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CONTEXT-AWARE SYSTEM FOR CARDIAC CONDITION MONITORING AND MANAGEMENT: A SURVEY

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Health monitoring assists physicians in the decision-making process, which in turn, improves quality of life. As technology advances, the usage and applications of context-aware systems continue to spread across different areas in patient monitoring and disease management. It provides a platform for healthcare professionals to assess the health status of patients in their care using multiple relevant parameters. In this survey, we consider context-aware systems proposed by researchers for health monitoring and management. More specifically, we investigate different technologies and techniques used for cardiac condition monitoring and management. This paper also propose "mCardiac", an enhanced context-aware decision support system for cardiac condition monitoring and management during rehabilitation.

Keywords: context-awareness, cardiac condition, cardiac rehabilitation, health monitoring

1. Introduction

Patient monitoring plays an essential role in handling critical situations especially for those in remote areas (Shanmathi and Jagannath 2018). It involves the use of digital technologies to monitor the health status of a patient within or outside the hospital environment. These technologies vary from sensors attached to the patient to sensors installed in the patient environment (Malasinghe, Ramzan, and Dahal 2017). Monitoring patients within the clinical area requires the presence of the patient in the hospital, while outpatient monitoring involves the use of wireless communication technologies along with digital sensors to transmit patient details to a server (Nangalia, Prytherch, and Smith 2010). This can be in the near real-time or offline transmission. In real-time transmission, data are sent at the point of acquisition, while in offline transmission, data are sensed and stored, then later transmitted for future analysis. Remote patient monitoring targets different categories of people such as the elderly, chronically ill and disabled patients(Malasinghe, Ramzan, and Dahal 2017).

Cardiac diseases such as arrhythmia, stroke and coronary heart disease (CAD) could possibly be managed by monitoring of patients' physiological signals in real-time. The symptoms of these diseases are diverse, ranging from minor chest palpitations, chest pain, fainting(syncope) to sudden heart attack, depending on the type and severity of the heart disease(WHO 2017). Fortunately, the most recent advances in ECG monitoring and with the help of modern mobile phone technology, monitoring a patient in remote areas has become easier and more accessible. However, it is essential to note that in order to predict abnormalities, a specific vital sign such as heart rate, ECG

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signals may not provide sufficient knowledge to assist physicians in decision-making (Shanmathi and Jagannath 2018). The combination of physiological parameters, environmental information, and patients activities can go a long way in providing a rich platform, that will enable physicians make accurate and timely decisions; thereby, offer a better environment for healthcare delivery services (Zhang, Thurow, and Stoll 2016).

Context-awareness is an important part of systems implemented in areas such as Intelligent Environment, Ambient Intelligence, Pervasive and Ubiquitous Computing (Alegre, Augusto, and Clark 2016). The fundamental idea behind context-awareness in healthcare is to develop a proactive and efficient system, that can correlate patient's contextual information and adapt to the changes in the patient condition and environment (Vashney 2009). A context-aware system is an application that uses contexts to provide vital information or services to the user (Abowd et al. 1999). These contexts could be location, time, identity or activity of the considered subject (Dey 2001). It plays essential role in the healthcare delivery decision-making process and assists physicians to properly and timely monitor patients in their care. Context-aware Decision Support System(DSS) uses context information in problem-solving task to provide service and minimize interaction between computer and human (Chen and Chen 2010). DSS are computer applications developed to assist clinicians in making decisions for patient wellbeing. Such systems range from simple software to complex artificial intelligence applications. It helps in establishing a diagnosis and provides reminder and alert to clinicians when new patterns in a patient's data are discovered (Payne 2000). The most promising applications of this technology in healthcare are for diagnosis of chronic and cardiovascular diseases such as heart disease (Abeledo et al. 2016), Brain disease (Albert et al. 2016), Kidney disease (Ahmad et al. 2017) and Diabetic disease (Kumar, Sharma, and Agarwal 2014), as well as monitoring of the activity of elderly people, using intelligent home monitoring devices (Abeledo et al. 2016; Mighali et al. 2017). It uses context data, in combination with learning algorithms to provide proactive services and highly adaptable context-aware system (Wang and Ahmad 2010).

Due to the increase in cardiac death and the financial burden it imposes on the government (WHO 2017), it is imperative to have a platform that uses modern technologies to correlate multiple vital parameters of a patient to facilitate physicians' decision-making process in cardiac diagnosis and management. In this survey, we consider context-aware systems proposed by researchers for health monitoring and disease management. More specifically, we investigate different techniques and technologies used for cardiac condition monitoring and management. To better understand this study, we formulate the scenario 1 below:
Scenario 1: John is a cardiac disease patient who lives far away from hospital and need to be monitored regularly. In order to assess John's health status, his doctor need a platform that will correlate multiple vital signs from John as he goes about doing his normal activities.

Based on the survey, we propose an enhanced context-aware decision support system (mCardiac) for cardiac condition monitoring and management during rehabilitation. The framework will utilize patient's contextual information to provide a useful tool to physician in order to make better decisions and recommend appropriate treatment mechanism to avoid cardiac readmission or perhaps death. The proposed framework will incorporate recommender module, which is not obtainable in existing context-aware solutions targeting cardiac condition monitoring. It will enable physicians to offer personalised recommendations to the patient under their care based on the contextual analysis. mCardiac is made up of the following features: (i) Context acquisition, (ii) Context modelling and storage (iii) Context analysis and visualization (iv) Personalised recommendation.

The rest of the paper is organised as follows: Section 2 talked about cardiovascular diseases and how it affect the society. Section 3 presented cardiac rehabilitation techniques, enumerating how technology has contributed to the improvement in cardiac rehabilitation process. Section 4 summarised the evolution of health monitoring system using different technologies. Section 5 presented context-aware system, discussing its components, challenges and existing context-aware systems for cardiac condition monitoring. In section 6, we presented a discussion and possible future directions based on the discoveries, and also proposed an enhanced framework for context-aware cardiac condition monitoring and management, while we conclude the study in section 7.

2. Cardiovascular Diseases

Cardiovascular diseases are diseases affecting the heart and blood vessels (WHO 2017). It is usually caused by the accumulation of fat inside the arteries which blocks the flow of blood to the heart (NICEimpact 2018). Figure 1 shows that cardiovascular diseases is the number one cause of death across the globe (Ritchie and Roser 2018). The chart indicates that in the year 2016, about 17.65 million people representing 31% of all global death died as a result of cardiac diseases (Ritchie and Roser 2018) and might increase massively in the future (WHO 2017). Benjamin et al. (2017) reported that about 2,300 Americans die of cardiac disease each day, which is an average of 1 death every 38 seconds. The report also stated that cardiovascular diseases claim more lives each year than all forms of cancer and Chronic Lower Respiratory Disease combined and it cost more than $329.7 billion for both health expenditures and lost productivity. Also, according to British Heart Foundation statistics report, heart and circulatory diseases cause about 28% of all death in the UK, accounting nearly 170,000 deaths each year - an average of 460 people each day or one death every three minutes(Bhf.org.uk 2019). Public Health England also reported that it cost about 7.4 billion every year for healthcare relating to cardiovascular diseases (GOV.UK 2019). As the effect of cardiovascular disease and the financial burden it imposes upon the society continue alarming, Celermajer et al. (2012) pointed out that the major challenges in tackling the burden of cardiovascular disease in developing countries are low budgets for health and the lack of professionals.

