A Wireless Sensor Network for Assisted Living at Home of Elderly People

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Abstract. This paper introduces an ubiquitous wireless network infrastructure to support an assisted living at home system. This system integrates a set of smart sensors which are designed to provide care assistence and security to elderly citizens living at home alone. The system facilitates privacy by performing local computation, it supports heterogeneous sensor devices and it provides a platform and initial architecture for exploring the use of sensors with elderly people. We have developed a low-power multihop network protocol consists of nodes (Motes) that wirelessly communicate to each other and are capable of hopping radio messages to a base station where they are passed to a PC (or other possible client). The goal of this project is to provide alerts to caregivers in the event of an accident, acute illness or strange (possibly dangerous) activities, and enable monitoring by authorized and authenticated caregivers. In this paper, we describe ubiquitous assistential monitoring system at home. We have focused on the unobtrusive habitual activities signal measurement and wireless data transfer using ZigBee technology.

Keywords: Pervasive computing, ubiquitous monitoring, wireless sensor networks, smart sensors.

1 Introduction

Increasing health care costs and an aging population are placing significant strains upon the health care system. Small pilot studies have shown that meeting seniors' needs for independence and autonomy, coupled with expanded use of home health technologies, and provide improved assistential outcomes. Difficulty with reimbursement policies, governmental approval processes, and absence of efficient deployment strategies has hampered adopting non-obtrusive intelligent monitoring technologies.

A wireless sensor network is an infrastructure comprised of sensing (measuring), computing, and communication elements that gives to the caregiver the ability to instrument, observe, and react to events and phenomena in a specified

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environment. Typical applications include, but are not limited to, data collection, monitoring, surveillance, and medical telemetry. In addition to sensing, one is often also interested in control and activation.

There are four basic components in a sensor network: (1) an assembly of distributed or localized sensors; (2) a wireless-based network; (3) a central point of information clustering (usually called base station); and (4) a set of computing resources at the central point (or beyond, e.g. personal computer board or other device like PDA) to handle data correlation, event trending, status querying, and data mining. In this context, the sensing and computation nodes are considered part of the sensor network; in fact, some of the basical computation may be done in the network itself. The computation and communication infrastructure associated with sensor networks is often specific to this environment and rooted in the device and application-based nature of these networks. For example, unlike most other settings, in-network processing is desirable in sensor networks; furthermore, node power (and/or battery life) is a key design consideration. The information collected is typically parametric in nature, but with the emergence of low-bit-rate signals algorithms, some systems also support these types of media. ZigBee communication technology has many advantages for the field of teleassistence and telemedicine. It enables ubiquitous assistential monitoring unobtrusively. Using ZigBee technology any problems regarding bandwidth, speed and battery life can be solved.

Projects on home health monitoring and telemedicine have been performed for two decades. In the paper of Choi et al. [1], Figueredo and Dias [2] or Eklund et al. [3], Virone et al. [4,5] home care system project was described. In this paper, we describe an ubiquitous assistential monitoring system at home. We have focused on the unobtrusive habitual activities signal measurement and wireless data transfer using ZigBee technology.

2 Application Scenario

A first prototype scenario is being developed in which a user will have a home assistence system that is able to monitor his or her activity in order to detect incidents and uncommon activities. The protoype house or scenario has a bedroom, a hall, a corridor, a toilet, a kitchen, and a living room. Movement sensors are installed in each location. Moreover, in the bedroom there is a pressure sensor in bed; in the hall, a magnetic sensor to detect the opening and closening of the entrance door, and in the sofa of living room another pressure sensor. All sensor boards have a complementary temperature sensor. The data is gathered from sensors mounted in the home. The sensor events are transmitted by the wireless sensor network to the base station by means ZigBee technology. A gateway is also included in the system to allow continuous monitoring. The gateway receives the events from the sensors through base station and decides what the appropriate action to take will be. Options could include querying the user to check on their status, storing (or forwarding) data on the event for future analysis by a assitential care provider, placing a telephone call to a care provider, relative or health care service, or other options. Fig. 1 shows a schematic overview of the system.

