Cyber Physical Systems and Smart Homes in Healthcare: Current State and Challenges

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Abstract—Cyber Physical Systems is an emerging paradigm which has gained particular attention in research and development. CPS has transformed the way we interact with the physical world by introducing smart communication between the physical world and its cyber components. As the requirements of today are increasing, a diverse range of applications has made its way in the healthcare domain. This paper provides a survey of noteworthy applications in the healthcare area, particularly smart homes, including state-of-the-art applications for medication intake systems and medical status monitoring. The success of every system is hindered by challenges that need to be addressed. Some of these challenges for CPS include security, patient information privacy, heterogeneous data management, real time patient monitoring, interoperability between different systems, system usability and energy consumption.

Index Terms—Cyber Physical Systems, healthcare applications, medical-intake, medical status monitoring, CPS challenges.

1 Introduction

Cyber Physical System (CPS) is an emerging paradigm which has recently started gaining significant momentum. This is especially evident in the domain of research and development. CPS facilitates smart communication between the physical world and virtual components. Undoubtedly, CPS applications have transformed the way humans interact with the physical world. There is a diverse range of healthcare applications incorporating CPS including applications for, but not limited to, patient data collection, medical status monitoring, surgery and medication adherence and monitoring.

The combination of cyber systems and physical world is seen as an advancement in information technology specifically in wireless based networking technologies. While the physical systems include the physical environments that require control and surveillance, the cyber systems refer to the embedded devices, also called the next generation engineered systems. The latter are responsible for processing information and communicating with the distributed environment in which the CPS based system is placed. Also in a CPS based system, the communication network, sensors and actuators all constitute the interface which serves the purpose of linking the physical world with the cyber architecture. The term CPS is not very different from Internet of Things (IoT), and there is a certain overlap between their applications [1]. IoT is referred to as a subset of CPS in recent research [2].

"Smart homes" is a very beneficial advancement under the umbrella of CPS in healthcare designed specially for elderly care and intensive care patients [3]. Some of the main aspects of elderly care that are addressed in smart homes are monitoring their medication intake including a reminder for their medication time, and monitoring their medical status. The latter includes monitoring different conditions like high-risk pregnancies, edema, bone fracture recovery etc. In this paper, we cover the literature on these topics and discuss the challenges associated with them.

The rest of the paper is organized as follows. In the following sections, we discuss the applications of CPS in smart homes. The following areas are explored: medication intake applications are discussed in Section 2 and medical status monitoring in Section 3. Section 4 presents some of the critical challenges faced by systems incorporating CPS along with possible solutions of how to address them. Finally, Section 5 concludes the paper.

2 Medication Intake

The role of CPS in medication intake applications is of prime importance. Whether non-adherence to prescribed medicine is intentional or not, it can become a complicated problem with serious implications. Certain factors may contribute to unintentional non-adherence to medication including forgetfulness due to aging or cognitive loads. Physical disability may also attribute to negligence in medication intake. Moreover, adherence to medication becomes cumbersome for the elderly as the diversity of medications increases due to their concomitant medical conditions. As a result, the treatment may reduce its effectiveness or have adverse effects on the patient's health thus degrading the quality of life. It also increases hospital admission rate and healthcare cost [4]. Additionally, precise evaluation of patient's level of non-adherence to medication is difficult to determine by the healthcare provider [5].

Smart systems for medication adherence provide convenience to both the patient and the physician by reducing the frequency of visits for the patient and allowing remote monitoring for the physician [5]. Substantial efforts have been made towards effective treatment of elderly patients through increased medication adherence and monitoring

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systems. Such applications promote medicine adherence among patients which ultimately leads to their well-being and an improved quality of life. This has been accomplished by the research community in the form of design and development of smart systems for reminding the concerned individual of the medication consumption time, notifying them of drug expiration dates, monitoring them for the appropriate dosage intake, detection of pill ingestion, detection of drug misuse and monitoring their daily activities and medical conditions.

