Development of a Decentralized Home Telehealth Monitoring System

Abstract

Although the usefulness of home telehealth systems has been recognized, and all technologies required are readily available, expectations for its widespread adoption have not been realized. This paper presents the development of a Portable Telehomecare Monitoring System (PTMS). What sets this work apart from most other systems is the focus on a highly decentralized monitoring model and the portable nature of the system. We believe that this is the approach that is needed to make such systems economically viable and acceptable to the end-users.

The PTMS is a decentralized system, in which a single household is the fundamental unit for sensing, data transmission, data storage and analysis. It is not necessary to subscribe service from a home health care provider, and the infrastructure required is minimal, too. Equipped with different sensors, the PTMS can be used for long-term personal health data management in a home environment. It can also be easily implemented in a home environment at very low cost. Like the large-scale home telehealth systems, the PTMS also provides care-givers with convenient access to the health data and real-time event-driven messages in urgent situations. Several PTMS applications are described in this paper, including environmental monitoring, monitoring of activities of
daily living, an RFID-based entrance guard system, sleep quality monitoring, vital sign parameter monitoring, and a tele-presence robot.

Key words: home health monitoring, telehealth, e-health

1. Introduction

Most developed countries are facing the problem of increasing number of elderly. In an aging society, it is highly desirable to reduce the need for medical services by maintaining the health of the population. The need of health care and management for the elderly is an urgent issue.

Home has become the centerpiece of health delivery system today. Intensive monitoring of health parameters in the home environment is necessary for health care and management. Telehomecare, or the more modern term home telehealth, can be defined as the use of information and communication technologies to enable effective delivery and management of health services at a patient’s residence [1]. Home telehealth differs from telemedicine in the sense that people who transmit and receive medical information are not necessarily medical doctors but the patients themselves and their families, nurses, care-givers, home-helpers and medical technical experts, etc [2].

Significant research activities are underway in the development of home telehealth systems. By reviewing 578 research papers published between 1990 and 2003, Koch gives an overview about the current state and future trends in research on home telehealth in an international perspective [3].

Beside academic research, commercial systems are already available in Europe, North America and Japan. For example, Japanese household electric appliance manufacturers such as Panasonic, NEC, Fujitsu, and Sanyo all sell remote monitoring devices, and more than 8,100 units have been in use [4]. The largest share “Urara”, invented by Nasa Corporation, has been adopted in Kamaishi City in Japan. The device uses cable TV or ISDN (Integrated Services Digital Network) for data transmission and is equipped with memory, sphygmomanometer, electrocardiogram (ECG), electric signboard, and a button for answering questions. Transmitted health data is checked by nurses at the hospitals and are reported to the doctors, as well as its users [5]. Other terminals with similar functions are “MEDICOM” form Sanyo and “Sukoyaka Mate” from NEC.

Most home telehealth systems adopt the following sequence for vital sign parameter (VSP) monitoring: sensing of various VSPs ➔ sensing data transmission ➔ data storage and analysis ➔ medical actions. Figure 1 shows a typical example of a home telehealth
system. Users use the terminals at home or public places to measure their VSPs, such as blood pressure, heart rate, ECG, weight and body temperature, and the data are sent to the home health care provider through the Internet. Medical institutions can access the health data and take necessary actions.

A centralized database is often used in this structure for data storage and analysis, and the home health care provider partnering with a medical institution plays the major role. Users subscribe to a service from the home healthcare provider, instead of buying a hardware product. Telephone line and the Internet, which are readily available in most homes, are commonly used for transmission of sensing data. To mobilize the VSP measuring devices, wireless communication technologies have been incorporated into the measuring devices.

Figure 1. A typical example of a home telehealth system

Although the usefulness of the home telehealth systems has been recognized in many studies [6, 7, 8], and all technologies required are readily available, expectations for its widespread adoption have not been realized. In our observation in Taiwan, the initial cost of such home telehealth service being too high, and this cost not covered by medical health insurance seem to be the main reasons why home telehealth systems are not well accepted.
Moreover, whether the users have enough trust on the home health care provider so that they are willing to transmit their private health data to the home health care provider on a long term basis is also an important concern. Finally, the route from the VSP sensor to the centralized server in the home health care provider is very long. System stability and data integrity are hard to maintain.

This paper describes the development of a Portable Telehomecare Monitoring System (PTMS). The PTMS is a decentralized system. Instead of using the centralized database structure that gathers data from many households, a single household is the fundamental unit for sensing, data transmission, storage and analysis in the PTMS. The monitoring data is stored in the Distributed Data Server (DDS) inside a household. The DDS is a microcontroller-based device which integrates the following four functions: receiving sensor data, computation capability for preliminary data processing, storage of monitoring data, and communication capabilities via Internet or using the mobile phone short message. Instead of login the centralized database in a home health care provider, authorized personnel directly access the DDS for monitoring data of the household.