Though there are different examples of cardiac diseases, such as cardiac arrhythmias, atherosclerotic disease, and cerebrovascular disease; Celermajer et al. (2012) stated that most of the cardiovascular challenges in the world is due to atherosclerosis. Atherosclerosis is a condition where arteries become blocked with fatty substances called plaques which can result to stroke or heart attack (Stanner 2008). Its symptoms include pain or discomfort in the chest, shortness of breath (Dyspnea), fatigue and nausea. In 2014, Bhatnagar et al. (2015) conducted research and discovered that 46% of cardiovascular disease death in UK is as a result of atherosclerosis. Another cardiac disease that worth looking into is arrhythmia. Cardiac arrhythmia occurs when the electrical impulses that coordinate the heartbeats do not work properly, causing the heart to beat too fast, too slow or irregularly (Stanner 2008). Its symptoms include palpitation, weakness and chest pain.

3. Cardiac Rehabilitation

“Cardiac rehabilitation is the non-pharmacological intervention using any combination of exercise, education or psychological support to restore by their own actions, the patient’s pre-disease or pre-cardiac event physical, psychological and social level of function” (Shepherd 2012). It is the main aspect of secondary prevention of cardiovascular disease (Nguyen and Silva 2016), which assists patients in the recovery process and creates avenue for professionals to frequently assess the health status and offer advice on time to avoid deterioration or perhaps death. It offers training and support that assist patients return to their normal work and activities (Gay, Leijdekkers and Brain 2009). Gimenez et al. (2006) proposed a framework aimed to develop and validate a system for integral community cardiac rehabilitation program based on technological platform for lifestyle change supporting system. The system consists of the following characteristics: personalized cardiac rehabilitation program, automatic support in establishing and modifying care program, risk factor, monitoring access for the patients, intensive cardiac monitoring with automatic alarms, support self-care programs and continuous information of the therapy results. The application acts as

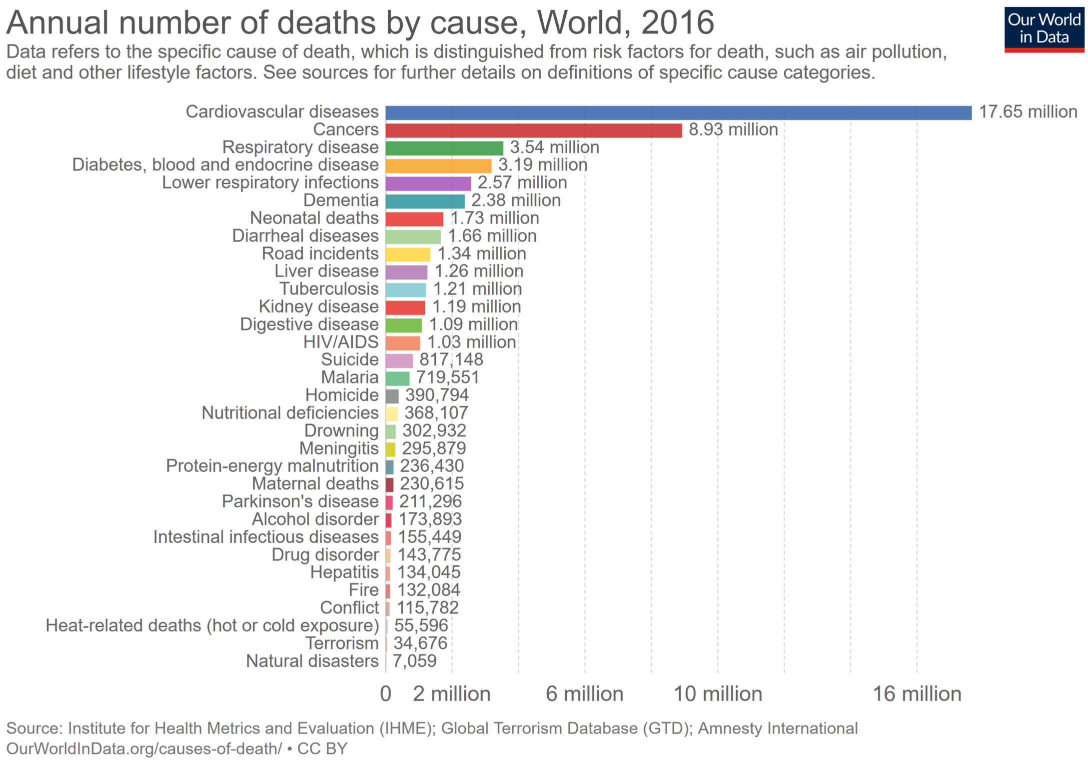


Figure 1. Comparison of annual number of deaths caused by different diseases

a personal trainer of the patient, motivating and guiding during rehabilitation. To validate the system, sensors are placed on the chest of the patient and 6 ECG signals are recorded during the exercise. Alarm warning is triggered when ECG frequency greater than the programmed value is detected, when ectopic activity is detected and when there is increment or decrement of ST segment. ST segment is the part of the ECG from the end of the QRS complex to the beginning of the T wave (Azoz et al. 2018).

Providing a rehabilitation scheme can effectively minimize cardiovascular readmission; however, patients regularly decide not to participate in the centre-based rehabilitation due to lack of motivation, distance to the rehabilitation centre and lack of time for the working class (Medina et al. 2017). To alleviate this challenge, Chatzitofis et al. (2015) proposed home-based rehabilitation system, HeartHealth, an exercise-based rehabilitation platform using gamification techniques. The main function of the system is the ability to record patient movements and compare them against the exercise level prescribed by the medical expert. It consists of two front-end interfaces, the game interface, and Android application. The user-friendly game interface supports the usage of motion capturing sensors, while the Android application is developed to assist the medical professionals in monitoring their patients. The system also has back-end where the motion data and the analysis carried out are stored. Though home-based cardiac rehabilitation approach has been effective, safe and relatively low-cost for patients that are unable to attend centre-based program, tele-rehabilitation was recently introduced to complement traditional means of cardiac rehabilitation (Dickins and Braun 2017). Several authors and medical professionals argued that tele-rehabilitation is the way forward for cardiac condition monitoring during rehabilitation (Melholt et al. 2018; Piotrowicz et al. 2016; Jafni et al. 2017).

Tele-rehabilitation is the use of information and communication technologies to monitor and assess patient during rehabilitation. In this approach, patients are not required to be present at the healthcare center, rather patients are monitored as they perform their normal daily activities.

