A UBIQUITOUS MODEL FOR HEART MONITORING BASED ON SITUATION AWARENESS

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ABSTRACT

Patients with heart failure and without daily medical monitoring may have their heart physiological signs compromised, causing them many health problems. This recurring scenario reduces the patient's life quality, resulting in new hospital admissions, thus becoming a cost to the health system. We consider that the use of ubiquitous healthcare, by using sensor and wearables, may improve this process by reducing the number of hospital admissions. In this context, this article proposes a model named UbHeart, which employs situation awareness to identify possible cardiac problems. As a scientific contribution, the model provides monitoring of degradation of the vital signs of the patient's heart through detection of situations of cardiac complications. Health parameters established by the Brazilian Society of Cardiology were used. Thus, the evaluation of UbHeart was made using physiological sings and developed prototype and showed promising results.

KEYWORDS

E-Health, Heartbeat, Blood pressure, Ubiquitous Computing, Situation awareness

1. INTRODUCTION

Readmissions in hospital systems have been significantly increasing in the latest years. Despite the advancements in healthcare for patients with health failure (HF), results after hospitalization are not getting any better (Chaudhry et al. 2013). This pathology is considered one of the main medical challenges of our time (Ukena et al. 2012). Without daily medical monitoring, the patients' physiological signs could be compromised and hospitalization becomes inevitable. This recurring scenario reduces the patient's life quality and results in return to the hospital, thus becoming a cost to the health system.

Factors associated with the increase of the rates of hospital admissions include noncompliance with the medication, failure to seek immediate medical treatment when the symptoms are exacerbated, and self-medication (Anker, 2011). A promising strategy is telemonitoring, which consists in observing the patient's physiological signs so that health care practitioners may intervene earlier in case there is evidence of clinical deterioration (Chaundhry et al. 2013).

The evolution of mobile and ubiquitous computing has favored the development of solutions that use sensors and mobile applications in benefit of human beings. The situation awareness allows to correlate logically aggregated contexts in order to determine a user's involvement in a given more complex scenario (Anagnostopoulos et al. 2007). Particularly, smartphones have significant context detection and user interaction capabilities, which may be explored in order to build powerful applications in the area of health care (Scott et al. 2015). Within this context, the area of ubiquitous health allows to use mobile and ubiquitous computing for monitoring the patient's health anywhere and at any time, with no need for the person to be in a clinic or hospital. The purpose of keeping medical care ubiquitously, which has been called ubiquitous healthcare, is to provide the patients with a convenient service, facilitating diagnosis of clinical conditions (Gelogo et al. 2013).

Considering ubiquitous healthcare, this work is particularly focused on heart failure and proposes a model named UbHeart. First, a previous diagnosis is made by using information acquired through sensors. When a situation of risk is identified, an alert is sent to the patient, also being possible to be communicated to the people responsible for the patient as well as to the hospital, which calls the doctor.

The main scientific contribution of UbHeart is the possibility of recognizing information that may identify possible physiological degradations and combine them in order to characterize a situation of heart risk to the patient. To this moment, no paper that uses situation awareness applied to monitoring of vital signals of patients with heart failure was found. During the research, the study highlighted as important the monitoring of the patient's progress over time and the need for analyzing the sorting order of measurements in order to help the doctor regarding the degree of investigation (Kashem et al. 2008; Mulvaney et al. 2012). Some papers listed point out that the measurements performed by the sensors were associated with the questions that the doctor asked the patient, and color codes informed in the system (Kashem et al. 2008).

This work is divided into five sections. Section 2 describes the related work. Section 3 describes the UbHeart model. Section 4 describes the model implementation. An evaluation based on a case study is presented in section 5. Finally, section 6 presents the conclusions.

2. RELATED WORK

The models analyzed during the study used features of ubiquitous computing and context awareness. The paper describes a model of use of a wireless sensor network to identify measurements and provide indices to analyze tendencies and send possible complication alert to the patient. The measurements of glucose, blood pressure, temperature and breathing were acquired through sensors and sent to the clinic through a mobile device. A communication layer provides transfer of information to the remote doctor and the clinic. The study points out the importance of tendency analysis for monitoring the patient's progress over time and thus determine the patient's situation and may give anticipated alerts of possible complications that might develop.

