Development of a Smart Health Monitoring and Evaluation System

Leroy L. Chan, Branko G. Celler, Nigel H. Lovell
Biomedical Systems Laboratory, School of Electrical Engineering and Telecommunications
University of New South Wales, Anzac Parade, Kensington
Sydney NSW 2052, Australia

Abstract- This article describes the design and implementation of a health monitoring and evaluation system based upon wireless technologies. The system provides a complete, end-to-end and scalable solution for a wide range of applications ranging from remote healthcare monitoring of elderly people living alone to health management for all the residents in an aged-care facility under a limited number of staff. The major benefits of such a system include its pervasive and unobtrusive nature, an elevated objectivity level and hence quality in health assessment and a significant reduction in service provision cost. The system architecture encompasses the abilities to collect multiple types of data from both static and mobile sensors, transfer such data over either a homogeneous or hybrid wireless network to a central server, and perform data fusion to extract vital information about the health status of the person being monitored.

I. INTRODUCTION

An aging population is one common challenge faced by many developed countries nowadays. While on one hand a prolonged average life-span certainly reflects on the improved quality of living, on the other hand it presents a lot of economical and social problems never faced before. In Australia, 13% of the population is aged 65 years and over in year 2002 and it is expected that, by the year 2051, this number will increase to 26% [1]. This is considerably lower than figures already current for many European countries [2]. Reports have also shown that within this group of the population, 93% have at least one chronic disease in 2004 [3] and this age group consumes 28.3% of the government expenditure on providing health services [4]. Apart from this economical implication, a large proportion of this age group lives in private dwellings. Whether this reflects on the severely insufficient places in aged-care facilities or is purely a matter of choice, better support for the healthcare need of the elderly living alone should become a major social consideration in the 21st century.

In recent years, technological advances in the areas of sensor instrumentation, short and medium range wireless communication platforms together with the ever increasing computational power in silicon IC running at a significantly reduced power consumption rate have made health telecare a reality. In general, health telecare refers to the mode of healthcare delivery in which certain types of traditional healthcare services previously carried out face-to-face with a healthcare staff can now be delivered remotely to the recipients’ homes using telecommunications infrastructure. Over the past few years different researchers have made promising efforts in this area of study. For example, electrocardiogram (ECG) from human subjects can be collected as described in the works of [5], and [6] using the IEEE 802.15.4 wireless standard over the 2.4 GHz band. In particular, Zhao et al have demonstrated [5] the collection of up to 5 ECG samples from different subjects simultaneously. Yet the authors also pointed out that time delay between data transmissions is approximately less than 125 ms but can increase when more sensor nodes are active. Significant effort has been made in the collection of neural signal samples by the authors of [7] and [8]. A bandwidth of over 1Mbps is required to re-construct neural signals accurately and thus Parthasarathy et al [8] have chosen to use the IEEE 802.11 standard in data transmission although this would imply increased power consumption requirements. Kameda et al [9] proposed the use of electric field sensors in an attempt to monitor human behavior based on the use of domestic appliances. Attempts have been made by the authors of [10], [11] and [12] to create an integrated physiological data collection system to support healthcare delivery to the elderly and the chronically ill. Researchers of [13] made one rare but noticeable attempt in making the wireless sensor network more pervasive in nature by deploying sensors both on the subject as well as within the ambient environment in which the subject will interact with. These are used to detect unobtrusively the daily living pattern of subjects.

This article aims at taking the research in this area one step further. It provides an overview of a low-cost, low-power health telecare system under current development at the University of New South Wales that encompasses the abilities to unobtrusively collect multiple types of data from both static and mobile sensors pervasively deployed with timing accuracy, transfer such data over either a homogeneous or hybrid wireless network to a central server, and perform data fusion to extract vital information about the health status of the person being monitored. This system is designed to address the forthcoming healthcare need of the elderly and the chronically ill in the 21st century.

II. METHOD

The major features of this system are its scalability, pervasiveness, unobtrusiveness and readiness to integrate with various existing building configurations.

A. System Implementation

The system can be broken down functionally into four different layers. These include data collection and data
conditioning (by sensors units equipped with intelligence), data transfer (via RF communication link in a homogeneous or hybrid configuration) and data management (by end server).

