Research Issues in Pervasive Health Care Monitoring Applications and Systems

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Abstract — **Health monitoring of patients has been proposed to reduce health care expenses by managing chronic conditions, resulting fewer hospitalizations and improving patients' quality of life. Thus health monitoring of patients can be applied at any time at any location. Pervasive health care monitoring has the advantages of reduced medical costs, increased medical quality, continuous and timely patient monitoring, complete patient physical data collection, and timely decisions of the correct adaptive remedy. They can also reduce the time between the occurrence of an emergency and the arrival of the needed help. Although a large number of research papers and survey papers on health care monitoring systems are already accessible, many novel ideas and applications are progressively emerging and providing potential opportunities and challenges for further research. In this paper an overview of pervasive health care monitoring systems is presented. The main objective is to identify emerging trends and research issues in health monitoring systems.**

Keywords - health monitoring; patient; pervasive health care.

I. INTRODUCTION

Patient monitoring systems can provide real-time, continuous, or intermittent assessments of critical physiological parameters [1-5]. The availability of a wide range of vital-sign parameters plays an important role in the clinical benefits that patient monitoring can provide [6-8]. Traditional monitoring systems track different types of biological measurements (e.g. electrocardiogram (ECG), arterial oxygen saturation (SpO2), and blood pressure) using dedicated sensors. Oswat *et al.,* [9], Neves *et al.,* [10], Dagtas *et al.,* [11] described monitoring of multiple vital signs based on mobile telephony and Internet.

Remote patient monitoring provides a different interaction between clinical professionals, care providers and the patients. Deployment of remote patient monitoring requires specific network infrastructure to be in place. Home networking is leading the way in the area of remote patient monitoring; for example, devices may be interconnected in a house using a local area network, with a central gateway governing the information access, processing, and controlling these devices. The requirement of remote patient monitoring includes continuous monitoring for some patients and event-driven monitoring for others, the frequency of monitoring, number and types of vital signs that must be monitored and transmitted, and the size and frequency of messages to be transmitted. The specific networking requirements include universal access to wireless networks, location management, high-levels of wireless network reliability, network scalability with an increased number of users and frequency of monitoring and support for prioritized transmission of vital signs of certain patients. The quality of service requirements is low delay and high probability of message delivery. The additional requirements include security and privacy, and ways to support the usage cost of mobile patient monitoring systems [12].

The remainder of this paper is organized as follows. Next section shows the models and architecture for pervasive health care monitoring systems. Then, security aspects are analyzed. In the following section, some techniques and technologies used in these systems are presented. Lastly, the last section presents the discussion and conclusions of this research work.

II. MODELS AND ARCHITECTURE

A typical pervasive patient monitoring system is an three-tier architecture. Each tier is distinguished by its localization and functionality within the broader system [13-14]. The first tier is the set of sensors that discern signals of interest, and then relay information to each other and the data hub, biological sensors that measure some vital signs from individuals. Tier two, the data hub, is a device that provides more computational capacity, allowing data to be stored or further processed before transmission to some outside medical network via the Internet, WiFi, GPRS/3G, or some other means. The third tier is the

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medical network, which is operated by a health care provider such as a hospital or telemedicine center where the staff can handle emergency situations. The control center in the medical network is responsible for the coordination with the physicians and is connected via a wireless connection to the data hub. Figure 1 shows this three-tier architecture of a pervasive health monitoring system. It consists of first tier (couple of sensor nodes), second tier (control device), and third tier (medical network, servers).

As a pervasive health care monitoring system, it includes several different pervasive computing technologies, whose scale and variety depend on the application and its usage model.

Otto *et al*.[15] proposed a wireless body area sensor network for health monitoring integrated into a broader multitier telemedicine system [15]. The telemedical system spans a network comprised of individual health monitoring systems connected through the Internet to a medical server tier that resides at the top of this hierarchy.

The top tier, centered on a medical server, is optimized to give service to hundreds or thousands of individual users, and encompasses a complex network of interconnected services, medical staff, and health care professionals. Each user wears a number of sensor nodes that are strategically placed on his/her body. The primary functions of these sensor nodes are to unobtrusively obtain vital signs and transfer the relevant data to a personal server through a wireless personal network implemented using ZigBee or Bluetooth. The medical server keeps electronic medical records of registered users and provides various services to the users, medical staff and caregivers. It is the responsibility of the medical server to authenticate users, update data into the corresponding medical records, analyze the data patterns, recognize serious health anomalies in order to contact emergency caregivers, and send new instructions to the users. The patient's physician can access the data from his/her office via the Internet and analyze the status of the patient. A server agent may inspect the uploaded data and create an alert in the case of a potential medical condition.

