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Survey on Context-Aware Healthcare Systems

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***Abstract*—Smart healthcare has promoted E-healthcare to a higher level in which healthcare and treatment services are ubiquitously and intelligently offered to users. Context-awareness is an important feature in smart healthcare systems that firstly deals with extracting current contextual information of users including patients, doctors, and nurses. Afterwards, by being aware of current context and situation of users, smart healthcare systems are able to provide autonomous and intelligent services to them. Due to the importance of this subject, several context-aware healthcare systems have been proposed in various aspects of healthcare and treatment; however, to our best knowledge not any survey paper has investigated and reviewed them. In this regards, this paper studies context-aware healthcare systems from four central viewpoints including environment, service type, context type and context source. The aim is to technically discuss and classify context-aware healthcare systems, to identify the advancements and shortcomings, and to illuminate the route for future research directions in this area.**

Keywords—***Smart healthcare, Pervasive healthcare, Context-awareness, Service, Survey.***

I. Introduction

Healthcare is the science and methodology of preventing diseases and improving user's physical, mental, and social well-being [1]. Treatment describes all activities that are performed in order to restore the previous state of health after suffering physical or mental illnesses [2]. Healthcare systems are important due to their relevance to the life of individuals. According to the World Health Organization (WHO), electronic healthcare means leveraging information and communication technologies in order to connect healthcare service providers, patients, and governments to each other. The aim is to educate and inform healthcare specialists, to manage healthcare systems, and to improve healthcare services [3].

Advancements in ICT (such as IoT) make it possible to find smarter healthcare solutions [4]. With the advent of ubiquitous computing [5] as well as related technologies, including body sensors and wireless communications, the domain of pervasive healthcare has enabled the remote health monitoring of patients [6-8]. Pervasive healthcare has various advantages, including automatically collecting data and early detecting patient's symptoms which reduce the costs of healthcare and treatment. Pervasive healthcare systems are based on smart environments and context-aware systems. Smart environments are equipped with various sensors for collecting background data [9, 10].

Several survey studies have investigated healthcare systems from particular aspects, like sensor energy consumption [11], reporting and sharing health data [12], privacy protection [13-15], security [16], and network [17]. Context-awareness plays a vital role in healthcare management systems [18] and causes the services to be provided in accordance with the users' situation. In the past, a preliminary survey investigated the basic concepts of context and context-awareness in the domain of healthcare [19]. In recent years, context-awareness has seen much growth and many research studies related to context-awareness have been conducted in the domain of healthcare. Therefore, the current paper investigates context-aware healthcare systems according to various parameters. In this regard, a two-dimensional classification framework for pervasive healthcare is proposed, which includes parameters of environment type, service type, context data type, and the context data source. Then, from a technical perspective, the pervasive healthcare systems are investigated and classified.

The rest of the paper is organized as follows: In section 2, the available research in this domain are introduced and discussed according to environment type and service type. Then, in section 3, they are reviewed according to the perspective of context-awareness. Finally, section 4 concludes the paper and discusses the future research directions.

II. Overview

In this section, research studies in the domain of context-aware healthcare system are discussed from a general point of view, including environment type and service type.

A. Environment type

The environment type parameter shows the environmental characteristics for which the system has been developed. From this viewpoint, the available research can be classified into the following categories:

Home: These systems are specific to providing healthcare services in the smart house environment of the patient. In the EWS [20] and CARA [21, 22], the vitals of the patient are monitored at home. In the DTM [23], the individual uses a personal electronic device, which measures and saves the amount of blood glucose from the home environment.

Hospital: These projects are specific to providing treatment services in the smart hospital environment. In this regard, PHS [24], MPHASIS [25], and JADE-PH [26] provide smart services (like detection of the patient fall from bed using sensors embedded in the patient's room) in the smart hospital environment.

Hybrid: These systems provide healthcare services in a hybrid environment including hospital and home, such that, the individual can manage the health information at both the hospital and home environments by using a variety of healthcare services. In this regard, the CHI [27] system provides the ability to monitor the health records using a cloud-based platform. Also, the EWS [20] project can be used in both hospital and home environments for monitoring the vitals of a patient.

Mobile: In the most systems, smart services are provided using the users' mobile phones regardless of their location. For instance, the IMHS [28] system helps diabetic patients to be always aware of their blood glucose situation. Similarly, IPM [29] pervasively measures the heartbeat count of individuals, and in case of detecting emergencies, warns them. Finally, in the PCAS [30] and UHMS [31], an individual is able to register and record his health records using a smartphone or any computer with an internet connection. The common feature of the systems of this group is that they provide basic and elementary healthcare services because they may not rely on smart places with high-level infrastructure.