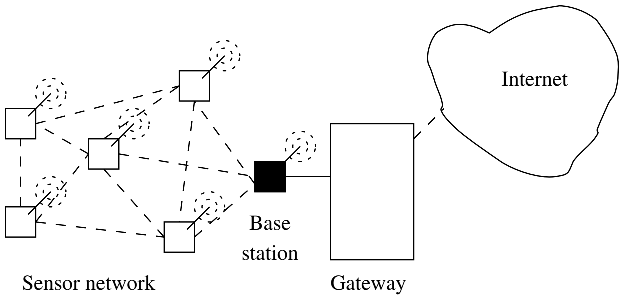

Fig. 1. Schematic overview of the system

The main idea consits in monitoring the person living alone in his home without interacting with him. To start, it is needed to know if he is at home in order to activate the ubiquitous custodial care system. It is easy to know by the context if a resident is at home knowing that the entrance door was opened and movement in the hall was detected. By means of distribuited sensors installed in each room at home we can know the activities and the elderly location. On the other hand, as the pressure sensors are located in the bed and the favorite sofa in the living room, we can know more of where he is even if he is not in movement. All this sensorial assembly will be ruled by an artificial intelligent software which will allow to learn of elderly diary activities. If the system detects a suspicious event, i.e., movement in any room at 12 a.m and pressure in the bed, then the system give an alert to the caregiver.

2.1 Assembly of Distributed Sensors

The basic functionality of a WN generally depends on the application and type of sensor device. Sensors are either passive or active devices. Passive sensors in single-element form include, among others, seismic-, acoustic-, strain-, humidity-, and temperature-measuring devices. Passive sensors in array form include optical- (visible, infrared 1 mm, infrared 10 mm) and biochemical-measuring devices. Arrays are geometrically regular clusters of WNs (i.e., following some topographical grid arrangement). Passive sensors tend to be low-energy devices. Active sensors include radar and sonar; these tend to be high-energy systems.

Activity monitoring can be beneficial for elderly people who live alone at home. By means of using electronic technologies to assist and monitor elderly, disabled, and chronically ill individuals in the home can improve quality of life, improve health outcomes, and help control assistential care. This is done with mote devices developed by us which are based on Iris mote from Crossbow [6]. The mote board developed by us uses a single channel 2.4 GHz radio to provide bi-directional communications at 40 Kbps, and an Atmel Atmega 1281 micro-controller running at 8 MHz controls the signal sampling and data transmission. The wireless sensor node is powered by a pair conventional AA batteries and a DC boost converter provides a stable voltage source. Fig. 2 shows a schematic overview of sensor node architecture.