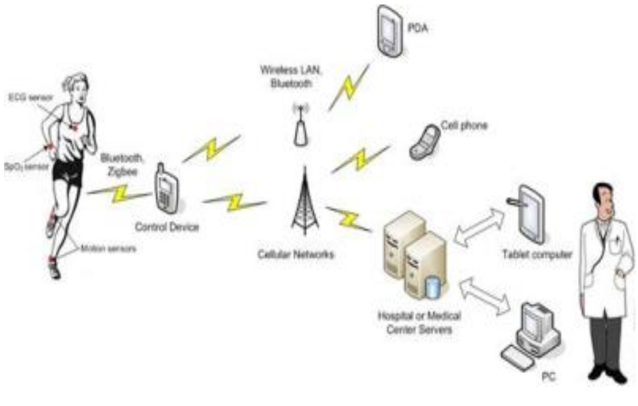

Figure 1. System Architecture of pervasive health care monitoring system.

III. SECURITY ASPECTS

Security is very important in pervasive health monitoring systems to protect the sensitive health information that it collects and manages; therefore, they have to maintain data confidentiality, data integrity, and provide strong authentication features, thereby controlling unauthorized access of personal health information [16].

Leister *et al*.[17] presented threat assessments of mobile patient monitoring systems. They not only scrutinized threats at different levels for those monitoring systems using long-range wireless communication and short-range wireless sensor networks, but also suggested recommendations for the overall patient monitoring system based on threat assessments.

For the patient monitoring systems, several security considerations should be taken [18-19]. These considerations are depicted in Figure 2.

Data Confidentiality: It is important to keep the medical information confidential, so that unauthorized parties cannot access this information. Some solutions have been presented to prevent malicious intruders and intentional eavesdroppers from intercepting or overhearing this information communicated in an open wireless environment. One of these solutions is to use a cryptographic algorithm to encrypt medical information and protect the necessary data.

Data Integrity: Preventing unauthorized modifications of data while, at the same time, ensuring that only legitimate nodes can create and inject data to the network prevents many attacks. The sensor nodes are vulnerable to physical tampering which cannot easily be prevented on a pure logical level. Using tamper-resistant devices is a viable but costly alternative. In the communication network, lightweight authentication and integrity check methods (e.g. using MAC) can provide integrity protection during transit. In the backend system, standard security mechanisms as well as privacy enhancing mechanisms should be deployed.

Authentication: During information retrieval, authentication is important. Only an authenticated entity can access the corresponding data that are available for that entity. Sometimes, cryptographic keys can be used as the means of authentication in current authentication technologies. For example, asymmetric cryptography (i.e. PKI) is often used, because these private keys are credentials shared only by the communicating parties.

Access Control: In traditional network security models, access control determines whether a subject can access an object based on an Access Control List (ACL). Access control can be achieved by combining authentication and authorization.

These solutions can work well in wired networks; however, they are obviously not sufficient for pervasive and wireless networks because the dynamic topology of wireless networks changes quickly, and the scalability of these networks sometimes needs to be handled.

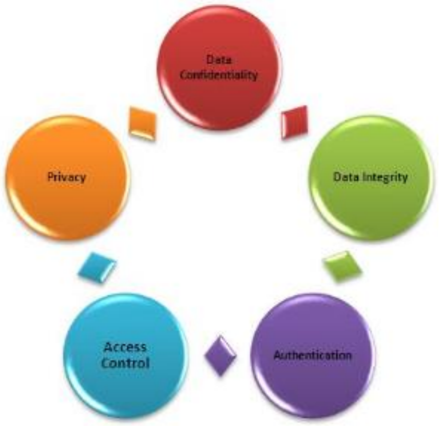

Figure 2. Security considerations for patient monitoring systems.