Kashem et al. (2008) propose a model applied to telemedicine that uses information on weight, blood pressure, and heartbeat, in order to find possible situations of risk to patients. The processing operation is performed on a server and the patient's clinic condition is defined by using measurements that the patients inform manually. The proposed system is divided into three parts: patients, domain providers and server, and it allows the patients to send data directly from the database and receive diagnoses provided by a doctor. Although the paper highlights the relevance of the patient's health situation, the model describes the situation qualification by means of analysis of measurements related to questions the patients are asked during the telephone call made by the nurse.

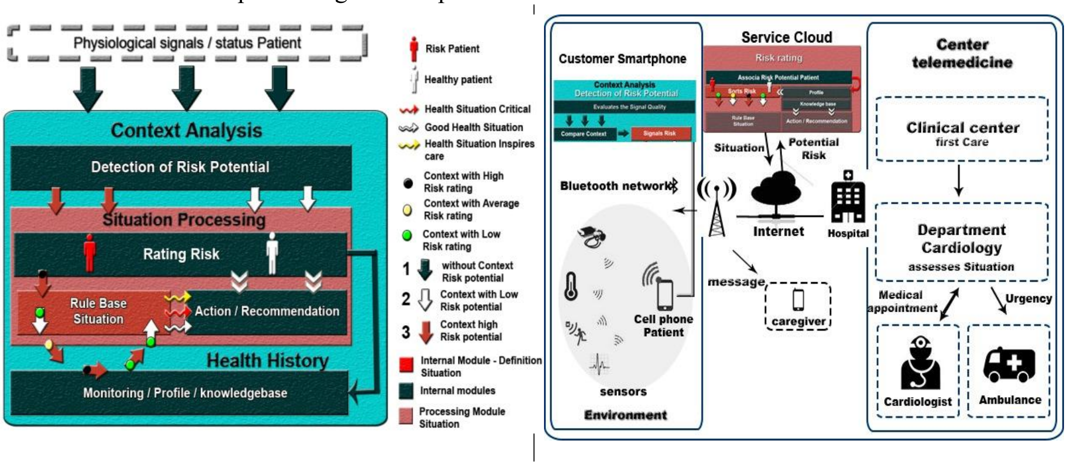
The model proposed by Winkler et al. (2011) allows for the acquisition of physiological signs by using portable medical equipment of electrocardiogram, blood pressure, body weight, and self-assessment measurements that are processed on a remote server. The measurements are classified individually by using a color code and received generating events according to the rules of medical prioritization to initiate a review process guided by workflow in the system and a more detailed assessment by the medical practitioners. The model allows to change the order of visualization of the data processed in the medical center according to its critical level and interaction by the patient, who makes their self-assessment by using a scale of a color code.

The model proposed by Suh (2011) makes an analysis of linear regression, in addition to checking the absence of a necessary piece of information and its integrity, in order to define the patient's health.

In general, the studied models demonstrated that the processing operation and situation analysis were performed asynchronously by the cardiologist physician. They indicated the need for monitoring the vital signs degradation of the patient over time. Furthermore, they showed the need to analyze the order of the measurements. Contexts are analyzed individually without monitoring evolution. The situation analysis applied in this way may hinder quick intervention in order to prevent degradation of the patient's physiological signs. Many false positives may also be generated based on an analysis over isolated contexts.

3. UBHEART MODEL

The proposed model allows monitoring vital signals by using medical equipments, wearables, interconnected through a Bluetooth network, which allow the acquisition of physiological signs in a way that is more convenient to the patient in residential environment, as it can be seen in Figure 1a. The patient's smartphone informs the patient's profile to the system, which through sensors, acquires the physiological signs and builds a health history, which is sent to the hospital through the Internet. The information base sent by the smartphone to a service on the cloud allows the system to analyze the health situation based on a risk classification, relating the patient's profile to the acquired contexts. The health history sent to the hospital allows the physicians responsible for the patient to know how health is in a short period of time, assuring quick assistance and thus preventing new hospitalizations.