2.1 Medication Reminder Systems in Smart Homes

The concept of smart homes is getting widespread in research and development of CPS. In the healthcare domain, certain systems have been designed that enforce medication adherence by integrating intelligent pill boxes with smart homes. These smart homes contain multiple ubiquitous sensors to gather user behavioral data and provide context aware solutions for medication adherence, adaptive to the user's lifestyle. Figure 1 illustrates the architecture of a medication adherence system in smart homes. Sensors are installed in the home for user's activity recognition to make the system context-aware. More sensors and cameras detect medication intake from the pill boxes. Data from these sensors are sent to a cloud server which notifies the concerned doctor and family of the patient. Dosage reminders are sent to the patient through some kind of a medium, depending upon the context. The illustration in Figure 1 is a summary of the systems discussed in this section.

A noteworthy contribution in this regard is the design and integration of iMec with smart homes by Suzuki and Nakauchi [6]. The iMec is an intelligent medical case that allows medical practitioners to monitor elderly patient's medicine dosage accurately and reliably. The smart case is able to detect incorrect dosage ingestion and determines adequate dosage quantity through the use of wireless ubiquitous sensors. These ubiquitous sensors are installed in the vicinity of the user's habitat to periodically gather data related to user behavior. The system provides a web interface to the physician for monitoring the behavior of the patient. Upon removal of a pill from iMec, the dosage adequacy for the rest of the medicine is calculated. Any estimated risk of error is communicated to the iMec server and conveyed to the physician. The iMec relies on the physician to stock the medicine case with the correct drugs, and does not possess the capability to recognize the types of drugs perfectly. It merely senses the presence of the drug in the partitions of the container through a camera. Their experiments verified that iMec is able to detect 4 types of medicines precisely in the pill box. The medication condition of the patient is updated frequently and the iMec server promptly notifies the concerned doctor via email upon incorrect dosage ingestion. The system can also estimate medicine intake timings through fuzzy inferences based on habitual conditions. A multitude of sensors are installed on the seats and ceilings of the house to detect the patient's position. In order to detect the use of objects, sensors are also installed in the kitchen appliances, home electronics and water pipes. The system observes the patient's daily activities through data collected from the installed ubiquitous sensors and matches them to the basic conditions predefined in the system e.g. eating food, sleeping, etc. and then classifies the conditions into three meals of the day. This is followed by calculating an estimation of the present possibility of being in one of those conditions. Their experiments demonstrated that iMec is able to determine the correct present behavioral condition from 11 predefined conditions with over 80% accuracy.