Privacy: It is necessary a high level of privacy in pervasive health care systems, which may become more aware of patient's behaviour, habits and movements, and should support patient-selectable level of anonymity in pervasive health care services. However, the major privacy issue is localization. In order to prevent location profiling, sensor nodes should be traceable only in case of emergencies and only by authorized medical staff. One way to achieve this is by getting the localization inside the sensor node and delivering it to external entities only in case of alarm situations. As the communication network may also be used for tracking node positions, this has also to be taken into consideration. Regarding the backend system, by storing the data using pseudonyms or providing a separate mechanism for pseudonym resolution, for instance, privacy can be retained.

IV. TECHNOLOGIES AND TECHNIQUES

A. *Mobile and Wireless Technologies*

Mobile devices are the most important tools for health care monitoring. Commonly used mobile devices are cellular phone, smartphone, PDA, notebook or tablets. The capabilities of mobile devices are continuously increasing with improved computing and communications power and growing levels of intelligence of hardware and software. Some of the devices have multi-network access, i.e., they can access to multiple wireless networks such as wireless LAN and Bluetooth. With the advancement of technology, more compact and powerful devices are being developed.

Wireless technologies such as cellular networks (e.g. GSM, GPRS, UMTS or CDMA), wireless LANs (WiFi, Bluetooth), wireless MAN (e.g. WiMax) and satellite networks can be used in pervasive and ubiquitous health care monitoring systems [20]. Some existing mobile patient monitoring projects such as PPMIM [21], MobiCare [22], MobiHealth [23], and AMON [24] employ cellular networks (e.g. GSM, GPRS, or UMTS) to transmit vital signs from Body Sensor Network (BSN) to health centers.

An integrated wireless architecture for location management could include GPS, cellular networks, Wireless LANs (WLANs) and Radio Frequency Identification (RFID). Each one of these networks and wireless technologies supports location tracking of people, devices and services in diverse locations accurately.

In recent years, most wireless and mobile devices incorporate Bluetooth technology to allow wireless connection with other Bluetooth-enabled devices. Bluetooth is a good candidate for low power consumption wireless communication because the transmission rate and range are nearly 1Mbps and up to 10 or 100 meters respectively. The intention behind Bluetooth development is simultaneous communications between multiple devices to create small group networks in which one master device operates up to seven active slave devices.

In addition to the Bluetooth protocol, the IEEE 802.15.4 standard specifies a physical layer and medium access control for low-rate wireless personal area networks [25]. The ZigBee technology, based on the IEEE 802.15.4, is a low-cost, wireless standard that provides short-range, low-power, and low-data-rate communication, and supports mesh networking and multi-hopping. ZigBee is intended to be simpler and less expensive than other WPANs such as Bluetooth. A large number of research papers used the Zigbee technology to develop inexpensive robust Wireless Sensor Networks (WSNs) with a very large set of sensor nodes [8, 26].

A WSN can be composed of large number of sensor nodes, constituting a multi-hop network, where vicinity nodes communicate with each other, with routing responsibilities. Advances in wireless communication and Micro-Electro-Mechanical Systems (MEMS) allow the establishment of a large scale, low power, multi-functional, and low cost network. Since a WSN can have many sensing nodes, they have advantages such as an increase in robustness, fault tolerance and increase in spatial coverage. Using sensors and WSNs provide non-obtrusive monitoring and unlimited mobile patient monitoring.

Body Sensor Network (BSN) or Body Area Network (BAN) consists of intelligent wireless sensors, transducers, and devices that communicate each other or within the immediate vicinity of the patient's body, for example, an ID tag, three ECG electrodes, and a bedside monitor with a measurement module to receive the sensor signals. The electrodes would transmit their data at regular intervals, along with an identifying code received from the ID tag, by sending low-power radio signals to the monitor for display [27].

It is quite obvious that Wireless Body Area Networks (WBANs) promise unobtrusive ambulatory health monitoring for extended periods of time and near real-time updates of patients' medical records through the Internet [28]. The WBAN technology is still in its primitive stage and is being widely researched. A number of innovative systems for health monitoring have recently been proposed [29-30]. Some of the research works focus on continuous monitoring and logging vital parameters of patients suffering from chronic diseases such as diabetes, asthma and heart diseases [31-32].

B. *Sensor and Wearable Technologies*

Physical, chemical, and biological sensors can also be used for health care monitoring applications. A physical sensor will measure physical parameters such as temperature or pressure.