In this decentralized structure, the PTMS is a product-oriented system rather than a service-oriented system. It is not necessary to subscribe service from a home health care provider. The word “portable” means that all devices of the PTMS are designed to be modular and portable, and the PTMS can be easily customized and installed in a home environment. Equipped with different sensors, the PTMS can be used for long-term personal health data management of the elderly in a home environment. Like the large-scale systems using the centralized-database structure, the PTMS also provides caregivers with convenient access to the health data, and real-time event-driven messages in urgent situations. The PTMS also has possible home security and smart house applications.

The rest of this paper is organized as follows. Section 2 of this paper describes the structure of the PTMS, and Section 3 presents the applications already developed based on this structure. Section 4 describes an extension of the PTMS, the “Telepresence Robot”. Finally, Section 5 outlines the possible future developments of PTMS.

2. The PTMS Structure and the Distributed Data Server

Figure 2 shows the structure of the PTMS. Sensing data from sensors embedded in the home environment are transmitted to the DDS, which is the core component of the PTMS. Sensing signals are then processed and stored in the DDS. Authorized remote users can request data from the DDS using an Internet web browser (through an application server) or a Visual Basic (VB) program (direct access to the DDS). Event-driven messages (mobile
phone short messages or emails) can be sent to specified caregivers when an urgent situation is detected.

Figure 2. The structure of the PTMS

Figure 3 shows a picture of the laboratory prototype of the DDS, which consists of a PIC server mounted on a peripheral application board. The PIC server integrates a PIC microcontroller (PIC18F6722, Microchip), EEPROM (24LC1025, Microchip) and a networking IC (RTL8019AS, Realtek). It provides networking capability and can be used as a web server. Most peripheral functions of the DDS are built on the application board. The peripheral application board (as well as the program in the PIC microcontroller) can be easily customized to adapt to different sensors and applications. The dimension of the DDS prototype is 40mm×85mm×15mm.

Internet and serial interface (RS-232) are the primary communication interfaces of the DDS with client PCs and other devices. The DDS also receives external signals (e.g., sensor signals) through specific analogue or digital I/O ports, and provides inter-integrated circuit (I²C) communications to allow connections with external modules. In addition, a mobile phone short message service module can be optionally connected to the DDS via I²C, which makes it possible to send text messages from the DDS to specified caregivers when an urgent situation is detected. The DDS can also be connected to a wireless Local Area Network (LAN) card and becomes a wireless device itself.
Long-term health monitoring data are processed and stored in a Multi-Media Card (MMC) in FAT16 file format. Remote users can request for historical monitoring data through a VB application program or an Internet web browser. Further data analysis or processing (such as authorization management, creating graphical displays and tables) can be built in the VB application programs or in an application server. Compared with using a PC as a home server, the DDS is low cost, has smaller package, consumes lower energy (thus can be powered by batteries), is not affected by virus, and is safer and more reliable.

Figure 3. Laboratory prototype of the DDS

There are several advantages of the PTMS structure over the traditional centralized database structure:

(1) The scale of the PTMS is much smaller. A single household can be a running unit of the PTMS. It is not necessary to subscribe service from a home health care provider. The infrastructure required is minimal, too. Thus the PTMS can be easily adapted (customized) and implemented in a home environment at very low cost.

(2) Instead of sending the health monitoring data to a centralized database in a home health care provider, health monitoring data are stored within the household. Only authorized caregivers can access the data. Privacy is better protected.

(3) The route from the sensor to server is much shorter. Data transmission is easier and more reliable, and communication bandwidth will not be occupied by meaningless sensing data continuously transmitted from sensors to the centralized database. When the Internet communication fails, the local system can still function normally and keep collecting data. Thus data integrity is better preserved.

(4) This distributed structure can be adapted if a centralized database is needed. As shown in Figure 2, instead of waiting passively for data, the centralized database can actively request for data from DDSs in many households in a batch mode.
3. PTMS Applications

This section describes the various PTMS applications that have been developed.

(1) Environmental monitoring

Equipped with sensors such as temperature sensor and humidity sensor, the PTMS can perform environmental monitoring, which is the most typical and fundamental application of the PTMS. Besides home environmental monitoring, this system also finds application in environmental monitoring of museums, libraries and exhibition halls. Figure 4 shows the VB interface developed for the National Palace Museum of Taiwan for temperature and humidity monitoring. On the left side of the screen, real-time data from temperature and humidity sensors mounted on four different DDSs can be monitored simultaneously. The user can also download historical data by clicking on the calendar on the top half of the screen, and perform analyses such as calculating average temperature of the day, and plotting the temperature trend of the week.

Figure 4. VB interface of environmental monitoring system
(2) Monitoring of Activities of Daily Living

The term “activities of daily living (ADL)” refers to a basic set of everyday activities or tasks, such as bathing, eating, dressing or walking, that an individual should be able to perform in order to live independently. An ADL monitoring system is developed based on the PTMS structure. The purpose is to monitor the change in pattern of daily physical activities, to recognize the transition of a senior from a healthy, independent state into a state of incapacity and dependency, and to remind the caregivers to take early actions. In this system, special-designed sensors detect activities such as eating, bathing, using the toilet, lying in bed and watching TV. All sensors are embedded in the home environment so that the subjects may not be aware of the sensing actions taking place. Sensor signals are transmitted to the DDS through a battery-powered RF transmitter. Besides the sensors installed in the environment, a wearable sensor based on a tri-axial accelerometer is now being developed to recognize postural movements of the subjects when walking, sitting and standing or in postural transitions. Caregivers can use an interface similar to Figure 4 to read real-time sensor data, download historical data, perform various analyses, or set up event-driven messages (mobile phone short messages or email messages) once any sensor is activated.