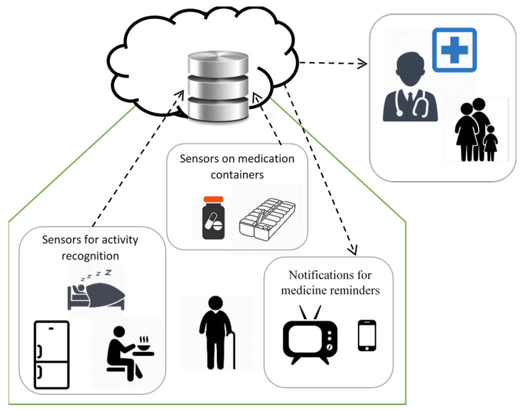

Fig. 1: Architecture of a Medication Adherence System

Another solution in the form of a context aware pill box system empowered by artificial intelligence techniques was proposed by Wu et al. [4]. The system packages the features of activity identification, reminder notification and recording medication consumption. Various sensors installed in the smart home gather data by observing daily activities of the user. The activity recognition module processes this data into context aware information using standard argumentation semantics. Based on the user's daily habits and medication schedule, the application adaptively determines the optimum timing and medium to issue a medication reminder notification without causing frustration to the user. Consequently, this results in an improvement in the user's medicine adherence contrary to strict time-based reminders. The system makes decisions through an expressive model of representation, called the decision graph with context. Decisions for generating reminders need to be taken in terms of three aspects. The first is to decide a suitable medium for displaying the reminder. For example, if the user is occupied in watching television then the reminder should be displayed on the screen, or if the user is traveling, then a notification can be sent on the mobile phone. The second aspect is to decide on a feasible time for the reminder so as not to cause frustration or disturbance to the user. For example if the patient is taking a nap and a delay in the medication intake will not cause any harm then the reminder is delayed. The third is to determine the volume of the ringer depending upon the situation. For example, if the device is far away from the user, then the ringer volume should be increased. Moreover, the application also tracks the user's medicine consumption by scanning the RFID tags attached to the drug packaging. Such applications addressing the problem through multiple aspects have been proved to be more successful in elderly patients [5]. Similarly, a smart medication management system was implemented by Varshney [5] that generates flexible context-aware reminders for medicine intake and manages the dose dispensing. It is based on health promotion model, which takes human behavior specific knowledge into consideration. It assists the patient in remembering the medicine type, quantity, time, and ingestion method. In case of missed doses, it reschedules the medication accordingly. The health condition of the patient is monitored through wearable sensors (ECG, temperature and blood pressure) fixated on the patient body. Moreover, it supports intervention from healthcare professionals by allowing them to monitor dose consumption and communicate with their patients. Medication adherence has also been shown to improve by involving the patient's social contacts in the loop. Ishak et al. [7] propose a smart medicine cabinet system that encourages the elderly to be punctual with their medicine intake and informs the family of the patient's medication intake. A buzzer is resonated when it is time to take the medicine. A microcontroller is attached to the medicine cabinet which turns off the buzzer when the cabinet door is opened. Upon retrieving the medicine and closing the cabinet, the medicine intake confirmation is delivered to the web database.

2.2 Detection of Pill Ingestion

Systems for the detection of pill ingestion have also gained attention in healthcare research. An interesting contribution in this domain is a medication adherence monitoring system by Chen et al. [8] using wearable sensors. It requires the user to wear a wrist band which includes a motion sensor. The motion sensor is configured to detect two gestures in a consecutive fashion within a time frame window: the action of twisting-open the pill bottle cap and the action of pill intake from the hand to the mouth. The system is trained to identify these actions specific to a user by repeated observation of these actions for the same user. Both gestures when detected within a predefined time frame indicate that the medicine has been ingested. On similar lines, Kalantarian et al. [9] developed a system based on a smart wrist watch which detects the hand gestures for opening the bottle and consuming the pill. Recently, in addition to the detection of opening the bottle via force sensors, they included the feature of detecting accurate pill ingestion through movement beneath the skin below the lower part of the neck [11]. This feature was integrated with a smart necklace by using a piezoelectric sensor. In a further study, they used Bayesian networks to classify the types of swallows based on the duration from opening the pill bottle to swallowing, and the skin pattern of the swallowing movement [10]. The data from the smart necklace is communicated to an Android application using a low-power Blutooth protocol for classification. The algorithm was able to distinguish between swallowing and speaking, and further classify swallowing into chewing pills, capsules, saliva and water with 90% precision. Eventually, Li et al. [12] designed a smart pill container with similar features that is simultaneously capable of wireless communication with the computer application as well as a wrist band. They provided the added functionality of monitoring the container to replenish the pills periodically along with the identification of hand gestures for medicine intake indication.

2.3 Systems for People with Cognitive Impairment

Applications incorporating CPS have also been developed to assist people suffering from medical conditions like memory degradation. Such applications are of crucial importance in providing them with an adequate level of care that eases their suffering and promises an improvement in their health condition. Of particular interest, Moshnyaga et al. [13] presented a medication adherence system for people suffering from dementia. It serves as a vocal reminder for the patient's medication intake through prior description of the prescribed dosage. The system also guards the patient against incorrect medication consumption by providing access to only the correct medication for a certain time out of the prescribed ones. The patient's medication intake and other daily activities are monitored in a subtle way so as not to make the patient conscious of the surveillance. The results of the monitoring are sent to the patient's concerned medical practitioner. Patterson et al. [14] describe a prototype for self management of dementia based on smart homes. The system is composed of four components, namely remind, sense, reason and act. The remind component is responsible for generating reminders for dosage intake at the prescribed timing through a mobile application. Unacknowledged reminders lead to repeat reminders and two consecutive missed reminders lead to alerting the concerned physician. The sensing component involves the placement of sensors in the patient's premises at specified locations for observing medication intake. Data from the sensors are sent to a cloud storage where the reason component evaluates adherence detection. The act component allows the physician to interact with the patient upon negligence towards medication intake.