(a) (b)

Figure 1. UbHeart proposal: (a) Overview of the general solution; (b) UbHeart architectural model

The clinic center takes the first care measures by passing information to the patient through recommendation made by the system. In case the health condition needs specialized assistance, an appointment with the cardiologist is made, just as, in case it is urgent, an ambulance may be sent to the place. Health changes are informed to the caregiver by cellphone messages. The patient receives several recommendations of how to proceed in order to improve their health indices or how to act to prevent worsening of their health condition upon immediate need. We can notice that the model proposes various features in order to prevent the patient from lacking medical care and prevent their physiological signs to go down to degrading levels, as it can be seen in Figure 1b.

The model of the service running on the patient's smartphone is presented in Figure 2a. The physiological signs and the patient's status are acquired by the system (arrow 1 in the Figure). The Situation Processing component gathers modules for classification of the risk, rules and actions of the system, definition of the health situation, and these are processed by a service on a computational cloud. This service receives the contexts from an analysis made by the module of risk potential detection on the patient's smartphone. This service is responsible for detection of the patient's risk potential. On this service, the model indicates the risk potential based on the context information and the norms of the Brazilian Society of Cardiology[1].

Contexts are acquired based on the patient's physiological signs (arrow 1 in Figure 2a). The *evaluate quality of sign* function checks whether the physiological sign detection was successful or features any abnormality, and in case it does, the sign is disregarded. Once this stage is completed, the context is sent to the *compare context* function, which is responsible for comparing the acquired values with the ones established by the Brazilian Society of Cardiology in issues related to age and pathology.

Each context is compared individually according to the patient's profile at the time it is acquired, and then the *indicate risk* function is activated. In case the context value is out of the one established by the standards, a risk potential is indicated with colors (arrows 2 and 3). It is appropriate to highlight that the identification of potentiality does not determines the risk, but it is exactly extremely important for determining its classification and later the situation, in addition to contributing to modeling the knowledge. This module is based on the context analysis and therefore does not correlate the contexts, but identifies them individually, passing it through to the UbHeart service on the cloud.

The cloud service classifies the patient's risk and is presented on Figure 2b. According to the previous classification of risk potential and the contexts of risk identified, the *associate risk potential with the patient*

[1] http://publicacoes.cardiol.br/2014/diretrizes.asp

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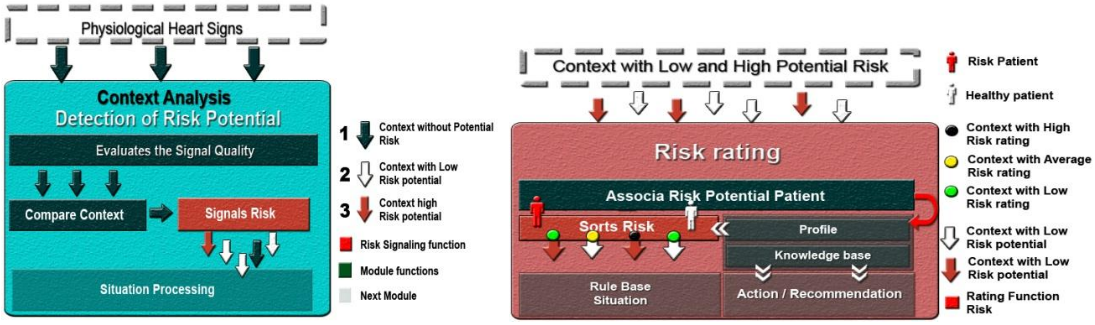
function makes a query to a knowledge base. There are two possible analyses, which are: (i) compare the contexts with risk potential indication and the patient's profile with the knowledge base; in case the patient's profile is not found, (ii) the model actuates the *classify risk* function, which is responsible for classifying the risk, associating it with the guidelines of the Brazilian society of cardiology.



(a) (b)

Figure 2. Risk analysis in UbHeart: (a) Risk Potential Detection Service on smartphone; (b) UbHeart Risk Classification through Situation Awareness

The risk classification is performed in three levels: black, yellow, and green, representing respectively high, medium, and low risk. Then it sends the contexts to the module that analyses the situation based on rules. This module perform actions based on various context associations. The information from the physiological signs identified with risk potential are associated with the contexts of the patient's profile and from the calculations made and the standards determined by the Brazilian Society of Cardiology, it classifies the risk in which the patient may be involved.