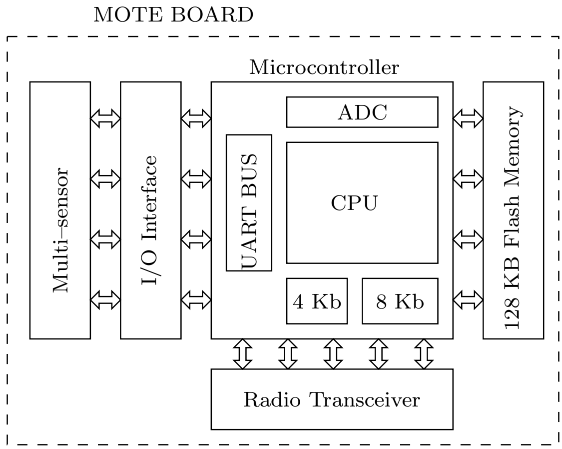

Fig. 2. Sensor node

This mote board was designed by us and provides basic environmental sensing, and expansion for other sensing functionality. In the near future, wearable sensors could be also included which could measure and analyze the users health as biomedicals signals (ECG, heart rate, etc) and activity such falls. Among other things because we have implemented an integrated antenna on the same board. The assembly of distribuited sensors are integrated in a mesh network. A mesh network is a generic name for a class of networked embedded systems that share several characteristics including: Multi-Hop– the capability of sending messages peer-to-peer to a base station, thereby enabling scalable range extension; Self-Configuring– capable of network formation without human intervention; Self -Healing– capable of adding and removing network nodes automatically without having to reset the network; and Dynamic Routing– capable of adaptively determining the route based on dynamic network conditions (i.e., link quality, hop-count, gradient, or other metric). Our multihop protocol is a full featured multi-hop, ad-hoc, mesh networking protocol driven for events [7] [8] [9]. This protocol is a modified protocol based on Xmesh developed by Crossbow for wireless networks. A multihop network protocol consists of nodes (Motes) that wirelessly communicate to each other and are capable of hopping radio messages to a base station where they are passed to a PC or other client. The hopping effectively extends radio communication range and reduces the power required to transmit messages. By hopping data in this way, our multihop protocol can provide two critical benefits: improved radio coverage and improved reliability. Two nodes do not need to be within direct radio range of each other to communicate. A message can be delivered to one or more nodes in-between which will route the data. Likewise, if there is a bad radio link between two nodes, that obstacle can be overcome by rerouting around the area of bad service. Typically the nodes run in a low power mode, spending most of their time in a sleep state, in order to achieve multi-year battery life. On the other hand, the node is woke up when a event happened by means of an interruption which is activated by sensor board when an event is

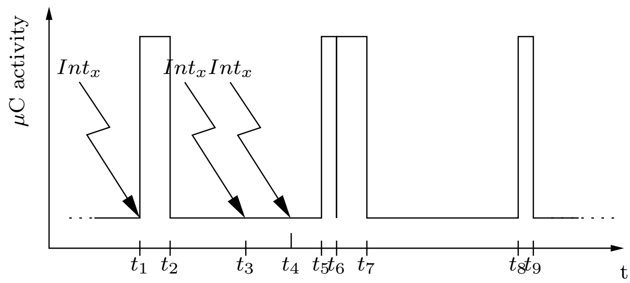

Fig. 3. Composite interruption chronogram

detected. Also, the mesh network protocol provides a networking service that is both self-organizing and self-healing. It can route data from nodes to a base station (upstream) or downstream to individual nodes. It can also broadcast within a single area of coverage or arbitrarily between any two nodes in a cluster. QOS (Quality of Service) is provided by either a best effort (link level acknowledgement) and guaranteed delivery (end-to-end acknowledgement).

2.2 Sensor Data Monitoring

Inside the sensor node, the microcontroller and the radio transceiver work in power save mode most of the time. When a state change happens in the sensors (an event has happened), an external interrupt wakes the microcontroller and the sensing process starts. The sensing is made following the next sequence: first, the external interrupt which has fired the exception is disabled for a 5 seconds interval; to save energy by preventing the same sensor firing continuously without relevant information. This is achieved by starting a 5 seconds timer which we call the interrupt timer, when this timer is fired the external interrupt is rearmed. For it, there is a fist of taking the data, the global interrupt bit is disabled until the data has been captured and the message has been sent. Third, the digital input is read using the TinyOS GPIO management features. Fourth, battery level and temperature are read. The battery level and temperature readings are made using routines based on TinyOS ADC library. At last, a message is sent using the similar TinyOS routines. In this way, the message is sent to the sensor parent in the mesh. The external led of the multisensor board is powered on when the sending routine is started; and powered off when the sending process is finished. This external led can be disabled via software in order to save battery power.

An events chronogram driven for interruption is shown in the Fig. 3, where next thresholds was established: $t_2 - t_1 < 125$ ms, $t_3 - t_1 < 5$ s, $t_4 - t_1 < 5$ s, $t_5 - t_1 = 5$ s, $t_6 - t_5 < 1$ ms, $t_7 - t_6 < 125$ ms, $t8\_t_6 = 5$ s and $t_9 - t_8 < 1$ ms.

The description of the Fig. 3 is as follows: at t_1 an external interrupt Int_x has occurred due to a change in a sensor. The external interrupt Int_x is disabled and the interrupt timer started. The sensor data is taken. The message is sent and the external led of our multisensor board is powered on. At t_2 the send process is finished. The external led is powered off. At t_3, an external interrupt Int_x has occurred. The exception routine is not executed because the external interrupt Int_x is disabled. The interrupt flag for Int_x is raised. At t_4, another interruption has occurred but the interruption flag is already raised. At t_5, the interrupt timer is fired. The external interrupt Int_x is enabled. At t_6, the exception routine is executed because the interrupt flag is raised. The external interrupt Int_x is disabled and the interrupt timer started. The sensor data is taken. The message is sent and the external led powered on. At t_7: The send process has finished. The external led is powered off. At t_8, the interrupt timer is fired. The external interrupt Int_x is enabled.At t_9, there are not more pending tasks.