It is clear from the previous section that some solutions are related and have similar features as it can be seen in Table 1.It is also evident in all the systems discussed above that they are heavily dependent upon the correct functioning of all the coordinating systems and networks. This underlying assumption may lead to system malfunction in case one of the external systems stops functioning or provides wrong information in error. Such a scenario may lead to incorrect instructions to the patient which may be of fatal consequences. Thus there is a need for constant monitoring of checking system status, improvising strategies for fault tolerance and ensuring coordination between all connected components. The challenges that need to be addressed for the success of CPS in healthcare are discussed in detail in Section 4.

3 Medical Status Monitoring

Monitoring the medical status of patients is extremely important in the medical field whether it is after surgical operation or during their routine activities. Elderly patients particularly require special monitoring due to their inclination towards adopting an autonomous lifestyle in this age. The following subsections describe some solutions from literature. Section 3.1 describes a CPS solution designed to help high-risk pregnant women. Section 3.2 and 3.3 describe e-diagnostic and medical monitoring solutions for elderly

TABLE 1: Comparison between medication reminder and pill ingestion solutions models

Study	Model Features	Features Functionality
Suzuki and Nakauchi [6]	-Wireless ubiquitous sensors in habitat -Fuzzy inferences based on patient's position detection -Sensors in pill box -Web interface	-Patient's behavior detection -Medicine intake timings estimation -Incorrect dosage ingestion detection -Patient monitoring
Wu et al. [4]	-Standard argumentation semantics -Decision graph with context -RFID tags scanning of drug packaging	-Patient activity detection -Medication reminder notifications frequency calculation -Medicine consumption tracking
Varshney [5]	-Wearable sensors -Patient behavior monitoring	-Patient's health monitoring -Reminder of medicine type, quantity, time, and ingestion method
Ishak et al. [7]	-Micro-controller attached to the medicine cabinet -Web database	-Medicine intake detection -Patient medicine intake monitoring
Chen et al. [8]	-Wearable wrist band sensors	-Patient's action detection
Kalantarian et al. [9]- [10]	-Wearable wrist band sensors -Smart necklace using a piezoelectric sensor -Bayesian networks -Android application using a low-power Bluetooth protocol	-Patient's action detection -Pill ingestion detection -Types of swallows classification -Classification display

people. Edema patients also need continuous monitoring since edema is a very important symptom of systematic diseases like heart failure. Therefore, section 3.4 provides a CPS application for patients with edema.

3.1 In-Home Monitoring for High-Risk Pregnancies

In-home monitoring systems for high-risk pregnancies could be either professional-centered where a professional care taker conducts the monitoring session at home, or patient-centered where the patients rely on themselves in conducting the medical procedure and understanding the feedback. Even though the second method is the more desired one, it tends to be more challenging due to the social computing factor. Currently, hospital monitors the fetal state mainly through cardiotocography (CTG) which analyzes the changes in the fetal heart rhythm though uterine contractions and fetal movements. The data gets transmitted to surveillance center which ensures obstetrical care coverage, signal analysis and documentation. Jezewski et al. [15] states that the current commercially available obstetrical care information system does not provide enough functioning features for in-home care duo to several issues.