Advances in technology enable the creation of different forms of technology-based intervention such as imaged based, sensor-based, and virtual reality-based approach (Dickins and Braun 2017). "Using tele-rehabilitation allows for the continuity of cardiac rehabilitation within the patient's own environment while reducing the barriers related to transportation, physical impairment and physical distance from health care facilities" (Dickins and Braun 2017). Kyriacou et al. (2010) proposed web-based remote monitoring system for the smooth cardiac rehabilitation process. The application monitors different biosignals such as ECG, Oxygen saturation, blood pressure and body weight of the patient. Lu et al. (2013) also described CAROLS, a motion-sensing enabled exercise system for cardiac rehabilitation. The system provides an interactive and user-friendly virtual gaming-platform for rehabilitation exercise. The aim of the project is to motivate cardiac patients to improve their exercise level during rehabilitation.

Due to the advancement in mobile technology, coupled with the wide use of mobile phones, researchers also examined the effectiveness of cardiac rehabilitation system using mobile technologies (Antypass and Wangberg 2014; Frederix et al. 2015; Maddison et al. 2015; Worringham, Rojek, and Stewart 2011; Park et al. 2016; Unal et al. 2018). Frederix et al. (2016) presented a "MobileHeart", to support and monitor patient during rehabilitation. MobileHeart is a smartphone-based application that supports and monitor ischemic patients during rehabilitation. The mobile application has the ability to tailor recommendation to individual patient based on the patient's initial clinical condition, pathology, and risk factor profile. Mio Alpha 2 was used to collect heart rate and activity data(Pedometer) and presented in a dashboard for visualization. E-learning module was also integrated into the system to educate patients on how to manage cardiac disease during rehabilitation. Though the system shows effective and useful, the mobile application only displayed details of the generated sensor data and lack knowledge base component to assist physicians in decision-making.

4. Health Monitoring

Patient monitoring at distance can be traced back to 1905 when Dr. Einthoven transmitted electrocardiograms (ECGs) from a hospital to his laboratory by directly connecting immersion electrodes to a remote galvanometer via telephone lines (Meystre 2005). This paved way for other researchers that used modern technologies for patient monitoring. Finkelstein, Cabrera, and Hripcsak (1998), developed a web-based asthma patient monitoring system that uses spirometer to transmit the result of Forced Vital Capacity (FVC) test from the patient's home to a hospital database through standard telephone landline, cellular digital packet data network and wireless RAM mobile network. A real-time diabetic patients monitoring system was also introduced by (Rahman 2017). The application monitors the ketone level of the patient by constantly measuring the breath using gas sensor. Barreto et al. (2014) proposed a system to monitor the environmental temperature, humidity, and location of Alzheimer patients using wearable device. The device sends the acquired patient information to a server and also to a caregiver through a mobile application. The focus of Arshad et al. (2016) and Hu et al. (2018) was on elderly people. Their system monitors sleep pattern, humidity and ambient temperature of the elderly at home. Gjoreski et al. (2014) also developed a system to monitor the elderly at home using ECG and accelerometer sensors. The application is capable of recognising users activities and detecting a fall event.

4.1. *Mobile Patient Monitoring*

Mobile patient monitoring involves the use of mobile computing, wireless communication and network technologies for continuous measurement and analysis of patient physiological signals while the patient is on move (Pawar et al. 2012). This means that the patient is not restricted in a particular domain, rather, he/she is allowed to carry out normal daily activities while being monitored. Patient monitoring approach described in (Finkelstein, Cabrera, and Hripcsak 1998) that transmit signals from a distance is regarded as remote monitoring, but not mobile monitoring, in that during mobile monitoring, patients are allowed to move about. Some good examples of mobile patient monitoring are the applications proposed by (Kumar and Venkatesan 2014; Ramesh, Anand, and Rekha 2012). These systems use mobile phone devices along with wearable sensors to sense, analyse and transmit patient signals while on the move.

4.2. *Cardiac Condition Monitoring*

There are several studies relating to monitoring of cardiac patients. However, most of these studies focus on identifying irregularities in a specific vital sign. A real-time system that transmits patient ECG signals to a mobile phone was proposed by (Kappiarukudil and Ramesh 2010). The system is capable of monitoring cardiac patients, detecting a sudden heart attack, and transmit alert to the patient's doctor or relatives. Bessmeltsev et al. (2015) introduced a prototype for continuous monitoring of cardiac activity using electrocardiography and heart rate. The system is made up of an intelligent sensor data acquisition system, a processing system based on Bluetooth technology and a communicator for transferring data to a medical server. Triantafyllidis et al. (2014) also presented a personalized health monitoring system for heart failure patients. The platform supports activation/deactivation of the system's components by the physicians based on the patient's condition during the monitoring process.

Most of these systems only display the raw data generated from the wearable sensors (Bourouis, Feham, and Bouchachia 2012), while some researchers used the smartphone sensors to display the raw data (Postolache et al. 2011). To complement this approach, Pierleoni et al. (2014) presented android-based heart monitoring system that uses a heart rate monitor data to provide a detailed report about cardiac patient health status, transmit the data to an online database and generate an emergency alert when necessary. They utilized sophisticated algorithms to detect stress states, classify arrhythmia events and also compute the amount of consumed calories in real time. Their goal was to implement an accurate, simple and inexpensive health monitoring system for patients with heart disease and for the elderly. The evaluation of the system proved its effectiveness, however, using only single parameter of the considered patient might not provide enough knowledge to the clinician in order to make appropriate decisions (Shanmathi and Jagannath 2018).

5. Context-Awareness

In this section, we consider what context and context-aware system represent in healthcare, discussing its components, applications and challenges.

5.1. *Context and Context-aware System*

Context is a concept used in different areas, and people understand it in different ways within Computer Science, and other disciplines that relate to Computer Science (Augusto et al. 2017). Several authors such as (Schilit and Theimer 1994; Abowd et al. 1999; Bazire and Brézillon 2005) have tried to define context and context-awareness. However, there is no consensus on the definition so far (Alegre, Augusto, and Clark 2016). The most adopted definition over the years is by Dey (2001), which state that "a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the users' task. While "context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves".

We define "context" *as the information which is directly relevant to characterize a situation of interest to the stakeholders of a system*, while "Context-awareness" *is the ability of a system to use contextual information in order to tailor its services so that they are more useful to the stakeholders because they directly relate to their preferences and needs.*

The main difference between Dey (2001) and our definition is that Dey (2001) emphasized more about the system and data, while we look at context and context-awareness from the stakeholder point of view. Context can be categorized into primary and secondary context (Perera et al. 2014). Primary context is any information relevant to the stakeholder retrieved without using any existing context, while secondary context is relevant information derived from the primary context (Temdee and Prasad 2018). For instance, location data from GPS sensor is primary context while calculating distance covered by fusion of location data is secondary context. Context-aware applications are enhancing interaction between human and systems in areas such as industry (Imtiaz et al. 2014), transportation (Binjammaz, Al-Bayatti, and Al-Hargan 2016) security (Park, Han, and Chung 2007), business (Zhao and Mafuz 2015) and healthcare (Bricon-Souf and Newman 2007), as well as smart home (Li, Suna, and Hua 2012). These systems provide a platforms for timely and better decision-making process for the user. There are different application domain of context-awareness (Yürür et al. 2016). However, the focus of this survey is in healthcare targeting cardiac condition monitoring and management.

