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A Novel Application of Sensor Networks in Biomedical Engineering

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Abstract

Born on other applications, wireless sensor networks (WSNs) grew on the promise of biomedical engineering applications. In this research we suggest system architecture for smart healthcare, based on a novel WSN. Our system particularly targets assisted-living residents and others who may help from continuous remote health monitoring. We present the objectives, advantages, and status of the design. An experimental livelihood space has been constructed at the Department of Biomedical Engineering (DBE) at Iran University of Science and Technology (IUST) for assessment of our system. A ten days monitoring and experimental results suggest a physically powerful potential for WSNs to open new research area in biomedical engineering, i.e. for low-cost, ad hoc use of multimodal sensors for a better quality of medical care.

Keywords: Healthcare; Wireless sensor network

Introduction

Sensor networks permit data gathering and computation to be deeply embedded in the physical environment.

WSN is built by connecting a group of nodes together to perform the required tasks. These nodes cooperate and automatically create a network among themselves. Wireless sensor node, also commonly known as mote.

Today, WSN technologies have the potential to change the way of living with many applications in industry, travel, trade, environment monitoring, medicine, care of the dependent people, and emergency management and many other areas.

Wireless sensors, sensor networks, information technology (IT) and artificial intelligence, together have built a new interdisciplinary branch of biomedical engineering in order to overcome the challenges we face in everyday life. One of the major challenges of the world is the continuous elderly population increase in the developed countries. Population reference bureau [1] forecasts that in the next 20 years, the 65-and-over population in the developed countries will be nearly 20% of the overall population. It means the need of delivering quality care to a rapidly growing population of elderly while reducing the healthcare costs is an important issue as well. One hopeful application in this area is the integration of sensing and consumer electronics technologies which would allow people to be constantly monitored. In-home pervasive networks may assist residents and their caregivers by providing continuous medical monitoring, memory enhancement, control of home appliances, medical data access, and emergency communication [2]. Continuous monitoring will increase early detection of emergency conditions and diseases for at risk patients and also provide wide range of healthcare services for people with various degrees of cognitive and physical disabilities [3]. Not only the elderly and persistently ill but also the families in which both parents have to work will derive advantage from these systems for delivering high-quality care services for their babies and little children. Researchers in computer, networking, biomedical engineering and medical fields are working together in order to make the broad vision of smart healthcare possible. The importance of integrating large-scale wireless telecommunication technologies such as 3G, Wi-Fi Mesh, and WiMAX, with telemedicine has already been addressed by some researchers. Further improvements will be achieved by the coexistence of small-scale personal area technologies like radio frequency identification (RFID), Bluetooth, ZigBee, and wireless sensor networks, together with large scale wireless networks to provide context-aware applications [4].

In addition providing pervasiveness with existing and relatively more mature wireless network technologies, the development of small or wearable sensor devices is a mater of today researches. These researches may lead to enabling not only accurate information but also reliable data delivery.

Furthermore, the integration of all these technologies is the application, which is the coordinator between the caregivers and the caretakers and between the sensor devices and all of the actors in the overall system cycle. Since the application is the core of the high-quality healthcare service concept, the need for intelligent, context-aware healthcare applications will be increased.

Given the importance of the subject, there are already several applications and prototypes on the issue. For example, some of them are devoted to continuous monitoring for cognitive disorders like Alzheimer's, Parkinson's or similar cognitive diseases. Some focus on fall detection, posture detection and location tracking and others make use of biological and environmental sensors to identify patients' health status. There is also significant research effort in developing tiny wireless sensor devices, preferably integrated into fabric or other substances and be implanted in human body.

Some other studies [5-10] have either only smart home perspective or limited information about the design issues and challenges. The interested reader may find a wonderful survey on wireless sensor networks for health care [11].

In our paper we provide discussions not only from a smart home perspective but rather from a more healthcare related perspective. We

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also discuss benefits that will be achieved and challenges that will be faced while designing the future healthcare applications.

Methods

In this research we developed network architecture for smart healthcare that will open up new prospects for continuous monitoring of assisted and independent-living people. While preserving resident comfort and privacy, the network manages a continuous medical history. No interfering area and environmental sensors combine with wearable interactive devices to evaluate the health of spaces and the people who inhabit them. Authorized care providers may monitor residents' health and life habits and watch for chronic pathologies. Multiple patients and their resident family members as well as visitors are differentiated for sensing tasks and access rights.

It is noteworthy that wearable sensors and systems have evolved to the point that they can be considered ready for clinical application. This is due not only to the tremendous increase in research efforts devoted to this area in the past few years but also to the large number of companies that have recently started investing forcefully in the development of wearable products for clinical applications. Stable trends showing a growth in the use of this technology suggest that soon wearable systems will be part of routine clinical evaluations. The interest for wearable systems originates from the need for monitoring patients over extensive periods of time. This case arises when physicians want to monitor individuals whose continual condition includes risk of sudden acute events or individuals for whom interventions need to be assessed in the home and outdoor environment. If observations over one or two days are satisfactory, ambulatory systems can be utilized to gather physiological data [12].