2.3 Base Station

The event notifications are sent from the sensors to the base station. Also commands are sent from the gateway to the sensors. In short, the base station fuses the information and therefore is a central and special mote node in the network. This USB-based central node was developed by us also. This provides differents services to the wirelesss network. First, the base station is the seed mote that forms the multihop network. It outputs route messages that inform all nearby motes that it is the base station and has zero cost to forward any message. Second, for downstream communication the base station automatically routes messages down the same path as the upstream communication from a mote. Third, it is compiled with a large number of message buffers to handle more children than other motes in the network. These messages are provided for TinyOS, a open-source low-power operative system. Fourth, the base station forwards all messages upstream and downstream from the gateway using a standard serial framer protocol. Five, the station base can periodically send a heartbeat message to the client. If it does not get a response from the client within a predefined time it will assume the communication link has been lost and reset itself.

This base station is connected via USB to a gateway (miniPC) which is responsible of determining an appropriate response by means of an intelligent software in development now, i.e. passive infra-red movement sensor might send an event at which point and moment towards the gateway via base station for its processing. The application can monitor the events to determine if a strange situation has occurred. Also, the application can ask to the sensors node if the event has finished or was a malfunction of sensor. If normal behavior is detected by the latter devices, then the event might just be recorded as an incident of interest, or the user might be prompted to ask if they are alright. If, on the other hand, no normal behavior is detected then the gateway might immediately query the user and send an emergency signal if there is no response within a certain (short) period of time. With the emergency signal, access would be granted to the remote care provider who could log in and via phone call.

2.4 Gateway

Our system has been designed considering the presence of a local gateway used to process event patterns in situ and take decissions. This home gateway is provided with a java-based intelligent software which is able to take decission about different events. In short, it has java application for monitoring the elderly and ZigBee wireless connectivity provided by a USB mote-based base station for our prototype. This layer stack form a global software architecture. The lowest layer is a hardware layer. In the context awareness layer, the software obtains contextual information provided by sensors. The middle level software layer, model of user behaviour, obtains the actual state of attendee, detecting if the resident is in an emeregency situation which must be solved. The deep reassoning layer is being developed to solve inconsistences reached in the middle layer.

The gateway is based on a miniPC draws only 3-5 watts when running Linux (Ubuntu 7.10 (Gutsy) preloaded) consuming as little power as a standard PC does in stand-by mode. Ultra small and ultra quiet, the gateway is about the size of a paperback book, is noiseless thanks to a fanless design and gets barely warm. Gateway disposes a x86 architecture and integrated hard disk. Fit-PC has dual 100 Mbps Ethernet making it a capable network computer. A normal personal computer is too bulky, noisy and power hungry.

The motherboard of miniPC is a rugged embedded board having all components– including memory and CPU– soldered on-board. The gateway is enclosed in an all-aluminum anodized case that is splash and dust resistant. The case itself is used for heat removal- eliminating the need for a fan and venting holes. Fit-PC has no moving parts other than the hard-disk. Fig. 4 shows the gateway ports base station and our mote board.

3 Results

Fig. 4 shows the hardware of the built wireless sensor node provides for our mote board. In our prototype, a variable and hetereogeneous number of wireless sensor nodes are attached to our multisensor boards in order to detect the activities of our elderly in the surrounding environment, and they send their measurements to a base station when an event (change of state) is produced or when the gateway requires information in order to avoid inconsistences. The base station can transmit or receive data to or from the gateway by means of USB interface. It can be seen that the sensor nodes of the prototype house detect the elderly activity. The infrared passive, magnetic and pressure sensors have a high quality and sensivity. Also, the low-power multihop protocol works correctly. Therefore, the system can determine the location and activity patterns of elderly, and in the close future when the intelligent software will learn of elderly activities, the system will can take decisions about strange actions of elderly if they are not stored in his history of activities. By now, the system knows some habitual patterns of behavior and therefore it must be tuning in each particular case. Additionally, connectivity between the gateway exists to the remote caregiver station via a local ethernet network. The gateway currently receives streamed sensor data so that it can be used for analysis and algorithm development for the intelligent software and the gateway is able potentially to send data via ethernet to the caregiver station. As the transmission is digital, there is no noise in the