5.2. *Components of Context-Aware System*

In this section, we briefly discuss different components of context-aware system, which was presented as the life cycle in (Alegre, Augusto, and Clark 2016) and (Perera et al. 2014).

- Context acquisition: This component is responsible for sensing of contextual data from sensors. Context acquisition techniques vary based on context source, frequency, sensor type, acquisition process, responsibility and frequency (Perera et al. 2014). Vashney (2009) presented three types of context acquisition which include sensed context, derived context and context explicitly provided. Sensed context is acquired through physical or software sensor such as pressure, temperature, lighting, and noise level. Derived context can be computed from primary contexts such as distance, time and date. While example of context explicitly provided is user's preferences, "when explicitly communicated by the user to the requesting application".
- Context modelling: Here, the sensed data is represented in an efficient and structured format for retrieval. Context modelling is defined by Sezer, Dogdu and Ozbayoglu (2018) as the "context representation that provides assistance in the understanding of properties, relationship and details of context".
- Context Reasoning: This component involves gaining knowledge from the context data. Researchers applied different techniques such as supervised and unsupervised learning methods in order to discover hidden information from the represented context.
- Content distribution: The context information is distributed to the consumers at this stage (Alegre, Augusto, and Clark 2016).

5.3. *Context-Awareness in Healthcare*

Contextual information could be used to enhance the quality of services in healthcare delivery and utilize human and healthcare resources efficiently during health monitoring (Vashney 2009). The fusion of patient's medical history, environmental information, health status, and physiological parameters can provide an improvement in medical services and assist physicians in the decision-making process (Zhang, Thurow, and Stoll 2016). Context-awareness is an important part of systems implemented in areas such as Intelligent Environment, Ambient Intelligence, Pervasive and Ubiquitous Computing (Alegre, Augusto, and Clark 2016). The fundamental idea behind context awareness in healthcare is to develop a proactive and efficient system that can adapt to the changes in the patient condition and environment (Vashney 2009). This system uses multiple vital signs of the patient to provide useful and accurate information to the physicians.

A context-aware system in healthcare could be regarded as a system that uses patient context details to provide useful information or services to clinicians, patient or relatives. Context-awareness has been successfully applied to healthcare in the areas of patient monitoring, elderly monitoring, disease diagnosis and treatment and accident and emergency situations (Skov and Høegh 2006; Bardram 2004; Jansen and Deklerck 2006; Mitchell et al. 2000). Several authors have proposed context-aware systems in the healthcare domain. Examples of these systems are a context-aware system (MobileWard) aimed to support nurses in conducting morning procedures in the hospital ward (Skov and Høegh 2006) and an intelligent context-aware system (OcarePlatform) developed to support independent living (De Backere et al. 2017). Fallahzadeh, Ma, and Ghasemzadeh (2017) also proposed low-power context-aware system for continuous assessment of Edema patients in a remote environment. The application keeps track of changes around the patient ankle as well as the body posture. Kramer, Covaci, and Augusto (2015) in their project- POSEIDON, proposed a context-aware system to assist people with down's syndrome to navigate their route without relatives or carer support. The aim of the project is to support people with down's syndrome to be more engaged in society through education, work, and socialization.

Due to the importance of security and privacy in context-aware system, Motta and Furuie (2003) proposed a contextual role-based access control authorization model to enhance patient privacy and data protection. The platform controls the user's access to electronic patient record based on the role set by the organization. It uses context data such as environmental information, user/patients relationship to decide whether to authorize a user to access patient record. Quinde, Khan, and Augusto (2018) proposed personalised context-aware solution for asthma disease management. Due to different triggers and symptoms experienced by asthma patient as a result of the high heterogeneity level of the disease, the approach allow users to set the indicators they want to track based on characteristics of their asthma. The aim of personalization is to present the right treatment and/or services to the considered patient (Chondamrongkul 2017).

5.4. *Current context-aware solutions for cardiac condition monitoring*

Recently, some authors proposed context-aware system for cardiac patient monitoring, however, research in this area is still in infancy and need significant improvement. Li, Berry, and Hayes (2009) developed a system that record biosignal of the patients and request for context information when there is abnormality. The patient has to input information about his/her daily life activities. So this system is not fully automatic since it requires user's intervention. The focus of Forkan and Hu (2016) was in the older adult, they developed a cloud-based system that extracts health parameters from Fitbit device and ECG sensors. The context information of the patient is sent via social media to the patient's doctor, relative or friends when there is abnormal changes. Kakria, Tripathi, and Kitipawang (2015), also developed a real-time heart monitoring framework using wearable sensors and smartphones to detect underlying heart condition. The system has two interfaces: one for the patient and the second interface for the doctor. The patient's platform consists of wearable sensors that generate medical data and transmit to Android based listening port using Bluetooth technology and subsequently transferred to the web server which process the data and display results on the doctor's platform. The system uses multiple parameters which include heart rate, blood pressure, and body temperature of the patient. The framework also incorporated alarming features that generate an alarm when there are abnormalities based on the programmed threshold values. Forkan, Khalil, and Tari (2013), proposed a cloud-based framework for early detection of cardiovascular diseases using smart sensors. The system is capable of detecting symptoms of heart disease, store patient's context history and send alert to users when there is abnormality. Using the stored context history and personal profile, the system can detect smoking habit, caffeine intake, alcohol consumption of the user and activities such as stress, anxiety, and hypertension using different parameters from the patient. Sannino and De Pietro (2011), introduced "intelligent mobile system based on rule decision support system for cardiac patients". The system correlates data from the ECG sensor with physical activities such as walking, running and body posture. They used threshold rule to determine the activity of the patient and argued that testing the system with 15 healthy persons proved the effectiveness of the proposed approach. Kunnath et al. (2013) also used threshold approach to detect different activities (Lying, Standing, Walking, Jogging) for cardiac disease monitoring and achieved classification accuracy of 94%. Though the approach shows effective; However, using threshold rule to determine the activity of the user might not be the best option because of the wide range of physical activities, coupled with the disparity in how a specific activity is to be performed. Another similar solution was presented by Miao et al. (2015), they combined the ECG signals with physical activities for cardiac disease diagnosis.