We are using rules to enable situation awareness.. The rules are defined according to the determined functions, which are: (i) Degradation – responsible for executing the activities *select the patient's profile* and *check the classification level* of the physiological sign; (ii) Monitoring – Started by an event sent by the rule of degradation, it is responsible for monitoring the evolution of degradation of the patient's vital sign, besides monitoring related contexts, whether from sensors or according to the patient's profile; (iii) Determining of the situation – this rule determines in which situation the patient is, correlating the values acquired by the *track the gradation evolution* rule based on the guidelines of heart care, in a period of time, to the contexts of location and profile. The results may converge into a situation that, although identified with potential and classification of low risk, may represent situations of imminent risk, depending on the location and context of the patient's profile, and vice-versa. The *action rules* are actuated according to the classification of the situation. They may be: (i) No action, in case there is no history for the rule or even because it is not a situation of risk; (ii) Recommend, situation with classification of low risk, it actuates the rule that sends guiding information to the patient's smartphone; (iii) Call caregiver, situations with medium and high classifications, which are reported to the patient's caregiver and finally to the center of telemedicine.

4. IMPLEMENTATION

The development of the prototype involves the implementation of three modules: the module for analysis of risk potential, located on the patient's smartphone, the module for processing the situation, and the module of action rules and inference in the Knowledge Base. We implemented a prototype for mobile devices, in order to make it possible to evaluate representing the contexts, which are used as requirements for situation analysis. We also implemented, in the cloud computing module, the algorithms for processing the situation analysis.

For implementation of the module for analysis of risk potential, the Android system was used with the SQL Lite database. The module of action rules and inference in the knowledge were programmed in Python.

Figure 3 describes the input data, processing and output of the algorithm for situation analysis in variations of hue of the colors gray, red and green, respectively, according to the proximity to the end of the processing operation. In this stage, calculations of standard and index of degradation and compromising rate were made, and they consubstantiated the algorithm decision regarding the degree of the patient's engagement concerning the health situation.

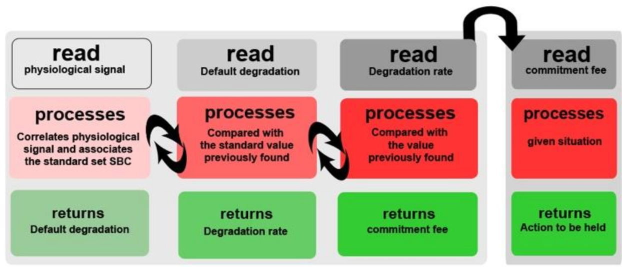


Figure 3. Calculation of the standard, index of degradation and compromising rate

Figure 3 shows the processing of events according to their output: (i) The first processing operation extracts the average difference of the physiological signs with relation to the patient's profile from the ones established by the standards; (ii) The second stage reads the standard value of degradation and compares it with the previous one. The difference between these values may be equal to, less or greater than zero. This stage informs the degradation index, which is responsible for identifying the evolution of degradation of the patient's physiological sign. In case it is greater than zero, it means that clinic deterioration of the patient is occurring; if negative, the patient is getting better over time; (iii) The third stage analyzes the uniformity of the degradation index regarding the occurrences. This stage informs the compromising rate of the patient concerning the situation. It analyzes the index of degradation, so that it does not undergo changes that hinder its uniformity, since the patient who is sensitively improving their index must show negative values, tending to zero. In case their health state is getting worse, they must show positive values or zero, and never alternated values between negative and positive in the analyzed interval.

5. EVALUATION AND DISCUSSION

The scientific community has used scenarios for evaluation of ubiquitous applications and context-aware systems (Satyanarayanan, 2011). From this strategy, a scenario was defined for evaluating UbHeart model. The objective is to evaluate health risk indication. This consisted in checking the operation of the model during analysis of the contexts and situation awareness from a set of physiological signs.