Another important point is that the patients under monitoring does not lose their mobility by the wire connections, it is why we considered wireless systems in our research as a practical solution.

We avoided high costs of installation and retrofit avoided by using ad hoc, self-managing networks. Based on the fundamental elements of future medical applications (integration with existing medical practice and technology, real-time and long term monitoring, wearable sensors and assistance to chronic patients, elders or handicapped people), our wireless system will extend healthcare from the traditional clinical hospital setting to nursing and retirement homes, enabling telecare without the prohibitive costs of retrofitting existing structures. The advantages of a WSN are numerous for smart healthcare with the main following important properties:

a) Portability and desirability

Small devices collect data and communicate wirelessly, operating with minimal patient input. They may be carried on the body or deeply embedded in the environment. Unobtrusiveness helps with patient acceptance and minimizes confounding measurement effects. Since monitoring is done in the living space, the patient travels less often; this is safer and more convenient.

b) Ease of deployment and measurability

Devices can be deployed in potentially large quantities with considerably less complexity and cost compared to wired networks. Existing structures, particularly decrepit ones, can be easily augmented with a WSN network whereas wired installations would be expensive and impractical. Devices are placed in the living space and turned on, self-organizing and calibrating automatically.

c) Real-time and always-on

Physiological and environmental data can be monitored continuously, allowing real-time response by emergency or healthcare workers. The data collected form a health journal, and are valuable for filling in gaps in the traditional patient history. Even though the network as a whole is always-on, individual sensors still must conserve energy through smart power management and on-demand activation.

d) Reconfiguration and self-organization

Since there is no fixed installation, adding and removing sensors instantly reconfigures the network. Doctors may re-target the mission of the network as medical needs change. Sensors self-organize to form routing paths, collaborate on data processing, and establish hierarchies.

System architecture

Figure 1 shows the layout of simulated experimental area in our research.

The medical sensor network system integrates heterogeneous devices, some wearable on the patient and some placed inside the living space.

The architecture is multi-layer oriented (in this discipline is called multi tiered) with heterogeneous devices ranging from lightweight sensors, to mobile components, and more powerful stationary devices.

Data is collected, aggregated, pre-processed, stored, and acted upon using a variety of sensors and devices in the architecture (RFID tags, pressure sensor, floor sensor, dust sensor, environmental sensor, etc.). Multiple body networks may be present in a single system. Traditional healthcare provider networks may connect to the system by a gateway, or directly to its database. Some elements of the network are mobile, while others are stationary. Some can use line power, but others depend on batteries. If any fixed computing or communications infrastructure is present it can be used, but the system can be deployed into existing structures without retrofitting.

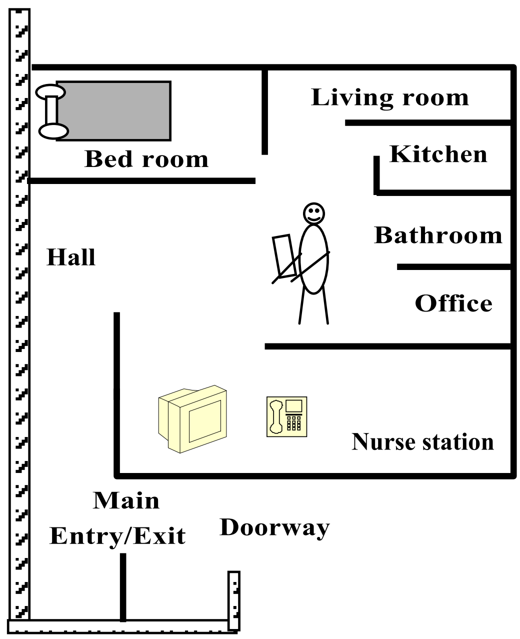

Figure 1: Layout of simulated experimental area in this research.

