rate sensors have been embedded to them to increase the use of context in the development of mobile and wearable applications. Because of that, those devices could be used to help patients and doctors on the administration of beta-blockade treatment as an ubiquitous healthcare solution [Gelogo and Kim 2013].

Thus, this paper proposes a project called Beta-Blocked Aware (BBAware). The hypothesis of this research is: if wearable and mobile devices tailored with context-awareness could be used for monitoring beta-blocked patients then these patients will have a safer heart rate monitoring and doctors will have better information to define the treatment.

BBAware uses smartwatches and smartphones to help patients, the patient family, and the doctors on monitoring heart rate. Doctors can administrate the beta-blockade treatment on patients that have some cardiac problem that demands the reduction of heart rate having precise measurement from the sensor.

This paper is organized as follows. Section 2 describes some related works on heart rate measurement. Section 3 introduces the BBAware Project. Section 4 presents some examples of use. The conclusions and future work on this study are given in section 5.

2. Related Works

According to Murnane *et al.* [Murnane et al. 2015] there are many applications for health care purposes. The most popular ones are for physical activities and education. The second ones are for medical purposes. The focus on these related works is on monitoring patients solutions that uses context-awareness.

To the best of our knowledge, there is no solution or proposal for monitoring beta-blocked cardiac patients with or without the use of context. However, there are several projects for monitoring heart rate for health concerns that use context-aware computing.

One problem of the proposed works would be if the sensor embedded on the device is not precise enough to be used in medical area. Important studies that evaluate the performance of the heart rate sensor embedded on smartwatches have been published. The results showed in Phan *et al.* [Phan et al. 2015], Jovanov [Jovanov 2015], and Lemay *et al.* [Lemay et al. 2014] have approved the use of the sensor, the photoplethysmogram (PPG), as a reliable heart rate sensor.

Studies have used devices to measure heart rate for specific purposes. One of them is presented in Rocha *et al.* [Rocha et al. 2015]. They presented a heart rate monitor model. It uses a smartphone to synchronize health care data with the cloud. A similar study was presented by Sannino and De Pietro [Sannino and De Pietro 2011], a solution that monitors patients for a nuclear medicine department. These solutions for generic patient monitoring differ from our solution, mainly on software adaptation from surpass safe limits from heart rate.

Another interesting study, in which the authors create a device is presented in Chigira *et al.* [Chigira et al. 2014]. The authors created a heart rate monitoring through the surface of a drinkware, a glass type drinkware that have PPG sensor to monitor heart rate during beverage consumption. However, this device is not indicated to use during the daily life, because is only connected to the body when the user is drinking something.

Wearable devices were used by specific health care solutions. One example is the study published by Rubin *et al.* [Rubin et al. 2015] that used a chest-worn device that measures heart rate, respiration rate, perspiration and skin temperature. They proposed a system that combines a wearable device with a smartphone to predict and react to approaching panic attacks. The study used one specific wearable device that was created for monitoring patient proposes. Our idea is to use devices that the user already have or can by at many general stores.

Other example is in Phan *et al.* [Phan et al. 2015]. They used a smartphone and a wearable device to measure sleep quality using the heart rate readings and accelerometer readings captured from the smartwatch. A solution that can be compared to our solution, however, it was created for other scenario and cannot be applied on beta-blocked patients.

To summarize, BBAware differs from the other projects because the solution adapts considering beta-blocked patient necessities. Its adapt on the use of sensors to notify doctors, the patient and patient family members that the patient heart rate is out of safety range. The idea is to have a long period monitoring using a wearable and mobile devices that the user already have or is easy to buy, like a smartwatch and a smartphone.

Some studies argues that the best way to monitor cardiac patients is using the electrocardiography (ECG) to evaluate heart rhythm [Crawford et al. 1999]. ECG is in use for decades, and is considered by doctors to be a better and more reliable sensor than the PPG used in BBAware. Popular smartwatches presented on the market does not have ECG sensors, only PPG.

Even with studies defending the use of PPG, as mentioned in this section, it is important to mention that BBAware is not a replacement for traditional ambulatory ECG monitoring solutions. BBAware is an alternative monitoring system that uses sensors that are related to daily life of the patients, reducing the traditional sensors intrusiveness.

3. BBAware Project

This research investigates in which ways mobile and wearable computing tailored with context-aware computing techniques can contribute on beta-blocked patient monitoring. As a motivating scenario, we consider the use of a smartphone and a smartwatch to help monitoring these specific patients.

BBAware is a software suite that unites a wearable application, a mobile application and an application server (web service). The Figure 1 illustrates how these devices are combined. The arrows presented in the figure represents the data flow between the devices.