Fig. 4. Gateway based on miniPC, Mote board and base station

signals. It represents an important feature because noise effects commonly hardly affect telemedicine and assistence systems. The baud rate allows the transmission of vital and activity signals without problems. The discrete signals (movement, pressure and temperature, for example) are quickly transmitted. Nevertheless, spending 5 seconds to transmit an signal sample or event does not represent a big problem. Moreover, the system can interact with other applications based on information technologies. Using standards represents an important step for integrating assisted living at home systems.

The system was implemented as previously we have described. As mentioned, the system uses Java programming language in order to describe the activity of the elderly and take a decision. The system guaranteed the transmission of a packet per less to 1 seconds, e.g. the baud rate is 57600 bps. Other signals, such as temperature, need the same time. Furthermore, lost packets are tracked, once it is using a cyclic redundancy code (CRC).

4 Discussion and Conclusions

There are a lot of sensors which can measure activities and environmental parameters unobtrusively. Among them, just a few sensors are used in our prototype home. In the future, other useful sensors will be used in experiments. For fall measurement [10], a method can be used applied using infrared vision. In addition, microphone/speaker sensors can be used for tracking and ultrasound sensors also can be used for movement. Other sensors can be easily incorporated into our system because we have already developed a small-size multisensor board. We have not done sufficient experiments on elderly people. In this paper, the experiments should be considered preliminary and more data is needed.

In the literature there is an absence of research data on a persons movement in his or her own house that is not biased by self-report or by thirdparty observation. We are in the process of several threads of analysis that would provide more sophisticated capabilities for future versions of the intelligent software. The assited living system is a heterogenous wireless network using and ZigBee radios to connect a diverse set of embedded sensor devices. These devices and the wireless network can monitor the elderly activity in a secure and private manner and issue alerts to the user, care givers or emergency services as necessary to provide additional safety and security to the user. This system is being developed to provide this safety and security so that elder citizens who might have to leave their own homes for a group care facility will be able to extend their ability to remain at home longer. This will in most cases provide them with better quality of life and better health in a cost effective manner. Also think that this assited living system can be used in diagnostic because the activity data can show indicators of illness. We think that changes in daily activity patterns can suggest serius conditions and reveal abnormalities of the elderly resident.

Summing up, we have proposed a wireless sensor network infrastructure for assisted living at home using WSNs technology. These technologies can reduce or eliminate the need for personal services in the home and can also improve treatment in residences for the elderly and caregiver facilities. We have introduced its system architecture, power management, self-configuration of network and routing. In this paper, a multihop low-power network protocol has been presented for network configuration and routing since it can be considered as a natural and appropriate choice for ZigBee networks. This network protocol is modified of original protocol of Crossbow because our protocol is based in events and is not based in timers. Moreover, it can give many advantages from the viewpoint of power network and medium access. Also, we have developed multisensors board for the nodes which can directly drive events towards an USB base station with the help of our ZigBee multihop low-power protocol. In this way, and by means of distribuited sensors (motes) installed in each of rooms in the home we can know the activities and the elderly location. A base station (a special mote developed by us too) is connected to a gateway (miniPC) by means an USB connector which is responsible of determining an appropriate response using an intelligent software, i.e. passive infra-red movement sensor might send an event at which point and moment towards the gateway via base station for its processing. This software is in development in this moment therefore is partially opperative.

This project intends to be developed with participatory design between the users, care providers and developers. With the WSN infrastructure in place, sensor devices will be identified for development and implemented as the system is expanded in a modular manner to include a wide selection of devices. In conclusion, the non-invasive monitoring technologies presented here could provide effective care coordination tools that, in our oppinion, could be accepted by elderly residents, and could have a positive impact on their quality of life.

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