Context-aware Cardiac Monitoring for Early Detection of Heart Diseases

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Abstract

The aim of this paper is to propose a scalable context-aware framework for early detection of several cardiovascular diseases by continuous monitoring using smart sensors and utilizing the strength of cloud computing. By constant sampling of ECG signal, vital signs, and activities our system detects possible symptoms of heart disease and alerts user by delivering context-aware service using flexible output modalities. A non-context-aware system that makes a decision based only on abnormal ECG signal can generate false alerts at high rate. Our proposed solution aims to reduce that rate by bringing different contexts in decision making process. As a proof of concept, we developed a simulated prototype to detect long term health risk of Premature Atrial Contraction (PAC), a common form of cardiac arrhythmia. The system can classify ECG signals as PAC using appropriate feature selection and learning algorithm. By tracking the stored context history and personal profile in the cloud database, our system detects smoking habit, alcohol consumption, caffeine intake of the user. It can also detect activities like stress, hypertension, and anxiety using different physiological parameters of the user and capable of sending situational warning notifications. Thus, this model can be a new mechanism for heart disease detection.

1. Introduction

Cardiovascular disease (CVD) is the most common disease in Australia especially for elderly people which caused 50,000 mortalities in 2008. While the treatment facilities for cardiac arrhythmias [1] are inadequate in most of the underdeveloped and developing countries, even western countries do not have proper technology to detect diseases at early stages. Aged people living alone in home die from CVD more than other members of the population. The death rate can be minimized if the causes of any potential CVD are automatically detected before the patient is in high risk situation.

In recent years various cardiac monitoring systems have been developed for detecting abnormalities in ECG [2, 3].

Most of the systems rely on stand-alone single processing server and analyze data locally. When abnormality is detected in ECG signals the system sends emergency alert to the caregiver for immediate help. So the decision is made upon only heart conditions of the user. There is no system that stores context as medical history and predicts symptoms by looking at the present and the past contexts and activities. But many of the cardiac arrhythmias which look normal from an instant EGC observation can create severe heart diseases due to some long term harmful habits and mental illness. Our context-aware solution targets to detect the occurrence of such situations. Upon discovery of such threatening patterns in context the system suggest patients to control those influencing factors to correct the arrhythmias and avoid severe danger like heart failure.

We picked the example of Premature Atrial Contraction (PAC), which generally occur in a normal heart. PAC can be triggered by alcohol, nicotine, caffeine, anxiety, fatigue, fever, and infectious diseases [1, 4]. In fact, PAC commonly cause no symptoms and can go unrecognized for years. PAC can be dangerous as an early sign of heart failure or an electrolyte imbalance. After occurrence of PAC, the doctor needs to ask patient about the habits and medical history for diagnosis. In addition, medical tests are required to identify the symptoms properly. Continuous context monitoring can eliminate these manual steps and simplify the jobs of health-care professionals. In summary, the advantages of having such system are:

- Many of the elderly patients who are not accompanied by family members can have certain habits or behaviours which may cause serious heart diseases later without their awareness. Our system will help those lonely elderly people by detecting potential cardiac syndromes at initial stage.
- Traditional systems generally lack context-awareness in their design and suffer from higher false alarm rate. Because, often the assumptions based only on ECG abnormality do not hold true. Our proposed system uses context-aware approach for more robust estimation of actual incidents and thus reduces diagnostic delay as well as false alarm rate.
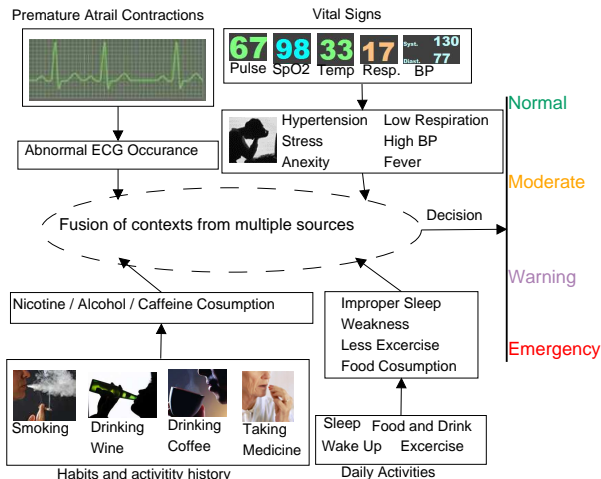- The system will minimize the extra burden on health-

Figure 1. The Generic system architecture of the proposed cloud-based context-aware model

care professionals. They will just define the rules for the symptoms in terms of causes and consequences. They don't need to follow any manual process. The system will automatically detect those causes from context knowledge and will send immediate alerts to the doctors and care-givers.