5.5. *Challenges of Context-Awareness*

In this section, we examine the challenges of context-aware system with respect to mobile devices. As technology advances, researchers design and implement context-aware applications for mobile devices such as smartphones, tablets, and smartwatches. Example of context-aware application for mobile device is a mobile application that can dynamically adjust their behaviour to suit the condition of the user at a particular time or location (Bricon-Souf and Newman 2007). For instance, a smartphone application which can automatically put mobile phone in silent when the user is driving or a smartphone application that can detect the activity of cardiac patient while monitoring the heart rate are regarded as context-aware system. There are so many challenges when it comes to context-awareness and mobile monitoring of patient. These include: Sensing context data, energy efficiency of smartphone, storing context information, security and privacy, and presenting context information in the small space of the smartphone. We elaborate on some of the challenges faced by researchers when implementing context-aware system for mobile devices (Yürür et al. 2016; Nalepa, Kutt, and Bobek 2019).

- Context acquisition: context-aware system development starts with the acquisition of contextual information. Context is a vast concept that involves all possible parameter to handle a situation. There are many categories of context that can be generated through sensors embedded in mobile devices; however, identifying relevant context while developing mobile applications and frameworks might sometimes require an expert in the domain and finding professionals especially in healthcare can be costly.
- Energy efficiency: developing context-aware applications for mobile devices is a challenging task due to the limited battery capacity of the devices. Context-aware system involves continuous sensing of contextual information in real time and requires a lot of energy to function effectively. Even though advances in technology have improved the battery capacity of mobile devices, it is not suitable for several context-aware applications (Yürür et al. 2016).
- Security and Privacy: context provides information that helps us to better understand a situation (Perera et al. 2014), however, it increases the security and privacy challenges of mobile applications due to the possibility of improper handling of contextual information. Context-aware applications targeting mobile devices could give a feeling that the user is being monitored all the time (Yürür et al. 2016). Therefore, security and privacy of users need to be addressed at every stage of the mobile application development process.

- Mobile device screen size: using the small size of mobile device to display contextual information in order to facilitate decision-making processing is a major challenge in developing mobile health(mHealth) application (Quinde and Khan 2018). “Mobile phones have small screens and this makes it difficult to fit all the data and information into them” (Kaur and Haghighi 2016). It is essential to seek a method by which the relevant contextual information of the entity will fit into the small size of the mobile phone.

6. Discussion and Future Direction

In this section, we aim to analyse state-of-the-art techniques and technologies for implementing context-aware system for cardiac condition monitoring, and compare the existing architectures with our proposed system “mCardiac”. Also discussed in this section is the future direction of this research.

6.1. *Discussion of the Existing Systems*

This section explore some of the methods and technologies used for cardiac condition monitoring and also highlighted possible areas of improvement. This will serve as a guide for future research regarding cardiac condition monitoring. Our discussion is based on the following areas:

Parameters for health monitoring: There are different parameters such as heart rate, activity data, Blood pressure and ECG signals which can be considered when monitoring a patient. These parameters can assist physicians in decision-making and create avenue for proper monitoring and recommendations. Due to several symptoms of cardiac diseases, there is no consensus on parameters to monitor cardiac condition. As indicated in table 1, researchers used different parameters for cardiac condition monitoring. Only in (Sannino and De Pietro 2011) that involved cardiologists stated the reasons behind choosing those parameters. Considering the limited battery capacity of mobile devices, and given that patients monitoring involves continuous context acquisition from sensors, a context-aware system for cardiac monitoring should consider minimal number of possible parameters without putting the subject in danger. Furthermore, it is essential to state that different patients might suffer different kinds of cardiac conditions, it worth considering personalizing context-aware system for patient monitoring in order to effectively monitor the subject based on his/her symptoms. For instance, a cardiac patient with high blood pressure might require that his/her blood pressure monitored alongside with other parameters, while the elderly patient might require that fall event is considered when choosing parameters for the subject. Tables 1 present different research on context-aware system and parameters used for cardiac condition monitoring.

Table 1. Different parameters used for context-aware cardiac disease monitoring(HR=Heart Rate, Temp= Temperature, MP=Medical Profile, AD=Activity Data, PS=body posture, OS= Oxygen Saturation,BP= Blood Pressure, Cal=calories)

Reference	HR	ECG	Temp	Time	BP	MP	PS	AD	OS	Cal
Li et al. (2009)	✓	✓	x	x	x	x	x	✓	x	x
Kunnath et al.(2013)	x	✓	x	x	x	x	x	✓	x	x
Forkan et al. (2013)	x	✓	x	x	✓	✓	x	✓	✓	x
Forkan and Hu (2016)	x	✓	✓	x	x	x	x	✓	x	✓
Sannino and De Pietro (2011)	✓	x	✓	✓	x	x	✓	✓	x	x
Maio et al. (2015)	x	✓	x	x	x	x	x	✓	x	x

Activity recognition: Recognising human activities such as walking and running or human-related actions aims to observe and understand what type of activities or routines performed by the subject at time-interval (Yürür et al. 2016). From table 1, all the researchers adopted physical activity recognition as part of the parameters for developing context-aware system for cardiac patient monitoring. This indicates the importance of physical activity data during cardiac monitoring and disease management process. Due to the significance of this parameter, serious attention should be given to the process of acquiring, processing and classification of different activities when monitoring cardiac patients. Forkan and Hu (2016) used Fitbit device to collect activity details of the user for cardiac condition monitoring. This device could only recognize steps of the subject and cannot show specific activity performed such as walking, running and sitting. There was improvement in (Sannino and De Pietro 2011) as the system is intended to recognize specific activity, however, applying threshold method to detect different activities might impose serious issues, as there are wide-range of physical activities, coupled with the disparity in how a particular activity is to be carried out. To complement this approach, Miao et al. (2015) applied machine learning techniques to recognize human activities. Machine learning provides computation methods and learning mechanism for developing a model to predict a situation based on the ground truth. Miao et al. (2015) recruited seven healthy persons who wore ECG sensor on their chest and carried smartphones in their pocket to collect sensor data. Each subject was asked to perform three different activities (Running, Rest and Walking). The sensor data from the seven participants were aggregated, processed and used to train J48 decision tree algorithms in order to predict the activity of the users when new data without ground truth are fed into the model. The experiment recorded an overall classification accuracy of 97.7%, which is reasonable for implementing real-time activity recognition. The work could be expanded in order to recognise more activities such as walking downstairs, walking upstairs. The machine learning algorithms are used with the default values set by WEKA software; other software such as Python and MATLAB, which allows the developer to adjust hyper-parameter values could be used in order to have more effective result. Some authors argued that personalised activity recognition is more effective as the sensor data collected from the user will be used to train the algorithm and detect his/her activities (Lockhart and Weiss 2014). There are a lot of issues regarding activity recognition such as location sensitivity, activity complexity, energy and resource constrains (Su, Tong, and Ji 2017), however, none of these research considered them in their implementation process.