Having real-time tele-monitoring, compatibility between multiple medical devices, workflows and interfaces,and having supportive Human-Machine Interface (HMI) are some of the main challenges faced while designing a CPS in this field. Therefore, Jezewski et al. [15] proposed a holistic approach to designing a medical CPS for monitoring the fetal and maternal health status of pregnant mothers utilizing body area network (BAN), HMI, and controller. BAN, which is a very essential component in any wearable CPSs, refers to a network of sensors attached to the patient's body including sensor implants. The fetal sensors capture fetal heartbeat and movement profile. Similarly, the maternal sensors monitor the mother's pulse, blood pressure levels and uterine contraction which helps in the early prediction of premature delivery. Signal processing and data communication for surveillance Center is accomplished by the use a personal area network. The controller manages smart alarms, communication with hospital Surveillance Center, and communication with mobile terminal that contacts care takers and physicians. Jezewski's proposed system also provides personalized medical care based on remote access to patient health records as well as trends observed through monitoring. Thus, the system relieves the mother of the obligation to visit the doctor for routine checkups. Figure 2 illustrates both physical and cyber parts of the proposed CPS. Figure 2 illustrates both physical and cyber parts of the proposed CPS.

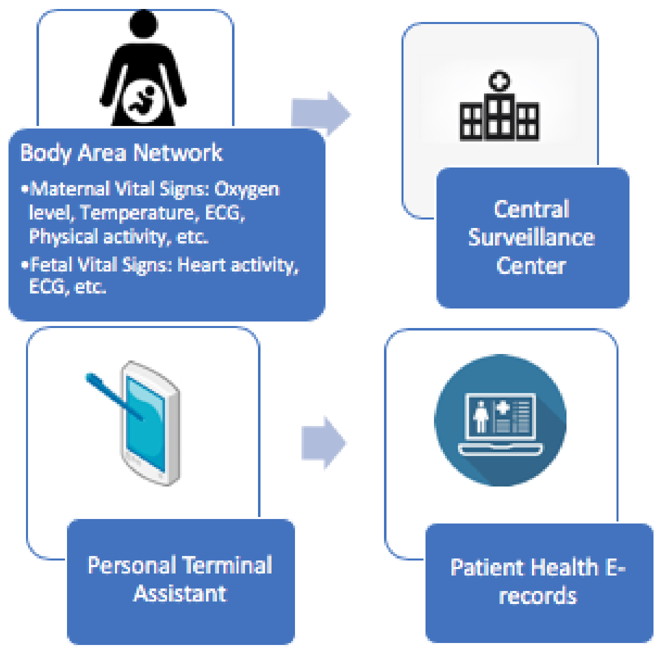

Fig. 2: Illustration of fetal and maternal health status monitoring CPS proposed by Jezewski et al. work [15]

3.2 Ambient Technology and E-Diagnostics

In order to help the increasing number of elderly people living autonomously, Costanzo et al. [16] implemented a system for monitoring their vital signs and environment. Their solution offered an affordable, real time monitoring system that informs both the patients and their hospitals and family about their health status and critical health conditions. In case of emergency situations, the system collects information about the patient location and transfer it to an ambulance to assist first aid personnel in choosing the fastest route. The designed system is composed of a pocket sized, Arduino based control module which extracts data from sensors that monitor the patient's physiological and environmental conditions in real time. In order to detect the patient's location, patients are provided with a cellular phone with GPS functionality and indoor localization features. The phone connects with the control module through a local area network (LAN) shield to acquire patient's data and transfers it to remote doctors and family members. At home, the LAN is replaced with home web service that has control over actuators affecting home climate conditions based on patient's conditions.It also uses a surveillance system based on fuzzy logic that allows the system to express risk codes determining the best course of actions during an emergency.

3.3 Monitoring Bone Fracture Recovery

The CPS framework can be of benefit in the orthopedics field, especially in resolving issues faced with external orthopedic fixation devices used for bone fracture recovery. A simple external fixation device consists of a rod mounted on the fractured bone with two or more pins. The aim of this simple mechanical structure is to carry the load of patient's body instead of the broken bone until it heals. However, patients are prescribed exercises and a load cell is attached to the rod as part of the treatment. Some of the complications in performing this treatment are mal-union, delayed-union, or non-union of the bones which indicates that the bone has healed but not perfectly or took longer time than it was supposed to or did not heal at all, respectively. Performing the procedure effectively depends on the surgeon's knowledge and experience in utilization hazardous, expensive, and time consuming diagnostic tools like X-Rays and MRI. This can be avoided by using an Aware, Sensing, Smart, and Active (ASSA) external fixation systems.