Table1 shows the general specifications of the relevant context-aware healthcare systems, including project name, country, publication type, and the environment type.

TABLE I. OVERVIEW OF RELATED RESEARCH

Name & Reference	Location	Publication	Environment
RHM [32]	Canada , China	Journal	Mobile
CWBAN [33]	China, Canada Saudi Arabia	Journal	Mobile
UHS [34]	China	Journals	Mobile
COMMODITY [35]	England	Journal	Mobile
DTM [23]	Spain	Journal	Home
MPHASIS [25]	USA	Journal	Hospital
PHS [24]	Greece	Journal	Hospital
Dementia [36]	Brazil , Portugal	conference	Mobile
PHM [37]	Taiwan	Journal	Mobile
JADE-PH [26]	Taiwan	Journal	Hospital
PHA [38]	Japan	conference	Mobile
MDR [39]	Portugal	conference	Home
CHI [27]	England	conference	Hybrid
CARA [21, 22]	Ireland	conference	Home
MDP [40]	Australia	conference	Mobile
IOTC [41, 42]	Greece	conference	Mobile
VSM [43]	China, Singapore	conference	Hybrid
UDP [44]	China	conference	Mobile
MSH [45]	UAE	conference	Mobile
EWS [20]	Italy	conference	Home
eWall [46]	USA	Journal	Home
CEA [47]	USA	Journal	Mobile
IPM [29]	Germany	Journal	Mobile
CBFPD [48]	USA, Bangladesh Saudi Arabia	Journal	Mobile
SPS [49]	USA	conference	Mobile
PCAS [30]	India	conference	Mobile
IMHS [28]	Taiwan	Journal	Mobile
UHMS [31]	USA	Journal	Mobile
CCPS [50]	Saudi Arabia	Journal	Mobile
TSSW [51]	Japan	Journal	Mobile
DICPer-Health [52]	India	book chapter	Home
Eye-Movement [53]	Iran	conference	Mobile

B. *Type of service*

In the healthcare domain, a variety of systems provide different services to users. In this subsection, available systems are reviewed according to the service type they provide to the user. From this point of view, previous research can be classified into the following general categories (table 2):

Monitoring: Promoting a healthy lifestyle by providing a continuous patient monitoring service is an advantage of pervasive healthcare [54, 55]. This service includes monitoring of vital signs, behavior, and daily activities as well as continuous health condition assessment. Generally, ongoing remote monitoring of patients is seen as an efficient solution, which reduces the workload of nurses, patients, and their families [56]. The majority of healthcare systems provide this type of service since monitoring is the foundation of healthcare services. As an example, the MSH [45] project helps the elderly to live lonely at their houses, while under continuous monitoring. The CARA [21, 22] system carries out remote patient monitoring and continuously measures the vital signs of the elderly using wearables sensors and shares them with the doctor through the internet. The IOTC [41, 42] project, after collecting information like the user's blood pressure and pulse, sends this information to the cloud to be monitored by the doctor. The MPHASIS [25] project uses smartphones and sensors embedded in the Masimo Rad-9 [57] device to measure and monitor hemoglobin, perfusion index, and pulse count.

Emergency management: One of the main requirements of the treatment domain is the management of emergencies, which, in fact, shows the manner in which the system encounters emergencies. Some projects of the monitoring domain also manage emergencies after detecting their occurrence. For example in the RHM [32] project, if the server detects the user to be in an emergency situation, it activates a defined approach and contacts an emergency center to dispatch a doctor for patient's rescue. In the MSH [45] project, the online data and the history of patient information are processed. If any doubts are raised about the health situation of the user, an alert will be sent (through SMS) to the related caregivers. Also, in the COMMODITY [35] project, when glucose measurements reach critical levels, the system will alert the doctor.

Assisted living: This type of service helps patients and the elderly to be able to live alone and provides them with the facilities of individual residence [56]. In this regard, the PHA [38] system helps users manage their own health and continuously improve their lives. For instance, it guides a user who does not consume vegetables to a stage where they consume 400 grams of vegetables in a day. The Dementia [36] project helps patients with dementia to live without a nurse at home by continuously receiving necessary care. In the MDR [39] project, sensors that are placed in wheelchairs, walkers, or walking sticks, monitor the pulse or physical activities of the elderly and provide necessary recommendations in case of emergencies. Finally, the eye pupil movement of patients suffering from Amyotrophic Lateral Sclerosis (ALS), who are unable to communicate with others due to paralysis, can be recognized using the Eye-Movement [53] system. Therefore, they can type whatever they want by pupil movements via a user interface.