Energy efficiency: Due to the limited battery capacity of mobile devices, energy management is a serious issue that need to be considered when developing context-aware system. From the survey, an approach that could handle this challenge is the context-aware system presented by Li, Berry, and Hayes (2009). The system only request for the activity of the patient when abnormality is detected in the patient's biosginals. For instance, if the heart rate of the cardiac patient is above the average normal heart rate, the system should request for the activity of the patient at that time, if the activity is a vigorous activity such as running, the system might choose not to send alarm, but record such incident. However, when the heart rate is below average and the patient activity is running, then sending alarm become necessary. Though the system shows effective and energy efficient, patient has to input information about his/her daily life activities. So this system is not fully automatic since it requires user's intervention. The approach can be improved by automatically collecting physical activity of the patient using sensors attached to the person or the environment. Kramer, Augusto, and Clark (2014) in their research argued that another means of preserving power of the monitoring device is by creating a system that is self-aware and adaptive. Yürür et al. (2016) also pointed out that reducing the amount of data to be processed or transferred by applying adaptive sampling, data compression, and network coding could discard unnecessary information during sensing, hence minimising the energy consumption of the device.

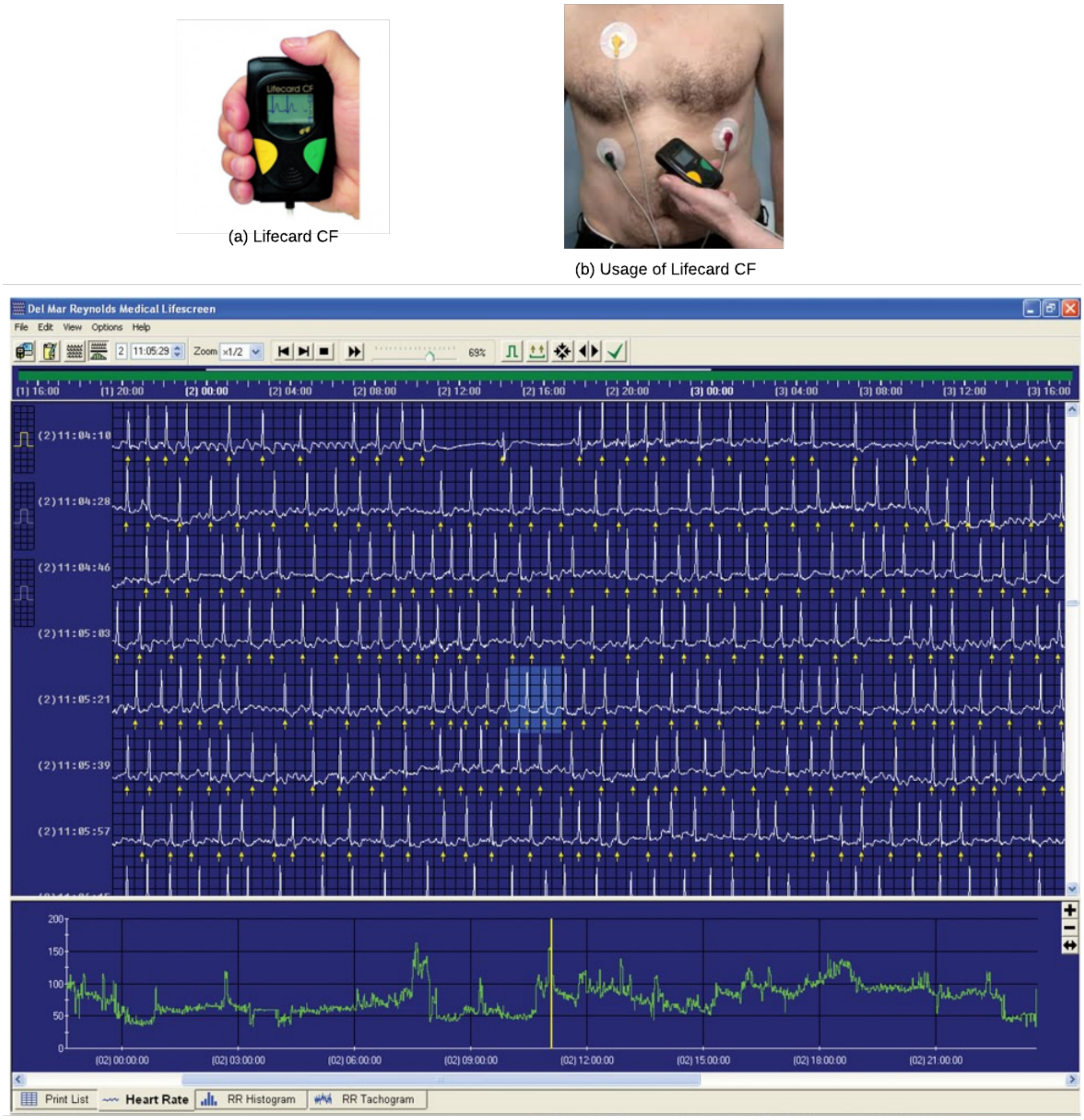
Health Monitoring Devices: As technology advances, modern smartphones and wearable devices are contributing immensely in the healthcare delivery process by assisting doctors and healthcare professionals to monitor patients at distance. Sensors embedded in these devices could be used to collect and aggregate a large amount of data from patient's biosignals, and analysed to assist doctors in decision-making. Several devices such as Fitbit, Mio Alpha 2 and Lifecard CF are available in the market for health monitoring. These gadgets range from portable, wearable to implantable tools. The most regularly used tool for cardiac condition monitoring is the Holter monitor. Holter monitor is a portable and continuous monitoring device used to generate and record ECG signals (Mittal, Movsowitz, and Steinberg 2011). Some of the modern Holter monitors allow users to wear the device while doing their normal activities and are capable of transmitting user's details to the physicians through mobile phones. Forkan and Hu (2016) proposed context-aware architecture that uses ECG sensor and FitBit to generate parameters to monitor older adult that lives alone and suffering cardiac disease. Sannino and De Pietro (2011) used Alive Heart Monitor(KardiaMobile), ECG sensor and accelerometer sensor to collect and aggregate different parameters for heart disease monitoring. Frederix et al. (2016) in their research used Mio Alpha 2 to collect user's details in order to monitor and support ischemic patients during rehabilitation. Some researchers such as (Miao et al. 2015), and (Kunnath et al. 2013), used smartphones to collect accelerometer data for activity recognition during the monitoring process. The raw accelerometer data were processed and used to train machine learning algorithms for human activity detection. In table 2, we summarised different features of the available devices in the market for health monitoring. Among the monitoring devices listed in table 2, Lifecard CF offers the advantage that it is capable of detecting Atrial fibrillation, heart attack, and heart disease while recording the ECG signals. However, none of these gadgets could provide a platform that generate contextual information, process, analyse and offer personalised recommendation to cardiac patient during rehabilitation. Figure 2 shows the (a) picture of Lifecard CF, (b) usages of Lifecard CF and (c) graphical representation of the ECG signals from the device.