ASSA systems, as the name suggests, are: 1) Self-aware and patient-aware by storing relevant data; 2) Sensing by collecting data about the environment such as the load level applied on the rod and pins; 3) Smart by delivering meaningful insights from the data; and 4) Active by performing instructions based on the insights gained. Technically, an ASSA system is achieved by embedding sensors to the devices connected to a processing unit that collects, stores, processes and classifies data in order to derive conclusions based on these sensor signals. Dragan et al. [17] developed an ASSA systemto be used for monitoring the load applied on fractured leg by the mounted load cell and recognizing patient's high risk activity that may hinder the healing process. Both problems were represented as a classification problems.They found that using a single accelerometer of high quality placed on the calf, 11 features represing acceleration magnitude, and k-nearest neighbour classification algorithm resulted in the most accurate human activity recognition (96.46%) compared to any other number of selected features or classification algorithms.

Broken bones can be more dangerous to some demographics than others. Approximately, a third of the elderly population suffer a fall each year and 1% of these falls lead to hip fracture which leads to their morbidity or even mortality. There are four stages for bone regeneration; from inflammation to developing soft callus which then hardens and finally remodels as a healed bone. Determining the exact timing of these stages is very difficult with elderly people since the most useful diagnostic method, X-ray, is not safe for repeated use on elderly. Perez et al. [18] noticed the problem and deveoped a CPS where they focused on the physical part of CPS by introducing two hip fracture follow-up healing tools to properly rehabilitate and monitor the bone healing process. The approach used sensed the tissues variation at three different femoral positions from the instance of fracture to its complete healing. Sensors were designed in a way that optimizes their tissue penetration and image resolution characteristics while the three selected femoral positions ensured the feasibility of monitoring the healing process. Consequently, the results gained were promising.

3.4 Continuous Edema Assessment

Edema is defined as the unusual accumulation of fluids under the skin, usually at the lower leg, ankle, or feet. It is a very important symptom of systematic diseases like renal, kidney or heart failure. In addition to that, pregnancy, post-surgery complication, and inflammatory diseases can also be a cause of edema. Clinically, edema is monitored in a subjective manner using as tape measure to assess the condition which is an approach sensitive to human errors. Several previous studies have developed sensors to quantify lower-limb edema. However, current techniques are measuring in discrete time matter and lack true efficient remote monitoring systems since they either depend on patient self-report of vital body measures or use threshold-based wireless sensors. Even though the wireless sensors are better than manual self-reports, threshold-based sensors generate 24% false negative and 57% false positive [19].

FallahZadeh et al. [20] proposed a more objective, context-aware, low-power, real time, wearable ankle edema continuous monitoring system that uses analytical approach for detecting alerts. The system for edema monitoring is composed of hardware and software components. The hardware part consists of two sensors and a transmission module while the software part consists of a data processing model and an energy optimization module. The multi-sensor device has one sensor that measures the ankle circumference which is then compared to a correlated ankle circumference value to report the changes. The other sensor is an inertial sensor that detects both physical activity and body posture. The data processing unit takes inputs from both sensors and applies an activity classification algorithm in order to validate the edema measurement and make the system context-aware. The energy optimization module takes its power consumption sources from the sensors and data processing module.

The team conducted experiments where they used one ankle measurement sensor on the left ankle and decision tree model for activity classification. The results of the experiment showed that the overall accuracy of the model is high with a precision of 97.2% for detecting medically relevant activities like sitting and standing. Also, the ankle circumference measurement was 97% reliable using Pearson Correlation measurement. Even though the results are promising, their approach is quite far from being available in the market since the results were only received from in-lab experiments and the activities detected did not include activities of daily living like playing sports and house cleaning.