The rest of this paper is organized as follows: section 2 summaries the architecture of the proposed model. The functional components are presented in Section 3. Section 4 briefly describes the prototype that has been built for evaluating the architecture. Finally, section 5 concludes the work.

2. Architecture

Our proposed cloud-based context-aware model is depicted in Figure 1. The Ambient Assisted Living (AAL) system consists of a target user, body worn sensors (ECG, SpO2, Blood Pressure sensor, accelerometers, etc.), environmental sensors (light, temperature, smoke, etc.), monitoring and communication devices (RFIDs, cameras, speakers, microphone, monitor, etc.), smart phone, and local processing server.

ECG data, sensor data and application data generated in AAL system, and profile data on personal cloud storage are forwarded to Context Aggregator (CA) cloud by local server. Context providers (CPs) collect data from CA, classify raw data to high level context using classification algorithms and send back to CA as context. CA combines all the contexts together in a model and delivers it to the Context Management System (CMS).

CMS stores context history in the cloud repository. It collects service rules from Service Providers (SPs) and looks for anomalous events by rule matching between contexts and services. The service rules are defined by experts such as doctors and emergency service providers. The CMS is properly trained to classify a rule-based situation correctly.

When an anomalous situation is detected the CMS sends appropriate context-aware actions to the user, his/her doctors and, emergency service providers according to the

rules defined for the situation.

3. System functionalities

The primary objective of the system is to recognize probable heart disease from long term observations and provide runtime context-aware actions to help the target user. The amount of information that can be categorized as context is large. The contexts that are captured from a single AAL system can be massive. The smart device is not much resourceful to process and store this huge amount of context. So we selected scalable cloud model for our system. The use of cloud computing escalate the capability of handling versatile contexts. From literature review of existing solutions we assumed the capability of detecting some contexts and activities in our model. As our system keeps track of complex situational context so it requires to sustain following functionalities:

3.1. ECG monitoring

ECG waveforms help to determine many cardiac arrhythmias [5]. An ECG waveform has three basic waves: the P, QRS, and T. When the values of intervals do not fall within the expected ranges, different cardiac abnormalities can be detected. As instance, PAC is the change in heart's normal rhythm sequence caused by an early extra beat originating from the atria. After PAC occurs sinus rhythm usually resumes. The hallmark ECG characteristic of a PAC is a premature P wave with an abnormal configuration when compared with a sinus P wave. The baseline rhythm is irregular here. Therefore, using these basic features an abnormal ECG is detected.

3.2. Vital signs monitoring

Using wearable sensors some vital signs (Figure 2) are measured continuously. These physiological parameters are important measurements to pick up some contexts. Stress [6], anxiety, fever and some other mental and physical illness can be recognized using the observed values of

Figure 2. Decision fusion from multiple observations

these vital signs. This kind of illness has direct impacts on some heart diseases.

3.3. Activity monitoring

Using wearable accelerometer, RFIDs and cameras in combination with ambient sensors and devices (Figure 1) it is possible to identify the daily activities of the patient. As example, using camera and smoke detector the smoking activity can be identified. Using user's e-prescription on personal cloud database and RFID it is easy to detect the medication [7] that user has taken. Moreover, some of the activities can be detected using sequence of primitive activities. Such as, making coffee [8] and drinking it afterwards can be treated as drinking coffee activity (Figure 2).

3.4. Activity logging

To obtain previous context information, each of the activity and related context is stored on cloud repository using time-stamp value. The history log simplifies the task of determining context like sleep and wake up time pattern, average exercise duration etc. (Figure 2). These long term features are the reasons of many diseases. So, such activity logs are useful for anticipating certain symptoms.

3.5. Symptom detection

As mentioned earlier the rules of the symptoms are defined by the experts and stored in service provider's cloud repository. The medical knowledge is necessary to detect any suspicious condition. The rules are also varied among individuals. When an abnormal ECG is detected and classified the CMS picks the rules associated with that arrhythmia. If the context matched with a rule then CMS

considered this as abnormal situation and take appropriate actions to help the user to overcome the problem. Some of the rules are presented Figure 3.

```
if { (PAC is detected in ECG)
     AND (previous PAC occurrence is true)
     AND ( (smoking habit is true)
        OR (drinking coffee habit is true)
        OR (drinking alcohol habit is true)
        OR (stress detection is true))
     AND (has no previous heart disease)
   }
then alertType = Warning /* eliminate taking caffeine/
alcohol/nicotine. Learn stress reduction process */

if { (PAC is detected in ECG)
     AND (previous PAC occurrence is true)
     AND (has previous heart disease)
     AND (any of the vital sign is abnormal)
   }
then alertType = emergency /* send emergency notification to
doctors as such PAC can serve as an early sign of heart failure */
```