A biological or chemical sensor involves a receptor (for example, an enzyme or antibody), which binds with an analyse (that is, a target molecule).

Each sensor node can sense, sample, and process one or more physiological signals. For example, an electrocardiogram sensor (ECG) can be used for monitoring heart activity, an electromyogram sensor (EMG) for monitoring muscle activity, an electroencephalogram sensor (EEG) for monitoring brain electrical activity, a blood pressure sensor for monitoring blood pressure, a tilt sensor for monitoring trunk position, and a breathing sensor for monitoring respiration; and motion sensors can be used to discriminate the user's status and estimate her or his level of activity.

Wearable systems for continuous health monitoring are a key technology in helping the transition to a more proactive health care. However, the conventional sensors cannot be used for wearable physiological monitoring applications, as they are difficult to wear for long durations, and cause discomfort to the wearer. So the sensors can be incorporated into watches, items of clothing, and eyeglasses. The use of wearable sensors for home monitoring provides an effective means of inferring a patient's level of activity. A wearable device would constantly provide the user with useful information. For example, cardiac patients wearing ECG sensor systems can be monitored remotely. Various types of wearable health monitoring sensor devices have been developed and integrated into patients' clothing [33-34], earlobe [35], or wrist-worn [36].

A number of wearable physiological monitoring systems have been developed to monitor the health status of the individual wearer. For instance, the CodeBlue project [36] developed a range of small and wearable wireless vital sign sensors based on the Mica2, MicaZ, and Telos [37], commonly used sensor platforms. The developed devices include a wireless pulse oximeter, wireless two-lead EKG, and some specialized sensor nodes. Many network-level and system-level mechanisms have been investigated to achieve wireless pervasive communication for health care monitoring architectures.

A wrist worn wearable medical monitoring and alert system (AMON) targeting high-risk cardiac/respiratory patients has been developed to monitor physiological parameters such as ECG, heart rate, blood pressure, skin temperature [24]. Additionally, Vivometrics has developed a wearable physiological monitoring system called 'Life Shirt' to monitor various cardio-respiratory parameters [38].

The WEALTHY (Wearable Health Care System) involves wearable textile interfaces integrating sensors, electrodes and connections realized with conductive and piezo-resistive yarns. The WEALTHY system is made up of a sensorized cotton or lycra shirt that integrates carbon-loaded elastomer strain sensors and fabric bio-electrodes, enabling the monitoring of respiration, ECG, EMG, body posture and movement [39].

A wearable physiological monitoring system called 'Smart Vest' to monitor various physiological parameters such as ECG, PPG, heart rate, blood pressure, body temperature and Galvanic Skin Response (GSR) is developed. The acquired physiological parameters are transmitted via wireless to a remote monitoring station along with the geo-location of the wearer [40].

Similarly, MEMSWear biomonitoring system [41] consists of the MEMSWear smart shirt with physiological sensors that can be used for remote monitoring of human vital signs. In this system, four physiological signs (ECG, SpO2, body temperature and blood pressure) can be continuously acquired or derived from two wireless sensor node. Each sensor node consists of a sensor probe and a Bluetooth transceiver. MEMSWear can detect fall events through the use of motions sensors, such as gyroscopes and accelerometers.

C. Smart Home Monitoring

A smart home is a residence equipped with a set of advanced electronics and automated devices that are specifically designed for care delivery, remote monitoring, early detection of problems or emergencies, and maximization of patient safety. It is usually linked with a local processor that analyses sensor data and detects critical situations; it is also connected to a remote control centre that notifies the appropriate emergency service such as the health agencies. Smart home features usually include motion-sensing devices for automatic lighting control; motorized locks; door and window openers; and motorized curtains; smoke and gas detectors; and temperature control devices etc. Such an infrastructure aims to address problems associated with neurological and cognitive disorders in the elderly and to enhance patients' ability to function independently within their own residence.

Assisted cognition has been coined to describe systems that use sensor data to determine the activities that a person is trying to perform and optionally provide prompts, warnings, or other kinds of interventions to help the person perform the activities safely and independently. Research in assisted cognition combines ideas form sensor networks and ubiquitous computing, Artificial Intelligence (AI), and Human-Computer Interaction (HCI) [42].