System designers and developers encounter a diverse range of challenging tasks posed by CPS in healthcare due to system's inherent complexity and dependency on various external systems and entities. The shift from traditional stand alone medical management systems to medical CPS has disclosed a number of new notorious challenges that must be addressed to make CPS a successful system in healthcare domain. We discuss some of these challenges namely Security, Patient Information Privacy, Real-time Patient Monitoring, Heterogeneous Data Management, Availability, Interoperability between Different Systems, Intuitive and Transparent System Usability and Energy Consumption in the following subsections.

4 Challenges

System designers and developers encounter a diverse range of challenging tasks posed by CPS in healthcare due to system's inherent complexity and dependency on various external systems and entities. The shift from traditional stand alone medical management systems to medical CPS has disclosed a number of new notorious challenges that must be addressed to make CPS a successful system in healthcare domain. We discuss some of these challenges in the following subsections.

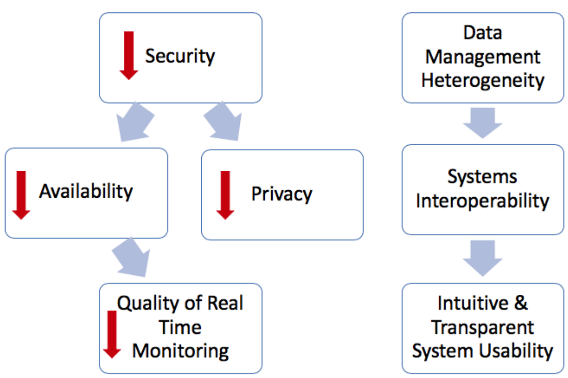

Fig. 3: Illustration of CPS challenges relationship

4.1 Security

Out of the many challenges that a medical CPS poses, security is of pivotal importance. Due to its complex and dynamic nature, both the cyber and physical components of CPS are vulnerable to a security attack. The patient is at high risk in case a cyber intruder reprograms the sensors and network activities or interferes with the communication protocols of the devices [21]. This may result in life threatening consequences for the patient. The attacker may also turn off the sensors or drain the battery of the sensors [21], which will stop communication between devices thus initiating a denial of service attack and limiting device availability [22]. On the other hand, in cases of secure systems based on cryptography, certain emergency situations may require unauthorized entities to access the system. Biometric security measures enable the patient to notify the relevant people during emergency situations but make remote access difficult [21].

4.2 Patient Information Privacy

As mentioned earlier, a system that incorporates CPS is usually involved in the processing of data it receives, thus acting as the central computational core. As a result, there is a possibility of unauthorized access to patient data coming from the sensors. Cyber attackers may exploit this data and disclose personal medical information leading to discrimination and harm [22], manipulate data logs leading to incorrect conclusions by the authorized doctor, and track the sensors thus violating patient confidentiality [21]. The data coming from sensors may also be tampered with or spied upon by an impersonator [23]. Thus, compromises on patient data confidentiality may result in degraded performance of the respective system.

4.3 Realtime Patient Monitoring

Due to the multi-step data transmission from the sensors to the healthcare provider, realtime patient health monitoring becomes a challenging task. Data from the sensors is received by the devices in the smart home, which sends the data to central remote servers in the cloud. The data is then transmitted to the healthcare provider. During this journey, the data packets may experience network traffic, packet loss and network jitter leading to incomplete or late data arrival [24]. Failure of the system or its components may also limit the availability of the CPS [23]. Consequently, this may influence the caregiver's decision which may adversely affect the patient's health. Combining comprehensive domain knowledge, realtime data and patient history is also challenging yet vital for remote health monitoring [24].