In the doctor vision, he/she can register a patient using a smartphone, including

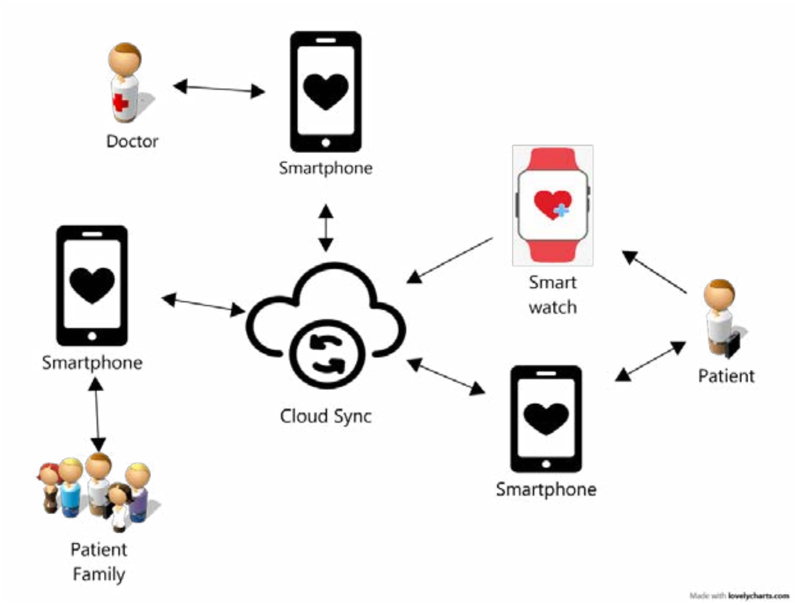

Figure 1. BBAware Overview.

patient safety range of heart rate, and synchronize within the cloud. The cloud presented in Figure 1 is an abstraction of a server application, an application that comprehends a reasoner and a knowledge data base, and a web service. The doctor has a list of patients that he/she is monitoring and can check a log from each patient. This log has data from user heart rate, time (date and hour) and if the patient had some problem, such as nausea, dizziness, and others.

Patient is monitored by smartwatch heart rate sensor. This information is synchronized with the web service. Further, patient and family members can check patient heart rate information on a smartphone application. The application of the patient connect patient with smartwatch device to inform that the data collected by a watch is from that specific patient.

3.1. Context Model and Rule Definition

In order to model a context-aware application, it is necessary to identify entities and contextual elements [Vieira et al. 2011]. The context model of BBAware is presented in Table 1. A contextual element can be static (does not change over time), dynamic (changes over time), explicit (informed by the user) and implicit (obtained without user interaction).

In the BBAware context model, one entity was identified, the patient that is monitored. The focus of this work is 4 contextual elements, maximum heart rate and minimum heart rate (safety limit range for the patient), current heart rate (patient heart rate monitoring), and ”patient condition” (the patient can inform if he/she is feeling sick, dizzy, etc.). The others contextual elements are mapped for future work.

Rules are defined in a knowledge base to help reasoner processing. To define those rules, a tool, called Drools[1], was used. A rule definition is presented in Figure 2, where is possible to see a rule that verify if the maximum heart rate limit was surpassed. If this test

[1] www.drools.org

Table 1. BBAware Context model

Entity	Contextual Element	Static	Dynamic	Explicit	Implicit	Context Source
Patient	Maximum Heart Hate	X		X	X	User profile or default value of 70 bpm
Patient	Minimum Heart Rate	X		X		User profile
Patient	Current Heart Rate		X		X	Heart rate provided by the smartwatch sensor
Patient	Patient Condition		X	X		Patient can inform if is feeling sick, dizzy, nausea, etc.
Patient	Activity		X		X	Data provided by the smartwatch accelerometer sensor, for example: to identify falls
Environment	Time		X		X	Time provided by the smartwatch sensor

rule is true, a notification is sent to the doctor, patient family members, and the patient. Hence, this rule will be invoked for each measured heart rate.

```
rule "Maximum Limit Surpassed"

    when
        p : PatientDataRule(
            heartRate > maximumHeartRateLimit,
            myHeartRate : heartRate )
    then
        p.sendNotification(p.MAXIMUM_LIMIT_SURPASSED);

end
```

Figure 2. BBAware Rule Example.

3.2. Architecture

The BBAware architecture has 3 main parts: a remote server application with a web service for communication, a smartwatch application, and a smartphone application. A better view of these parts is in Figure 3.

The smartwatch application has the Dynamic Context Acquisition module, where current heart rate and time are obtained from the patient. This data is persisted locally inside a log database, until the device connect to internet to synchronize data with the web service.

The smartphone application has two main modules. The Context Acquisition module receive profile information about the patient from the doctor and the Notifier