We created a database to represent heartbeats and blood pressure, complying with the measuring intervals established by the Brazilian Society of Cardiology. The simulation methodology by means of a database and development of ubiquitous algorithms is used by the scientific community for heart health applications, which perform context analysis and have been showing satisfactory results (Sarkar, 2011; Landolina, 2012). The database created contained 100 physiological signs obtained from typical values of patients according to their age, varying from 18 to 65. There were modeled heartbeats in the range between 60 and 100. Regarding blood pressure, Table 1 describes the values assumed.

Table 1. Values established for the testing base

Classification	Systolic pressure (mmHg)	Diastolic pressure (mmHg)
Sleep	~110	~70
Optimal	<120	<80
Normal	<130	<85
Limitary	130	85-89
Hypertension stage 1	130-139	90-99
Hypertension stage 2	140-159	100-109

The generic rule was actuated for values out of the ranges established for the heartbeats and the limitary classification for the systolic and diastolic blood pressure described in Table 1. For patients above the age range, specific rules were used based on the normal classification and heartbeat range 60-90. The physiological signs were filled in manually, where the generic and specific rules were actuated for monitoring the patients with features described in Table 2.

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Table 2. Patient with change in physiological signs

Classification	Heartbeat	D/S diastolic / systolic pressure
72-year-old elder	96	15/80
23-year-old youngster	100	14/80

During the monitoring, 100 physiological signs from each context in five intervals were selected, in sequence, where the standard of degradation, index of degradation and compromising rate were calculated, determining the degree of certainty that we assert for involvement of the patient with the situation of risk. A chart of heartbeat, presented in Figure 4, was used to analyse the results. The vertical axis represents the oscillation for heartbeats and blood pressure, and the horizontal axis represents the physiological signs that occurred. The lines in blue show the beginning of the monitoring that occurs when the physiological signs are found outside the acceptable limits.

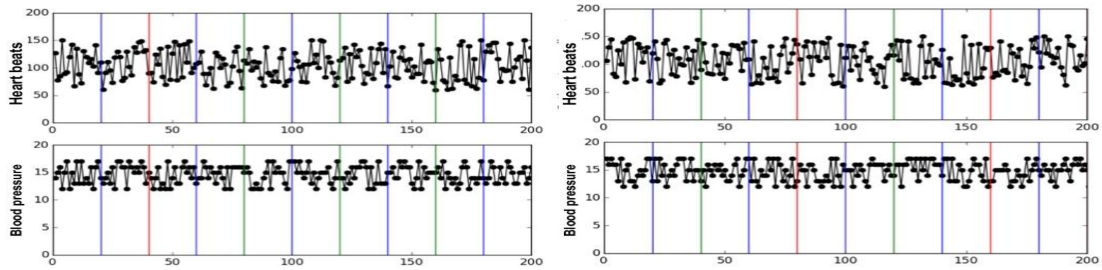

Figure 4. Heartbeat physiological sign and systolic blood pressure of (a) elderly patient and (b) young patient

By making an analysis for the elderly patient in Figure 4a, in the first stage of monitoring of heartbeats and blood pressure, we may notice that although the elder features some physiological signs within the limits established in Table 1, most of the other signs are out of the limit, and this occurrence is determining for the degradation analysis. The chart demonstrates that there is an evolution of the degradation of the physiological signs, whose calculation is made based on the average found, according to the red line in Figure 4a.

Regarding the young patient, the results are different, because the average was below their limit, according to the green line in Figure 4b. Therefore, the values out and within the range have their tendency analyzed and are considered for the calculations of situation analysis. During the monitoring intervals, the physiological signs oscillated, making it difficult for a visual conclusion of the patient's real health situation. After obtaining the average of the values in the interval, it was possible to indicate the health risk. However, the statement of possible health compromising based on the average of the values may not demonstrate the real situation; therefore, it is necessary to calculate the compromising rate of the indication of risk based on all the intervals.

The correlation between the various contexts related to heart health was analyzed associatively, once specific rules were adapted to each patient's profile. Patients with different physical features, which inspired health care, were represented without any difficulty. In practice, an elderly patient features physiological signs with different limits due to their age. Moreover, some of the absolute values of the contexts have representation, as they actuate the monitoring rules.

Nevertheless, the other contexts acquired in the interval must be considered for determining the real health situation, because the lack of a sufficient amount of contexts may compromise the indication of risk. The calculation of the compromising rate accomplishes the comprehension of the acquired physiological signs, logically aggregating them in order to analyze the patient's degree of involvement with the situation of risk based on situation awareness.