Medical assistance: This type of service consults the patient about their illness and helps them in the process of treatment. In this regard, through analysis of previous patients' data, the RHM [32] system provides new patients that use the same medication with feedback. The DTM [23] project helps diabetic patients in using a personal device to control their blood glucose. To this end, it advises the patients about their next meal and insulin injection through a personal diabetes management device. The aim of the UDP [44] project is to approximate the user's depression level using EEG signals. Hence, it recommends a song from among those favored by the user (which the user sets manually), to prevent acute depression.

Pervasive access to health information: One of the needs of the healthcare domain is to maintain records related to illnesses, and other current and previous health information of patients and enabling other actors, like doctors and nurses, to be able to access those records. As an example, in the CWBAN [33] project the patient's health related information together with their ID is saved in the private cloud. If necessary, doctors can have access to this information. The eWall [46] project exploits a cloud that stores all the medical information and daily activities of the elderly, which are collected through monitoring. This information is accessible anywhere and at any time using the internet. Also in the PCAS [30] project, which is designed for finding the nearest specialist according to the needs of the patient, the information of the patient is saved in the cloud through a request. Therefore, the doctor accepts or rejects the patient after seeing their situation.

TABLE II. PROJECTS CLASSIFICATION BASED ON TYPE OF SERVICE PROVIDED

Project name	Monitoring	Emergency management	Assisted living	Medical assistance	Pervasive access to health information
RHM	✓	✓		✓	✓
CWBAN	✓	✓			✓
UHS	✓				✓
COMMODITY	✓	✓		✓	✓
DTM	✓		✓	✓	✓
MPHASIS	✓	✓			✓
PHS	✓			✓	
DEMENTA	✓	✓	✓	✓	✓
DHM	✓				✓
JADE-PH	✓	✓		✓	✓
PHA				✓	
MDR	✓		✓		
Chi	✓				✓
CARA	✓	✓			
MDP	✓				
IOTC	✓	✓			
VSM	✓				
UDP				✓	
MSH	✓	✓			
UHMS	✓			✓	
eWALL	✓				✓
ImHS	✓	✓			
SPS	✓	✓			
IPM-mHealth	✓				
PCAS				✓	✓
EWS	✓				
CEA	✓				
CBFPD	✓	✓			
CCPS	✓	✓			
TSSW	✓				
Eye Movement	✓				
DICPer-Health	✓				✓

III. Context-Awareness: Project Review

The most important characteristic of pervasive healthcare systems is the matter of context-awareness. In fact, context-awareness is an important cause of these systems to be intelligent. The level of intelligence for the service provided depends heavily on the kind of context information used and its method of collection. In this section, a review of the previous research according to context-awareness is carried out. In this regard, these systems are investigated from the viewpoint of the type of contextual information used and the source of this information.

A. *Context type*

Previously, several classification schemes for contextual information in the general domain have been proposed [58, 59]. Because of unique characteristics of the healthcare domain, they are not applicable to it. With regards to the features of healthcare, it is proposed to classify context into the three main categories, which are elaborated in the following.

User medical context: This category of information shows the vital and physiological signs of the user. This class constitutes the most important contextual information of the healthcare domain and all the reviewed projects make use of it. Results show that blood pressure, pulse, and body temperature are the most used medical context elements, and have been used in most of the projects. In addition, in the DTM [23] project, the glucose level is used to monitor and help treat diabetic patients at home. Also in the CEA [47] project, the body volume is used to detect swelling inside the patient's body, in the UDP [44] project, signals received from the user's brain are used to determine the degree of depression, and in the CBFPD [48] project, the sonic signals of the user are used for diagnosis of Parkinson disease. Additionally, in the MPHASIS [25] project, the number of breaths and the level of blood oxygen are used in treatment of patients in emergencies. Finally, in the eWall [46] project, visible parameters like the state of the body, the vocal condition, and the facial expression are used to help the elderly in their solitary life.