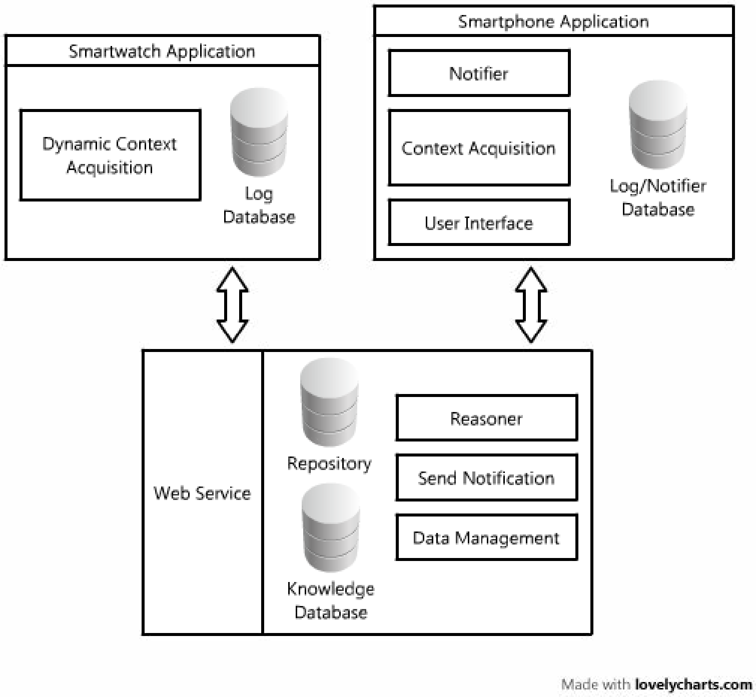

Figure 3. BBAware Architecture.

module that notifies patient, doctor and family members through software adaptation after analysis of patient heart rate and when patient explicit say that is not feeling well.

The server side contain a web service to synchronize data between smartphone and smartwatch applications. Moreover, the processing of the context rules is made by the Reasoner module. A history repository, a knowledge base and a Data Management module is also located at the remote server.

4. Example of Use

In order to illustrate the use of BBAware, this section introduces a scenario of use. Consider a patient, called Robert Smith, that just has had a heart attack. He is recovering and just left the hospital. He is using beta-blockers and he is undergoing therapeutic test. Consider another patient, called Daniel Clark, that had a heart attack several years ago and also uses beta-blockers.

Considering the ideas presented in Diaz *et al.* [Diaz et al. 2005], Fox *et al.* [Fox et al. 2008], and Mathers and Loncar [Mathers and Loncar 2006], Daniel Clark should maintain his heart rate below 70 bpm. Furthermore, his heart rate cannot be too short, or he will feel dizzy, nauseous, etc. To monitor this patient and guarantee that his heart rate is between safety limits, BBAware can be used. If heart rate is out of range, the system will adapt and notify patient family members, the patient, and his doctor. If the doctor deems necessary, he can communicate to the patient and can conduct him for an evaluation.

The other patient, Robert Smith, is undergoing therapeutic test, he is at home resting and is using BBAware to monitor his heart rate. His next evaluation with the doctor is in next week. However, today he felt really dizzy when he went to the toilet and interact using BBAware to tell that he did not feel well. The system will adapt and notify patient family members, the patient, and his doctor. Then anyone can check the moment that the patient interact with BBAware and check his heart rate during that phase. If the doctor deems necessary, he can communicate to the patient and can conduct him for an evaluation and not to wait for next week. Family members can contact the patient to know if patient need help.

At any time, the patient, family members and the doctor can check the patient heart rate associated with the time. An example of Robert Smith heart rate is presented in Figure 4, where is possible to see a list of the patient heart rate and one interaction. The interaction has a different image (exclamation) that can be related to the low heart rate before the interaction (39).

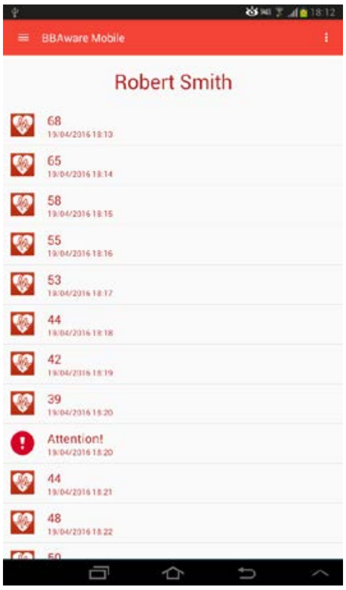

Figure 4. Heart rate list screen inside BBAware mobile application.

Is important to mention that if the doctor have many patient, BBAware could be intrusive, because the mobile application would send him/her many notification about different patients. To avoid this situation BBAware has a notifier module that can be managed by the doctor. Thus, the doctor can choose if he/she want to receive notifications or not, and can choose how many times he/she want to receive them. For example, a doctor can receive notifications once a day.

5. Conclusions and Future Work

This paper presented a smartphone and smartwatch integrated solution for monitoring patients that are under treatment using beta-blockade drugs. For this, it was developed a study on monitoring beta-blocked patients using a smartphone and a smartwatch and it was proposed BBAware, a software suite that unites a wearable application, a mobile application and a remote server application. A context model and architecture was presented to demonstrate our solution.

As ongoing work we are planning the following (i) the execution of an experiment with real patients that are undergoing treatment using beta-blockers; (ii) the evolution and implementation of the modules described for the proposed architecture.

As opportunity for future work we indicate: (i) the use of machine learning techniques to learn, identify, and adapt to harmful changes on patient heart rate; (ii) the use of others contextual elements to identify, for instance, if a patient fell and adapt to this scenario.

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