Table 2. Features of Health Monitoring tools

Monitoring Device	**Features**
LifeCard CF	- Built in ECG display for monitoring ECG data. - Ability to mark when it detects Atrial and ventricular pacing spike. - Built in voice recording feature which can be used to identify patient. - Ability to diagnose complex arrhythmias.
KardiaMobile	- Captures a medical-grade ECG in just 30-seconds. - Detect Atrial Fibrillation, Bradycardia or Tachycardia. - Can record weight and blood pressure of the user.
Apple Watch	- Ability to detect atrial fibrillation and sent a notification to the user. - Activity tracking and built in GPS for location tracking.
FitBit	- Ability to detect heart rate, record steps, calories, and distance. - Sleep tracking feature.
QardioCore	- Continuous Wireless ECG recording. - Monitors heart rate and heart rate variability, - Record skin temperature, respiratory rate and, activity tracking.
Mio Alpha 2	- Ability to monitor heart rate, - Record activities including steps, calories, and distance.

6.2. *Research Direction*

From the literature, context-aware system is a promising research area in healthcare, especially for cardiac patient monitoring. However, the survey shows that existing context-aware solutions lack some important features and requires significant improvement. For instance, existing context-aware architecture for cardiac condition monitoring does not allow healthcare professionals to offer recommendations to patient during the monitoring process. Again, most of the existing context-aware solutions for cardiac condition monitoring basically target disease detection and diagnosis, none of the researchers that proposed context-aware system regarding cardiac condition monitoring considered monitoring patient during rehabilitation process. Therefore, an efficient and effective decision support framework is required to correlate multiple vital signs such as heart rate, ECG signals and physical activities of the considered patient during rehabilitation. The platform will process and analyse the context data and enable the physician to offer personalized recommendations to the



(a) Lifecard CF

(b) Usage of Lifecard CF

(c) ECG signals from Lifecard CF

Figure 2. Lifecard CF gadget, the usage and graphical representation of the ECG signals

patient. The recommendation can be in form of text or auditory format (McNaull et al. 2014) and tailored to their specific needs and conditions. This will enable the subject to identify and solve any health issue relating to their behaviour or activities without visiting the hospital.

6.2.1. Proposed Context-Aware System

To improve the existing context-ware solutions for cardiac condition monitoring, we propose an enhanced context-aware decision support system, mCardiac , for cardiac condition monitoring and management during rehabilitation. The framework will incorporate a platform that will enable clinicians make personalised recommendations based on the outcome of contextual analysis, and the patient will be able to see the recommendations and adjust accordingly without visiting the hospital. To illustrate the importance of the proposed solution, we consider a physician in need of mCardiac in scenario 2 below.

Scenario 2: *Mike was recently discharged from the hospital after suffering cardiac disease. In order to avoid cardiac readmission, his physician, Dr. Charles need to keep in touch with him frequently. Mike lives far away from the hospital, therefore creating a barrier for constant visit to the hospital. To constantly monitor Mike's health status and offer personalised recommendations, Dr. Charles need a platform that will generate and correlate Mike's physiological signals and activity data from distance. The platform will enable Mike see his physician's recommendations and adjust accordingly without visiting the hospital.*

The proposed architecture in figure 3 is made up of the following features: (i) Context acquisition, (ii) Context modelling and storage (iii) Context analysis and visualization and (iv) Personalised recommendation. During the monitoring process, the subject will be required to carry smartphone running android app for data collection. Android is selected for this research due to wide use of Android phones around the world. The android app will collect and aggregate huge amount of data from sensors attached to the user, this form the context acquisition unit. Then, at the modelling and storage stage, the acquired contexts will be presented in an efficient and structured format and stored in a database for retrieval; while at the context reasoning and visualisation stage, relevant features will be extracted from the context data and fed into machine learning algorithms. Also at this stage, the outcome of the analysis will be presented as a decision support tool using mobile and web technologies. Finally, the healthcare professionals will be able to offer personalised recommendations to the patient based on the contextual analysis. These recommendations could be in the form of text or auditory format advising patient to increase or minimise the level of physical activities. In this research, DSS and mobile application will be developed, the mobile application will collect and aggregate a huge amount of multiple vital signs from ECG and activity recognition sensors, while the DSS will train the up-to-date records and provide better data understanding for early abnormality detection, pattern discovery and personalized recommendations.

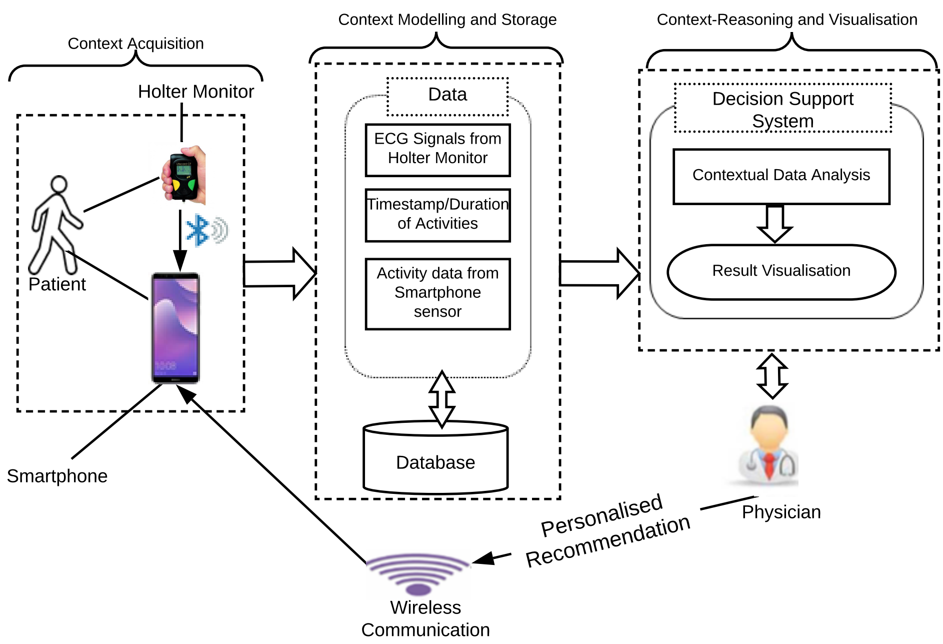


Figure 3. Proposed context-aware system architecture

In order to gain more insight from Mike's contextual information, we aim to utilize the power of machine learning for analysis and knowledge discovery using Mike's contextual information. This will assist Dr. Charles in the decision-making process and offer a better platform for healthcare delivery services. Machine Learning assist in providing computational techniques and learning algorithms for gaining knowledge from data. Most of the machine learning techniques fall into one of two learning tasks: supervised and unsupervised learning. Supervised learning task the machine to learn from data when we specify a ground truth (Harrington, 2012). In this case, the processed data are fed into algorithms, the algorithms learn from observations and make a prediction based on the class label. Such data could be sensor, image or historical information. In unsupervised learning, the algorithm observes the input variable and try to discover pattern. Here, there is no ground truth, rather the algorithm defines the correlations and relationships by analysing input variables.