(3) Integrating RFID with PTMS

Figure 5 shows the structure of a PTMS-based entrance guard system. Radio Frequency Identification (RFID) readers combined with optical switches are used as the sensors in the PTMS. The DDS is also connected to a mobile phone “Short message Module for Data Transmission (SMDT in Figure 5)”. When a person with an RFID tag passes through the entrance, the RFID receiver identifies the ID and sends it to the DDS. Combined with the sensor signals from the optical switches, the DDS can also identify whether the person is entering or leaving. This event is then logged in the DDS. An email or a mobile phone short message is sent to the management personnel if a specific event is detected. This system can be used for ADL monitoring of the elderly at home, and it also finds applications in nursing homes, hospitals and kindergartens.
A great percentage of the elderly has sleep problems. Figure 6 shows the structure of a PTMS-based sleep quality monitoring system. Special-designed sensors are connected to the DDS to evaluate sleep quality from the subject’s external behaviors (body temperature, body movement, breath, and snoring). The sleep quality sensors are designed in an unrestrained, non-conscious way, so that long-term sleep quality monitoring can be performed in a home environment – on the subject’s own bed. From the external behavior signals instead of vital signs (e.g. brain waves), the algorithm built in the DDS can determine sleep quality indices such as the time in bed, sleeping time, latent period, times of awakening.
(5) VSPs monitoring

Commercial VSP measuring devices can be integrated with the DDS for VSPs monitoring, including body temperature, blood pressure, weight, glucose and ECG. Integration of an electronic sphygmomanometer and a glucose monitor with DDS has been successfully demonstrated. The data acquired from these two measuring devices can be transmitted to the DDS through RS-232 serial interface for data processing, storage, and further analyses.

The application board of the DDS is also adapted to become an ECG Holter. ECG impulse signals are sent to the DDS for signal processing, including amplification, DC-bias isolation, A/D conversion and digital filtration. With built-in algorithm in DDS, QRS wave, RR-internal, heart rate (sphygmus) can be calculated, and the possible occurrence of arrhythmia can be predicted. ECG waveform and resulting data can be displayed on a PC which DDS is connected to, or remote PC clients through the Internet in real time. These data are also stored in the MMC using the FAT16 file format, and can be later accessed by doctors through the Internet for evaluation of cardiovascular diseases.

4. Telepresence Robot

Telepresence means visual, kinesthetic, tactile or other sensor feedback from the teleoperator to the human operator that is sufficient and properly displayed such that the human operator feels that he is present at the remote site, and that the teleoperator is an extension of his own body [9]. “Dr.Robot” developed by InTouch Health Inc. is a good
application example of a telepresence robot [10]. The doctor can drive this telepresence robot to patrol and check up on patients.

Aging is associated with an increased risk for isolation. A telepresence robot (Figure 7) is designed to provide a new way of communication and a possible tool for telehomecare visit by a healthcare provider at his/her residence. Basically, the telepresence robot is a “mobile DDS”, which integrates various sensors, a network IP camera with audio module, a wireless LAN access point, actuators, and batteries, altogether inside a vehicle. Users can control the movement of telepresence robot from a remote client PC to move around. Two-way audio and one-way video communication can be transmitted through the Internet. Any PTMS-related function can be carried out as well.

The telepresence robot also has the ability to perform fundamental autonomous behaviors when not being controlled, such as following a given track, detecting obstacles, and auto-charge at low-battery capacity.

![Figure 7. Tele-presence robot](image)
5. Discussion and Future Work

Although the usefulness of home telehealth systems has been recognized in many studies, expectations for its widespread adoption have not been realized. This paper presents an on-going project of developing the PTMS, which aims to satisfy the needs for efficient and individualized home telehealth systems with limited financial resources. What sets this work apart from most other systems is the focus on a highly distributed monitoring model (and the portable nature of the system) together with a mobile robot. We believe that this is the approach that is needed to make such systems economically viable and acceptable to the end-users. The PTMS also provides a solution to the shift from provider-driven home telehealth systems to user-centered home telehealth systems.

Several PTMS applications are demonstrated. A patent portfolio of the PTMS (Figure 8) is constructed to provide a system level concept of the various applications of the PTMS. Some of these applications have been tested in practical environments, and are proven to be stable and reliable in collecting, transmitting, and storing sensing data. The elderly people and their caregivers are the main target users when this project was first initiated. Currently, the environmental, ADL and the VSP monitoring systems are under long-term evaluation by the users and caregivers in a nursing home for the elderly, and by several selected elderly who live in their homes. The future work will focus on the commercialization of the PTMS to provide a portable, low-cost, user-centered tool for home telehealth.
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Reference