The components of the proposed architecture are shown in Figure 2, dividing devices into layers based on their roles and physical interconnection. Each layer of the architecture is described below:

a) **Network of body and its Subsystems**

This network consists of small portable devices equipped with a variety of sensors such as heart-rate, heart-rhythm, temperature, accelerometer, oximeter. This layer performs biophysical monitoring, patient identification, location detection, and other desired tasks. These devices are small enough to be worn comfortably for a long time. Their energy consumption should also be optimized so that the battery is not required to be changed regularly. They may use "kinetic" recharging. Actuators notify the wearer of important messages from an external unit. For example, an actuator can remind an early Alzheimer patient to check the oven because sensors detect an abnormally high temperature. Or, a tone may indicate that it is time to take medication. The sensors and actuators in the body network are able to communicate among themselves. A node in the body network is designated as the gateway to the emplaced sensor network. Due to size and energy constraints, nodes in this network have little processing and storage capabilities.

b) **Emplaced Sensor Network**

This network includes sensor devices installed in the environment like rooms, hallways, furniture and so on to support sensing and monitoring, including: temperature, humidity, motion, acoustic, camera, etc. It also provides a spatial context for data association and analysis. All devices are connected to a more resourceful backbone. Sensors communicate wirelessly using multi-hop routing and may use either wired or battery power. Nodes in this network may vary in their capabilities, but generally do not perform extensive calculation or store much data. The sensor network interfaces to multiple body networks, faultlessly managing handoff of reported data and maintaining patient presence information.

c) **Backbone**

A backbone network connects traditional systems, such as PCs, and databases, to the emplaced sensor network. It also connects no neighboring sensor nodes by a high-speed relay for efficient routing. The backbone may communicate wirelessly or may overlay onto an existing wired infrastructure. Nodes possess significant storage and computation capability, for query processing and location services. Yet, their number is minimized to reduce cost.

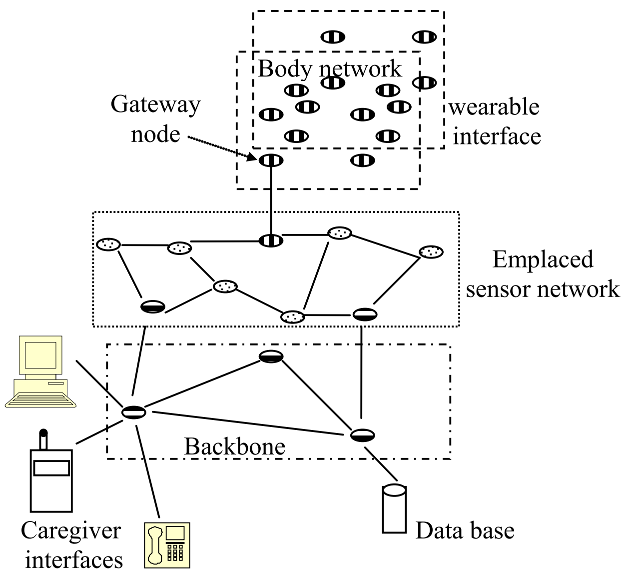

Figure 2: Our multi layered based proposed architecture.

d) **Back-end Databases**

One or more nodes connected to the backbone are dedicated databases for long-term archiving and data mining. If unavailable, nodes on the backbone may serve as in-network databases.

e) **Human Interfaces**

Patients and caregivers interface with the network using PDAs, PCs, or wearable devices. These are used for data management, querying, object location, memory aids, and configuration, depending on who is accessing the system and for what purpose. Limited interactions are supported with the on-body sensors and control aids. These may provide memory aids, alerts, and an emergency communication channel. PDAs and PCs provide richer interfaces to real-time and historical data. Caregivers use these to specify medical sensing tasks and to view important data.

Hardware and devices

We implemented our proposed system by using MicaZ motes and some other following hardware and devices. MicaZ is easy to implement and can be used to build WSN.

Existing motes typically use 8- or 16-b microcontrollers with tens of kilobytes of RAM, hundreds of kilobytes of ROM for program storage, and external storage in the form of Flash memory. These devices operate at a few mill watts while running at about 10 MHz [13]. Most of the circuits can be powered off, so the standby power can be about 1W. If such a device is active for 1% of the time, its average power consumption is just a few microwatts enabling long-term operation with two AA batteries.

Motes are usually equipped with low-power radios such as those compliant with the IEEE 802.15.4 standard for wireless sensor networks [14]. Such radios usually transmit at rates between 10 and 250 Kb/s, consume about 20-60 mW, and their communication range is typically measured in tens of meters [15,16]. Finally, motes include multiple analog and digital interfaces that enable them to connect to a wide variety of commodity sensors.

Data acquisition

a. **Motion sensor**

We have adapted a sensor module that is capable of detecting motion and ambient light levels. The module also has a simple one-button and LED user interface for testing and diagnostics. It is interfaced to a MicaZ wireless sensor node that processes the sensor data and forwards the information through the wireless network. A set of such modules is used to track human presence in every room of the simulated smart health home.

b. **Body network**

We have implemented a wearable WSN service with MicaZ motes embedded in a jacket, which can record human activities and location using a 3-axis accelerometer and GPS. The recorded activity data is subsequently uploaded through an access point for archiving, from which past human activities and locations can be reconstructed.