Incorporating context awareness is to create "proactive" and "smart" operations of devices and objects surrounding us by minimizing user efforts and interactions, creating a level of intelligence in the systems, adding adaptability and effective decision making, and increasing the level of customization and personalization for users. Context awareness is also interpreted as adaptive, responsive or context-sensitive so a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task. Thus context-aware systems have the ability to discover and react to changes in their environment so that the usability of information appliances can be considerably improved. The user's context depends on physical location, physiological state, emotional state, personal history and behavior. So a personalized health monitoring system can provide, for example, functions such as reminder services or medication support depending on measured vital signs and individual disease patterns.

Since many functions can be controlled without explicit interaction, an implicit human computer interaction can be realized in various pervasive computing environments such as health monitoring system. In fact, computer understanding of human actions and intentions becomes the key issue. In this regard, context awareness plays a significant role in the domain of implicit human computer interaction and assistive environment, since context is tightly correlated to the analysis of human actions and intentions. With advancement of AI technologies, agents and multi-agent systems have become relevant for developing distributed and open systems. The applications of agents and multi-agent systems in the health care and clinical management environments are becoming a reality; some of the agent-based applications are related to the use of this technology in pervasive patient monitoring. Mobile multi-agent based, distributed information platform (MADIP) is an example of agent-based system for e-health monitoring [43].

Assistive technology is any device or system that allows an individual to perform a task that they would otherwise be unable to do, or increases the ease and safety with which the task can be performed [44]. Recent developments in ICTs (Information and Communication Technologies) have increased the potential for assistive technology to support people, through the use of sensors, robotic devices and remote control devices. Pollack categorizes such assistive technology as meeting the goals of assurance (making sure the individual is safe when performing routine activities), support (helping individual compensate for impairment), and assessment (determining physical or cognitive status) [45].

Similarly, smart care technology is any sensor-based technology used to aid and support human independent living [46]. Such technologies offer new potential and can arise new problems for making the technology accessible to users. Rapid deployment of wireless sensor technologies, along with ubiquitous and pervasive computing and mobile and wearable smart devices, make it possible to provide services for smart homes or remote health care monitoring. These technologies will have a profound impact on the type, content, location, operation and functionality of care products and services, and all this must be integrated with the earlier information services. It is therefore crucial to adopt the concept of universal access at this initial stage of smart care research. With the growth of smart care technologies, at-home automated assistance can allow people with mental and physical challenges to lead independent lives in their own homes.

V. CONCLUSIONS

Novel technologies in patient monitoring are emerging to meet the increasing demands of an aging population, the decreasing health care resources, and an emphasis on reducing hospitalization days. Almost all of them focus on some form of ambulatory monitoring using emerging and converging technologies [47-48].

Advances in remote patient monitoring include new peripherals, real-time audio and video for “face-to-face” interaction between clinicians and patients, wireless communication, systems that “sort” the vast amount of data collected in order to put it in the context of a patient’s condition, portable and ambulatory monitors, web-based access to the patient record, systems that transfer data to an Electronic Medical Record (EMR), and full-service outsourcing that includes a clinician to evaluate data and send a report to the attending physician.

In the future, mobile devices can become heath-aware, detecting certain conditions by the touch of a user. This could include measurement of pulse-rate, blood pressure, level of alcohol, etc. Also some smaller medical devices can be integrated or added in the hand-held/wearable wireless device. The mobile devices can also store the patient’s health history and all known medical conditions in the form of an abbreviated EHR. As wearable electronics and intelligent textiles may become key-elements for ambient intelligence, recent developments illustrate the promising character of them. Hence, advances in technology have propitiated the emergence of electronic textiles, creating the opportunity to develop wearable fabric sensors, which offer novel biomonitoring.

Emerging technologies such as nanotechnology, smart sensors, ambient intelligent environments, grid computing, advanced power management and new implantation techniques open up many future possibilities for innovative mobile health services. However it is expected that, along with these advances, issues such as quality of service, safety, security and privacy will present ever more interesting challenges in future.

The aim of this paper was to reflect on an overview of pervasive patient and health monitoring systems and technological advancements as well as to identify emerging trends and research issues with regard to those systems. The foremost observations to be drawn include: a) innovation in ubiquitous and pervasive networks, b) miniaturization of mobile devices, c) security and privacy issues, d) potential of fabric sensor, and e) advancement of nanobiosensors. These observations should be taken into account while designing future generation pervasive patient and health monitoring systems.

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