Figure 3. Some rules for detecting abnormalities

3.6. Context-aware service action

When any anomaly is detected in the ECG signal as well as in context information, the CMS selects specific services based on the importance of the situation. As in Figure 3, if PAC is detected for a patient who does not have heart disease but have habit of drinking too much coffee the context-aware system can send a warning message to the patient. But, if PAC is detected for a patient having heart disease and with other abnormal vital signs (e.g. High BP) then this is a severe case and immediate emergency alert is send to the doctor.

4. Prototype and results

We have built a small prototype in java which is capable of making context-aware decisions when any anomaly in context is detected. We picked 50 records from MIT-BTH arrhythmia database. Each of the ECG signal is classified based on average length of PR interval, QRS complex, QT interval and RR intervals. So, using these features a PAC signal can be detected [9]. A screen-shot of PAC detection prototype is shown in Figure 4.

We have generated 30 different rules like in Figure 3. Then we have created different patient profiles and randomly generated some contexts for each of the patient. The profile and the rules are stored in remote database. Afterwards, different ECG signal is attached with the profile of the patient. When the total value set matched with a rule, corresponding context-aware action was reported. Some of the observed results are presented in Figure 5. There was no false negative situation which could threaten the condition of the patient being monitored. A non-context-aware system would not able to detect such situations.
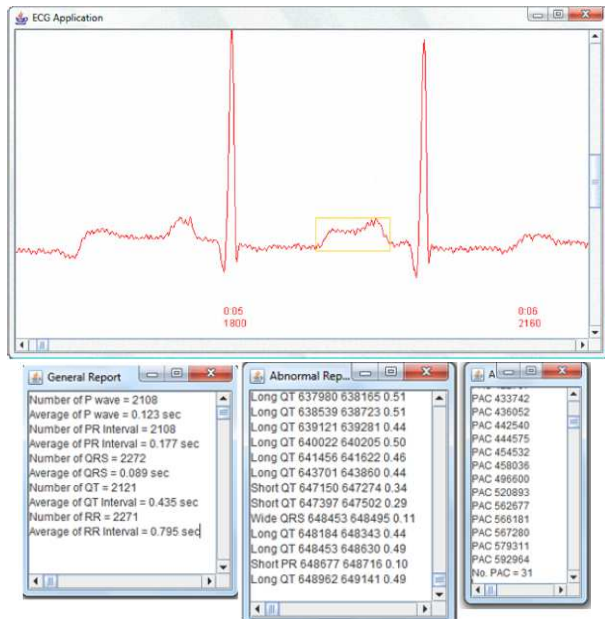
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Figure 4. The screen-shot of java prototype to distinguish between normal sinus rhythm and PAC

ECG	Vital Signs	Heart Disease	Past PAC occurrence	Recognized Habits and Activities	Medicine Taken	Other Signs	Alert Type
Normal	Normal	No	False	Smoking	None	None	None
Normal	High BP	No	False	None	None	None	None
PAC	Low respiration	Yes	True	Drinking coffee, Less Sleep	Taken	Fever	Emergency
Normal	Normal	No	False	None	None	None	None
PAC	High HR	Yes	False	Smoking, Drinking alcohol	Taken	Fever	Moderate
PAC	Normal	No	True	Smoking , Drinking Coffee, Less exercise	Not taken	Stress	Warning
Normal	All Normal	No	True	Drinking Coffee	None	None	Moderate
PAC	Low respiration	Yes	False	None	None	None	Moderate
PAC	High BP	Yes	True	Drinking alcohol	Not taken	Stress	Emergency
PAC	Low SpO$_2$	No	True	Smoking	Taken	None	Warning

Figure 5. Experimental observations

5.   Conclusion

In this paper we have presented a framework that can provide remote monitoring facilities for heart disease detection using context. The system classifies the heart condition of the patient not only based on ECG analysis but also taking into account of different contexts and activities. The proposed system is expected to be useful to detect many cardiac arrhythmias precisely. A small prototype is described as proof of concept for the model. In the future, we plan to develop more modules to support the detection of other arrhythmias which vastly depends on user's context for diagnosis.

Acknowledgments

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