5.1 Situation Awareness Evaluation

Two approaches were used for the situation awareness evaluation, and they allowed for more accurate results, without need for other invasive methods of acquisition of physiological signs. The first consists in calculating the compromising rate based on the average of the physiological signs (TxM) found in the intervals. Therefore, we obtained five average values that serve as the basis for calculating degradation for each of them comparing to the one before it. The index of degradation, difference of the degradation found with relation to the previous one, may represent an ascending sequence for evolution of degradation, descending for the patient's improvement, or stable in case none of the previous ones occur. The TxM is calculated based on deduction of 20% for the values of the index of degradation, which does not follow the sequence, since five reference values are used. The second form is to calculate the average of the compromising rates based on the logic (TxL) of the physiological signs found in each interval. The physiological signs were analyzed in the interval and may feature a sequence of ascending values for the evolution of degradation, descending for the patient's improvement, or stable, in case none of the previous ones occurs.

At the end of 20 physiological sings, the compromising rate of the interval was calculated, where each physiological sign that is out of the logical sequence had a discount of 5%. The TxL represents the average of all the rates of the five intervals. In Table 3, the TxM column describes the compromising rate based on the average values of the physiological signs. The variation of the degradation standard (DS) showed an improvement in the patient's clinic condition. In the case of the young patient, results that describe up to the third value to the right were found, discounting only 20% in the case of the value of 4.75, which switches to increase of the degradation. Then we obtained the TxM with value of 8% and so for the other patients, according to Table 3. The values of the column TxL demonstrate a low compromising rate.

Table 3. Average of the physiological signs (TxM) and average of the compromising rates (TxL)

<table>
<tr><th>Patient</th><th>Heartbeats</th><th>Standard (DS)</th><th>Index (ID)</th><th>TxM</th><th>TxL</th></tr>
<tr><td>72-year-old elder</td><td>108.3 /108.9 /97.15 /108.9 /97.1</td><td>10.83 < 10.89 > 7.15 < 10.89 > 7.10</td><td>0.06 | -3.74 | 3.74 | -3.79</td><td>80%</td><td>50%</td></tr>
<tr><td>23-year-old youngster</td><td>115.25 /109.8 / 106.35 104.0 / 104.75</td><td>15.25 > 9.8 > 6.35 > 4.0 < 4.75</td><td>5.45 | 3.45 | 2.35 |-1.75</td><td>80%</td><td>20%</td></tr>
</table>

The occurrence indicates that a significant amount of physiological signs was deducted from the found logic. The analysis demonstrated that despite having an indication of evolution of degradation for the elder and improvement for the youngster, this assertion was not accurate, because some of the acquired physiological signs in the interval compromised the assertion and, therefore, they were deducted. For further analysis, the physiological signs were grouped five times, each group containing 25 physiological signs. Although a physiological sign may show, in insolation, health problems, when analyzed based on the degradation standard, that is, the difference between the one before and the one after it, there is a reconsideration of the isolate analysis, because they are grouped.

The degradation standard demonstrated that the features associated with the physiological sign do not represent imminent risk, as the history associated with the occurrence of the context and the rule generated by the monitoring actuated by this sign will or will not determine the evolution of degradation of the physiological sign. During the evaluation, we observed two perspectives for comprehension of the situation, in order to issue the compromising rate. Both perspectives have distinct possibilities to comprehend the relation between the values of the contexts logically aligned and determine the patient's degree of involvement regarding the health situation. However, the possibility of considering the logical sequence of the physiological signs represented a considerable difference with relation to the average obtained in the intervals.

With these results, we observed that one context does not determine the situation that the patient is in and its absolute value combined with a physiological profile may raise doubts regarding the situation analysis. The UbHeart model considered that a degraded physiological sign may feature low compromising of the patient regarding the health situation, due to the absence of contexts in the very same interval or low health risk, if the degradation standard associated with it decreases. Furthermore, the assertions made by the system regarding health risk were analyzed based on a compromising rate, which by means of the situation awareness determines the degree of reliability of the assertion.