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c. **Indoor temperature and light sensor**

These sensors give the environmental conditions of the habitat and are also connected to the backbone via MicaZ. Bed sensor. The bed sensor is based on an air bladder strip located on the bed, which measures the breathing rate, heart rate and agitation of a patient.

d. **Pulse-oximeter and ECG**

These sensors are wearable, connecting to MicaZ and Telos devices, and collect patient vital signs. Heart rate (HR), heartbeat events, oxygen saturation (SpO2), and electrocardiogram (ECG) are available.

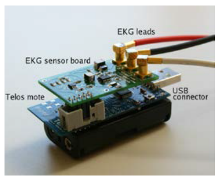
Backbone infrastructure: The backbone of our system is a single Stargate serving as a gateway between the motes deployed in the home environment and the nurse station. Motes use a Zigbee compliant (802.15.4) wireless protocol for communication. The Stargate runs Embedded Linux and possesses more power and capabilities than the motes.

Database management and data mining: A MySQL database serves as a backend data store for the entire system. It is located in a PC connected to the backbone, and stores all the information coming from the infrastructure for longitudinal studies and offline analysis.

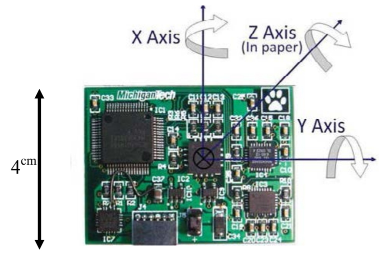
The user graphical interfaces (UGA): Interfaces with residents, healthcare providers, and technicians have different requirements. Each must present an appropriate interface for performing the intended tasks, while conforming to the constraints imposed by form factor and usability. Currently, the system offers four different GUIs. The first is located on the local nurse station, and it tracks the motion of the resident using motion activations. A second GUI (Figure 3), which can run on a PDA, permits a caregiver to request real time environmental conditions of the living space and the vital signs of the resident.

It uses a query management system distributed among the PDA, Stargate and the sensor devices. The interface graphically presents requested data for clear consumption by the user. An LCD interface board was also designed for the MicaZ for wearable applications. It presents sensor readings, reminders and queries, and can accept rudimentary input from the wearer. A final GUI, from a direct medical application based on motion sensors, exists to study the behavioral profile of the user's sleep/wake patterns and life habits, and to detect some pathologies in the early stages. Figure 4 depicts some devices used in our system.

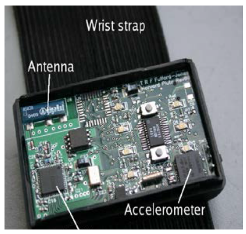
Figure 3: A typical GUI used in our system.



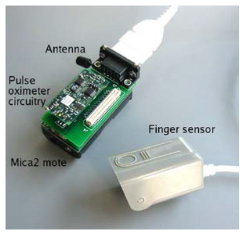
a) ECG device



b) Accelerometer and motion detection device.



c) A typical wearable mote



d) Pulse oximeter.

Figure 4: Some devices that has been used in our system.

Results

Validation of the system as a whole requires several complementary efforts. These include calculation of correct sampling of the signal, and assessment of system performance in real-world settings. The system is single hop, as the radio range covers all of the facility. A multi-hop protocol will be necessary for access of multiple floors, or if transmission power is reduced (we consider multi-hop routing algorithm in our next research). Data communication is bi-directional between the motes and the Stargate. Time-stamping is done by the PC when motion events are received.

A first experiment based on eight MicaZ motes, programmed to send motion events over the network containing the location of the user, was performed with no activity in the lab for five days. We observed no false detections in the system under these conditions. However, this experiment showed the necessity of enhancing the power management scheme to prolong the lifetime of the sensors. In another experiment, the supervision program located at the control station correctly displays the location of a mobile resident by polling the MySQL database for motion events.

A ten days experiment showed a robust system with some straight forward communications from front to backend of the system. We hope our system will greatly enhance quality of life, health, and security for those in assisted-living communities.

Discussion

Data association is a way to know "who is doing what?" in a system without biometric identification and with multiple actors present, such as an assisted-living community. It permits us to recognize the right person among others when he is responsible for a triggered event. This is indispensable for avoiding medical errors in the future and properly attributing diagnostics. Consequently, dedicated sensors and data association algorithms must be developed to increase quality of data.

When the data association mechanisms are not sufficient, or integrity is considered critically important, some functionalities of the system can be disabled this preserves only the data which can claim a high degree of confidence. In an environment where false alarms cannot be tolerated, there is a tradeoff between accuracy and availability.

The system is monitoring and collecting patient data that is subject to privacy policies. For example, the patient may decide not to reveal the monitored data of certain sensors until it is vital to determine a diagnosis and therefore authorized by the patient at the time of a visit to a doctor. Security and privacy mechanisms must be throughout the system.

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