User non-medical context: This class of contextual information describes the patient's situation, but they are non-medical. In this regard, the location and activity of the user are the most used non-medical context in the investigated projects. For example, in the CWBAN [33], the location of the user is used for observing and tracking the elderly outside of home. In the COMMODITY [35], the patient's activities are used for monitoring and prevention of activities contrary to treatment. Also in the CEA [47] project, the sleep time, sitting time, and standing up time of the individual is used for diagnosis of normal swelling. In the UHMS [31], the wake up time, time taken for having breakfast, and time of exercise are used for providing medical consultancy to the user. Finally, in the IMHS [28], the characteristics of patients and their caregivers are used for their identification. Besides, the caregivers' permit is used for accreditation of the individual responsible for looking after the patient.

Environmental context: These context elements describe the environment of the user. In the studied projects, this type of contextual information is mostly used for helping the elderly individuals in their solitary lives. For instance, in the MSH [45] project, the weather temperature, and in the eWall [46] project, the noise level of the environment and the quality of air are used in order to create a comfortable environment for the elderly to live in alone. Similarly, in the EWS [20] project, the level of light, temperature, and the humidity of the environment are used in order to create an environment appropriate for accelerating the treatment of patients.

B. *Context source*

In the domain of healthcare, context elements can be extracted from particular sources according to their nature. In general, the context sources of the investigated systems fall into five categories, which are elaborated in the following (table 3):

Mobile, wearable & body sensors: These sensors are part of a user's mobile devices or are positioned on parts of body; and therefore, always accompany the user. Nearly all of the projects receive parts of their contextual needs in this manner. Besides, all of the wearable sensors sense user medical context. The GPS is the most used sensor of this category. Regarding this, the PCAS [30] project uses the GPS in mobile phones to detect the user's current location and find the nearest doctor. In the UHMS [31] project, an arm wrapped device is used for finding out the level of blood pressure. In the DTM [23] project, the amount of blood glucose in a diabetic individual is measured using a personal diabetes management device. In the IPM-mHealth [29] project, a seatbelt-like sensor is placed on the individual's body to continually measure the heartbeat rate. Afterwards, using Bluetooth, it transmits this data to the application installed on the individual's mobile phone.

In the UDP [44] project, brain's signals are sensed by a device similar to a headphone, and then the depression level of the individual is processed. The SPS [50] project uses a sensor positioned in the frame of a wristwatch for measuring blood pressure and calculating the blood circulation speed in the internal carotid artery and major brain vessels. In the EWS [20] project, a device called Bioharness [60] is used for data collection. This device includes a wearable sensor pack for the chest, which collects heartbeat rate, breath count, and body temperature. A pulse oximeter [61] is also used for measuring blood oxygen saturation.

Static infrastructure: Smart spaces play a major role in the realization of ubiquitous computing. These sites are outfitted with various sensors. Also in the pervasive healthcare domain, environmental sensors have been mainly used to gather information like air temperature, humidity, and brightness in order to look after the users. For example, in the EWS [20] project, a DHT11 [62] sensor, which senses the temperature and humidity, as well as a photocell, which measures the environment light, are used. In the RHM [32] project, using a camera installed in the home of the elderly person, his movements are registered and sent to the doctor in order to take care of him (for instance, in the event of his fall). In the CARA [21, 22] project, which serves a similar purpose to RHM [32], Flash Media Live [63] and a webcam are simultaneously used to send a photo of the elderly person.

User interface: A noticeable part of the contextual information is directly and explicitly entered into the systems by the user. For example, in the CHI [27] project, the nurse measures the patient's blood pressure, and using a user interface, uploads it to the cloud. In the PHS [24] project, the user explicitly provides the symptoms like dizziness, nausea and chest pain to the system. Also, the beginning and end time of activities like shopping, driving, and exercising are directly inserted into the system using a mobile phone. Finally in the JADE-PH [26] project, through an interface the user registers the contextual elements like blood pressure and heartbeat rate to the system for the doctor review.

Web and cloud services: Web and cloud have been used as a platform for communication, as a source for computation, and also as a persistent memory [64]. In this regard, in the IOTC [41, 42] project, the data collected from different sensors is imported to the cloud for storage and distribution. As a result, doctors can retrieve this information at any time. Similarly, in the CWBAN [33] project, the cloud is used as a persistent memory for maintaining patient's information so that the corresponding doctor has quick access to the patient's records and is able to make appropriate decisions in case of emergencies.