The proposed "mCardiac" is ongoing research targeting cardiac rehabilitation monitoring using context-aware approach. The research involves data collection from ECG and smartphone sensors, machine learning algorithm training for activity recognition and pattern discovery, and finally, implementation of a decision support system using mobile and web technologies. The system will provide an interface for effective communication to the monitored patient. During the monitoring process, the subject will be required to carry a smartphone running android app for data collection and Holter monitor for ECG signals recording. The context information from these devices will be aggregated, analyzed and visualized for early abnormality detection, pattern discovery and personalized recommendations. A number of machine learning techniques will be considered for the analysis, ranging from K-means, DBSCAN, K-Nearest Neighbour while emphases will be given to discovering of underlying patterns among the context data. These patterns will be used as a guide for decision-making, problem-solving and personalized recommendations.

The research will provide a rich pattern discovery approach with the corresponding time-of-the-day information, that will enable the healthcare professional to understand the daily activity pattern of the subject, the change in daily behaviour, change in physiological information and its effects on the recovering process. It will enable the physician to understand time spent on each activity on a daily or weekly bases and the implication of such in the patients' health condition. This kind of analysis will also be useful to compare and understand the differences in the behaviour pattern of groups of cardiac patients. The proposed system will consider some of the gaps discussed in section 6.1 to present effective, robust and energy-efficient decision support system for cardiac rehabilitation monitoring. The study will consider the following core research questions:

a. How can we extract useful information from context data of cardiac patient? Is there any hidden relationship among the contextual data that reveals some specific pattern to physicians for effective decision-making?

b. How can we develop a decision support system for effective cardiac patient monitoring using machine learning techniques, wireless communication, mobile and web technologies?

For effective cardiac rehabilitation monitoring, the finalised system will incorporate personalized recommendation module to communicate to the monitored patient regarding his/her health status. Different kinds of recommendation approaches exits ranging from providing a simple user interface to using machine learning techniques. By providing a user interface, the healthcare professional study the outcome of the analysis of the contexts and offer personalized recommendations to the patient; while in the machine learning approach, the system learns from itself and provides the right advice to the subject. The recommendations can be in the form of a text or auditory format and tailored to the patient's specific needs and conditions. The aim of the recommendation is to continue to engage the patient in order to adjust or change behaviour and maintain the change. We formulated the scenario 3 below to explain the proposed framework in a real working environment.

Scenario 3: *Mike was recently discharged from Hendon Medical Center after suffering from Coronary Heart Disease(CHD). In order to avoid cardiac readmission, his physician, Dr. Charles needs to keep in touch with him regularly. However, Mike lives about 20 miles from the hospital, there-*

fore creating a barrier for a constant visit to the hospital. In order to frequently monitor Mike's health status and offer a personalised recommendations, Dr. Charles needs a platform that will generate and correlate Mike's physiological signals and activity details from distance. To carry out this exercise, Mike has to wear Holter monitor to record ECG signals and smartphone to record his daily activities. To assist Dr. Charles to monitor Mike's health status and offer personalised recommendations, mCardiac will collect, aggregate and process Mike's contextual information and present as a decision support tool. The outcome of the analysis will help Dr. Charles in providing personalised recommendations to Mike and he (Mike) will be able to view the recommendations through his mobile phone and adjust accordingly without visiting the hospital.

6.2.2. Comparison of the existing context-aware systems and mCardiac

Table 3 presents different reasons for cardiac condition monitoring. However, most of these research are for detection and diagnosis of cardiac condition, for instance, Miao et al. (2015) was for diagnosis of arrhythmias, while Forkan et al. (2015) was for detection of heart disease using contextual information. None of the researchers considered cardiac condition monitoring and management during rehabilitation. Rehabilitation process offers training and support that enable patients to recover and return to their normal activities (Gay, Leijdekkers and Brain 2009). During this process, patients are assessed based on the exercise level performed. Some patient requires vigorous exercise, while some might need minor exercise in order to restore the person back and avoid cardiac readmission (Heart Foundation 2004). In this case, the healthcare professional prescribes the kind of physical activities the patient needs to perform and monitor him/her based on the recommended exercise level. Some authors such as Kunnath et al. (2013), and Miao et al. (2015) used machine learning technique in their research to classify the activity of the user. Existing architecture for cardiac condition monitoring can greatly assist in patient monitoring. However, from the literature, existing context-aware architectures for cardiac condition monitoring does not consider the recommendation component, which our proposed approach incorporated in the design. mCardiac facilitates communication between the healthcare professionals and patients under their care. This approach can also be used in other wellbeing and lifestyle improvement systems. Table 4 summarize the comparison of mCardiac and existing context-aware system for cardiac condition monitoring.

Table 3. Purpose of monitoring cardiac condition using context-aware systems

References	Purpose
Li et al. (2009)	Request context information when arrhythmia condition occurs.
Forkan and Hu (2016)	To monitor older adult suffering cardiac disease and live alone.
Forkan et al.(2013)	Detection of heart disease using contextual information.
Kunnath et al. (2013)	To monitor people with cardiac diseases and live in rural areas
Sannino and De Pietro (2011)	To enhance the accuracy of reporting dangerous HRV.
Maio et al. (2015)	Diagnosis of arrhythmias.

7. Conclusions

Advances in technology have made it possible for healthcare professionals to monitor patients at a distance using different contextual information. The fusion of patient contextual information such as medical history, environmental information, and physiological parameters can provide an improvement in medical services and assist physicians in the decision-making process. In this survey, we considered different techniques and technologies used to implement context-aware systems for health monitoring and disease management. More specifically, we studied context-aware systems relating to cardiac condition monitoring and management. The analysis of state-of-

Table 4. Comparison of mCardiac and Existing Systems

Reference	Cardiac Rehab.	Context-Aware Approach	Machine Learning Approach	Mobile Tech. Used	Personalised Recommend.
Li et al. (2009)	x	✓	x	✓	x
Sannino and De Pietro (2011)	x	✓	x	✓	x
Forkan et al. (2013)	x	✓	x	x	x
Kunnath et al. (2013)	x	✓	✓	✓	x
Maio et al. (2015)	x	✓	✓	✓	x
Forkan and Hu (2016)	x	✓	x	x	x
mCardiac	✓	✓	✓	✓	✓

the-art technology reveals that research on cardiac condition monitoring is still in infancy and requires significant improvement. Furthermore, we proposed "mCardiac" to enhance the existing architectures for cardiac condition monitoring and management. mCardiac is a context-aware solution that facilitate communication between physicians and the patients under their care. It provides an interface that enables healthcare professionals to offer personalised recommendation after contextual analysis. The study also highlighted several challenges faced by developers when implementing context-aware system for health monitoring. **In future, the work will design and implement the proposed mCardiac to demonstrate the results of the research.**

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