4.4 Heterogeneous Data Management

As CPS is composed of multiple components, it is obvious that data comes from multiple sources (hospital, wearable devices, laboratory etc.) with diverse data types (text, image, audio etc.) in different formats (structured, unstructured etc.). Moreover, it is generated at an alarming speed, creating a huge amount of data to be managed. This introduces the need for combining big data and cloud computing technologies for efficient data storage, analysis and retrieval [25]. Despite the effectiveness of using big data and cloud computing technologies in handling data heterogeneity, manipulating and communicating patient information over the network might be subjected to security attacks. As mentioned in Subsection 4.2, patient information privacy is one of the most important factors to consider while designing healthcare applications. Thus, CPS based systems should be developed in such a way that they are able to leverage cloud computing technologies without violating patient information privacy [21].

4.5 Availability

The property of constantly being available even when a fault occurs is a necessity in most healthcare based systems. This is especially important in those that monitor critical patients' medical intake and administer their medical dosage according to pre-defined times. Furthermore, in systems that have to constantly keep a check on a patient's status and warn the relevant doctors in case of an emergency. In practice, a CPS based system should be able to continue to function even during a malfunction, thereby minimizing any situation of unavailability that may be caused. These malfunctions could be caused by malicious cyber-attacks, namely, denial of service attacks [23]. Thus CPS based systems should be developed in such a way that they are able to overcome malfunctioning gracefully and operate without any major inconveniences and or risk to the users of the system.

4.6 Collaboration between Different Systems

Most CPS are composed of multiple components (sensors, networks, storage, etc) that require synchronous communication (through cellular, Ethernet, etc) with each other for the system to function well [26]. The ability of a CPS to operate with each other in coordination is a complex constraint specially when devices have varying storage and computational capacities. One problem that may arise is that the devices may produce conflicting suggestions regarding a treatment due to the different type of sensor data received at different points in time. Another problem could be the devices experiencing signal interference due to being in close proximity with each other.

4.7 Intuitive and Transparent System Usability

Although the errors in a care provider's decision may be due to stress and related factors, poor user interface design has been frequently labeled as a cause for errors in care provider's decision [22]. Errors are bound to occur if the system user interface is not intuitive, lacks ease of use, or provides unexpected outputs. The dynamic aspect of the system must also be considered since caregivers have various roles, responsibilities, skills, and duties (doctors, nurses, patient's family member, etc.). Thus, good care should be taken to design a CPS user interface that supports collaboration between care teams. The functionality of a CPS interface should also adapt to changing interactions depending on the role of the caregiver's and patient's context (emergency vs. typical case) and should predefine a flow of operation in order to allow all members of caregivers' team to learn their tasks in a specific procedure. E-learning isn't limited to caregivers only but also to the patients themselves. In the case of using daily monitoring CPS devices, patients should be able to easily learn how to correctly place sensors and perform a simple signal quality verification procedure on their own [15]. Also, Using CPS for monitoring health status daily requires the system design to be comfortable for the patient and also be user friendly. However, achieving this goal might come in expense of system accuracy and energy consumption. Human activity recognition requires attaching several sensors to the patient to produce accurate results but, on the other hand, it would cause great discomfort and inconvenience to the patient. Finding the right balance is a critical part of the design.

Although most of these challenges could be addressed independently, ignoring one of them may affect another. Figure 3 shows the correlation of the different challenges and how not addressing any of these challenges can have an impact on the others. Compromising on security can eventually make the system unavailable as it is easy to hack into an insecure system. This will eventually impact real time monitoring systems. Making systems overly secure will make it difficult to share data between the different systems, thereby compromising on transparent system usability. Therefore, there needs to be a balance between addressing the different aspects of the system according to the application.

5 Conclusion

In this paper, we surveyed the role of CPS in smart homes. Although several beneficial systems related to elderly care and intensive care patients have been developed that would facilitate their autonomous living, we found many challenges that still hinder the acceptance of these systems in practical life. Many of these challenges could be addressed by extensive research especially researches such as Varshney's [5], where a performance evaluation of several combinations of medical interventions was studied and showed an evidence of high improvements when medical solutions are combined. While the involvement of CPS has started to increase in healthcare systems, specially smart homes, its safe integration is a necessity to ensure its positive advancement.

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