From the hardware perspective the system consists of a few standalone devices, each spanning across one or more functional layers as described above. The sensor units, for instance, were designed to take advantage of a dual-microcontroller architecture. A generic motherboard provides access to an 802.15.4-based, ZigBee ready RF module controlled by an ultra low power, 16-bit microcontroller. Connection pins are provided on the motherboard to allow various daughter boards to be “piggybacked” to form different sensor units. Each daughter board consists of a specific type of sensor controlled by another microcontroller. The whole unit is supplied by a single Lithium-polymer rechargeable battery permanently connected to the motherboard under the control of a charging and protective circuit. Fig. 1 shows the look of the motherboard and a daughter board. Fig. 2 is a photo of the motherboard “piggybacked” with the daughter board to form a complete sensor unit.

The robustness of this sensor unit design provides many advantages. This includes better system scalability since a different sensing unit can be produced by simply designing a different daughter board with the particular sensing element. The system cost can also be reduced since various types of off-the-shelf sensors can be deployed by ensuring the correct interface is provided on the daughter board to access the RF section on the motherboard. The unit is also more efficient in power usage since the RF section (including the microcontroller) can be put to sleep mode if not transmitting or receiving and likewise for the sensing part. This counts heavily towards the system obtrusiveness as a whole since having a long-lasting system will imply less disturbances to the user in terms of battery recharging. If desired, the motherboard can even be used as a standalone device to provide identification information.

Apart from acting as static sensors collecting ambient data such as movement within a room, weight generated by a person lying in bed, or even simple parameters such as light intensity, temperature and humidity, the sensor units are expandable to become mobile to provide vital information about the health status of a person. ECG, heart rate, body temperature, blood pressure and oxygen content data can all be collected by specifically-built daughter boards (or multiple sensors can also be integrated into a single daughter board). A daughter board, namely the Triax device, has been built to collect acceleration data in three axes and also integrate an alarm button and a voice circuit for emergency assistance. The whole sensor unit is designed to fit within a clip-worn box of dimensions 55(W) x 70(H) x 17(D) mm, making it ideal for uninterrupted and pervasive data collection. Fig. 3 shows a photo of the clip-worn box in which the sensor unit can fit into.

Data conditioning circuitry is included on each daughter board to perform specific functions such as input scaling and filtering before the data signal is fed into the microcontroller via an on-chip, 16-channel A/D converter and stored in the built-in RAM. The microcontroller then transfers the digitized data to the microcontroller on the motherboard for transmission via an SPI interface. An extra 512 kB flash RAM chip is available on the daughter board to buffer data should the communication link between the microcontrollers become temporarily unavailable or the data collection rate exceed the data transfer/transmission rate. Each sampled data is time-stamped at the point of sampling to ensure that the signal can be correctly reconstructed in the end regardless of when the signal is being transmitted.

The software that resides in the microcontroller on the daughter board provides intelligence to decide if all data collected should be transferred to the motherboard. For example, the Triax device collects data of 2 bytes in length at a sampling rate of 45 Hz. To transfer all this data continuously would consume a great deal of bandwidth and power. Eventually this can potentially block other sensor units from transmitting their data via the RF link. Therefore the microcontroller has been programmed with enough intelligence to execute the option of analyzing the data and deciding on an appropriate posture classification or energy level for that set of data. This will then generate a status summary for the data collected that can be transferred to the motherboard for transmission.

![Fig. 1. The motherboard (left) and a daughter board with an alarm button (right)](image1)

![Fig. 2. The complete sensor unit](image2)

![Fig. 3. The whole sensor unit can fit into this box and become mobile](image3)
The data transfer layer takes care of data exchange between the sensor units and the end server. Both the sensor units and the end server utilize the same motherboard design with different software to perform different network roles. Depending on application and building configuration, a homogeneous or a hybrid network topology can be deployed. In the case of monitoring an aged individual living alone the simple star network such as the one in Fig. 4 can be used which sees the end server also acting as the 802.15.4 PAN (Personal Area Network) coordinator while the sensor units are the PAN nodes. Up to 65536 logical nodes can be supported within the same 802.15.4 PAN. The typical range of the 802.15.4 standard (100 meters indoor and over 200 meters outdoor line-of-sight with the inverted-F PCB antenna have been tested) would be able to provide coverage for all areas within a house so that one coordinator is sufficient. To cover an area larger than the typical range of a 802.15.4 network, as in the case of an aged-care facility, a hybrid network can be deployed. A hybrid network takes the form of multiple 802.15.4 PANs integrating with an 802.11 WLAN. Each room maintains an individual 802.15.4 star-typed network but the coordinator is connected to another piece of specifically-designed hardware which transforms 802.15.4 signals to 802.11 signals. Such a coordinator is called a Bridge. An example of such a network topology is shown in Fig. 5.