Reasoning: Some of the contextual information cannot be sensed directly, but can be inferred from lower-level context elements [65]. For example, in the eWall [46] project, the occurrence of cooking incidents and the quality of the elderly sleep are inferred by intelligent decision support system using information collected from gas sensors and bed sensors, respectively. Furthermore, in the SPS [50] project, information from different sensors like blood pressure and blood flow in the carotid artery are sent to a module responsible for inference. This module infers the threat level of a stroke using the principles of the Bayesian network.

TABLE III. CONTEXT SOURCES EXPLOITED IN THE PREVIOUS RESEARCH

Project	Wearable & mobile sensors	Static infrastructure	User interface	Web & cloud services	Reasoning
RHM	✓	✓		✓	✓
CWBAN	✓			✓	
UHS	✓			✓	
COMMODITY	✓		✓	✓	
DTM	✓			✓	
MPHASIS	✓	✓		✓	
PHS	✓		✓	✓	
DEMENTA	✓	✓		✓	
DHM	✓	✓	✓		
JADE-PH	✓		✓		
PHA	✓	✓	✓		✓
MDR	✓				
Chi			✓	✓	
CARA	✓	✓		✓	✓
MDP	✓				
IOTC	✓			✓	
VSM	✓				
UDP	✓				
MSH	✓	✓			✓
UHMS	✓		✓		
eWALL	✓	✓	✓	✓	✓
ImHS	✓		✓	✓	
SPS	✓		✓		✓
IPM-mHealth	✓				
PCAS			✓	✓	✓
EWS	✓	✓			
CEA	✓				
CBFPD	✓		✓	✓	
CCPS	✓			✓	✓
TSSW	✓		✓	✓	
DICPer-Health	✓				
EyeMovement			✓		✓

IV. Conclusion

In this paper, the context-aware systems of the healthcare domain have been investigated according to the parameters of environment type, service type, context type, and context source. The results show that many systems still manually receive the vital signs of the user, which is far from the realization of invisibility in ubiquitous computing. Also, only a few number of systems receive their contextual information from static infrastructure. This matter emphasizes the lack of smart places, which are the specific infrastructure of ubiquitous computing. As a result, there is still a long way to the realization of pervasive healthcare.

The first step in healthcare is the matter of patient monitoring. Good works have been performed toward this objective, and nearly all the systems accomplish it. The most complex branch of healthcare is assisted living, which only a very small number of projects have focused on. Also, a few number of systems have used inference. As a result, the services provided are far away from those expected from smart diagnosis systems in the healthcare domain. Finally, with regards to monitoring, the user's behavior and activity have a significant effect on their condition, which is ignored in almost all of the existing systems, because obtaining the activity and behavior of the user requires various embedded sensors and complex artificial intelligence algorithms.

Considering that healthcare is a critical domain, the quality of contextual information and inference algorithms is especially important in this domain. False contextual values that can be a result of faulty sensors or inference algorithms can result in irrecoverable consequences. Furthermore, premature, late, or incorrect treatments can lead to irredeemable effects or at least spoil user's trust to the system. Assessing the quality of context and service are considered to be important challenges of this domain that are rarely paid attention to.

Finally, the patient's living environment has a major effect on the acceleration of his treatment process, but a small quantity of studies has exploited environmental contextual information. In this regard, hospital infections can considerably increase the time of hospitalization, and this matter can be minimized with remote patient checkups. In a higher level, the system should also be able to control and manage environmental conditions in order to help with everyday life or treatment. To this end, the Internet of Things is used in a variety of medical fields including remote patient care, diagnosis, management of emergencies, and caring for the elderly.

Considering the high number of requests and the execution of computational-intensive inference algorithms, constantly monitoring and serving patients require robust servers. In this regard, cloud computing can provide the adequate infrastructure for the healthcare of a population and conceal the underlying technical complexities and details from developers. Cloud is also able to collect and aggregate data more easily and with lower costs, so that developers can implement healthcare systems with simplicity. On the other hand, many of the services in this domain are either interactive or real-time, where the cloud has limitations. For this purpose, Fog and Edge computing are beneficial; as they include a large network of computational and storage resources and are also able to execute real-time or interactive applications.

Even though many healthcare applications exist and introduced daily, the focus has been limited toward a few categories of illnesses like heart disease and diabetes, as well as particular contextual information, like blood pressure and heart beat. In order to realize the objectives of Pervasive Healthcare, research and development efforts for new types of diseases by leveraging more comprehensive contextual information are necessary.

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