All bridges are in turn, network nodes of the larger WLAN coordinated by the end server. As such, the data transfer layer is designed to maximize flexibility and scalability and can be readily integrated into any existing building structures since no wires or cables are involved.

Finally, the end server performs all the functions of managing the data received including data fusion, data reconstruction, data storage, feature extraction and alert generation, just to name a few. The server also has direct control over when sensors should start and stop collecting data and when bridges should send accumulated sensor data to the server. The server is also capable of ensuring each individual sensor is time-synchronized with the server to guarantee the accuracy of each time-stamp applied on each sampled data.

B. System Application

One cutting-edge application of this system is to provide an alternative to the existing Resident Classification Scale (RCS) used by the Australian healthcare sector.

The Commonwealth Government of Australia adopts a comprehensive but lengthy process in determining the level of financial subsidy each resident living in an aged-care facility should receive. The Residential Care Manual (RCM) [14] documents this procedure. Each aged-care center is required to perform a classification appraisal for new residents and annually for existing residents. The appraisal process is score-based. Every resident assessed will be given a rating for each of the twenty-one appraisal questions listed on the RCS. Pre-defined weights are then applied to these ratings before they are added to generate a final score. This score corresponds to one of the eight classification categories, with Category One the highest. A higher category reflects the higher degree of care provided to the resident and justifies a higher level of government subsidy.

Despite the comprehensiveness of the RCM that ensures taxpayer money is spent on those who need them most, the whole appraisal system is manual and consumes significant amount of time for the aged-care facility staff.

Our system can potentially deliver an automated version of the appraisal system to comply with the RCM but at a reduced cost and increased objectivity. Static and mobile sensor units can be deployed to target some of the care areas of focus as described by the RCM as shown in Table 1.

For instance, the care area of “Toileting” relates to the degree of assistance required by the resident to use a toilet. This includes any kind of toilet such as a commode, urinal, bedpan or a continence sheet [14]. A resident with problems of attending the toilet independently will most likely require assistance from the nursing staff. As a result the Triax data will reflect the relative inactiveness of the resident. Identification tags worn by the resident and the
TABLE 1. SOME FOCUS CARE AREAS FROM RCM

<table>
<thead>
<tr>
<th>Communication</th>
<th>Mobility</th>
<th>Eating and Drinking</th>
<th>Personal Hygiene</th>
<th>Toileting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bladder Management</td>
<td>Bowel Management</td>
<td>Problem Wandering or Intrusive Behavior</td>
<td>Emotional Dependence</td>
<td>Social and Human Needs of Resident</td>
</tr>
<tr>
<td>Technical and Complex Nursing Procedures</td>
<td></td>
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staff will show the relatively higher frequency of the two people located in the same room while at the same time both the motion sensor and light sensor situated in the toilet record some activities. All this data will be collected and analyzed by the end server to decide that for this aspect of living the resident does require a higher level of care.

Different types of sensors can be used to objectively measure a specific care area of focus.

III. RESULTS

As shown in Fig. 6, the overall system has been designed with scalability, pervasiveness and unobtrusiveness in mind. The hardware components are modular, small in volume, power efficient and intelligent. More importantly, its wireless nature means that it can be retro-fitted into existing houses or buildings without the need of any modifications to the building structure itself. Its modular design concept implies that the components can be upgraded or replaced individually without affecting others.

IV. CONCLUSION

The flexibility of our system, suggests that if adopted on a wide basis both in individual homes and nursing homes, the system can alleviate the pressure on the Australian healthcare system by: (a) ensuring those elderly living alone are regularly monitored for health status changes and existing chronic conditions; and (b) providing a cost-effective, accurate and objective solution to determining the level of subsidy to nursing home residents.

![Fig. 6. The model of the overall system](#)