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Experimental e-Health Applications in Wireless Sensor Networks

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Abstract

In this paper, we will describe the implementation and experimental analysis of a wireless sensor network application for e-Health. The main idea of the application is to use simple distributed sensor nodes in a home environment, to provide home assistants, nurses, healthcare centers and relatives with a degree of "understanding" and information about the actual persons health and activity status in order to fast determine what kind of help is needed. Another feature of the with the sensor application is the application of localization and tracking within the home environment. We propose a simple localization algorithm based on special sensor data and received signal strength indicator (RSSI) which has a low complexity suitable for small sensor networks. The experimental results show that the proposed algorithm works fine in a home environment.

1. Introduction

With the increasing growth of Internet usage among people, E-services for the healthcare which is commonly known as e-Health, have recently attracted significant attention within both the research society and industry. The reason for this is the common belief that e-Health can give extensive benefits for the patients, healthcare professionals and healthcare facilities. Because of the fast development of broadband network infrastructure, the telecare medical applications to provide long-term monitoring and healthcare by transmitting personal physical information via the Internet have become highly feasible [1].

Recently WSN has started to enter the e-Health business and there are several ongoing projects. In [2], a project called CodeBlue proposes a new architecture focusing on tracking and monitoring of patients and first responders. They use MoteTrack location system which employs many beacon nodes, which broadcast beacon messages at various transmission powers. In [3], a prototype system is built where sensor tags are placed on everyday objects such as a coffee cup or a toothbrush and the system monitors the movement of the tagged objects through tag readers. Another system is ALARM-NET [4], which is a WSN built for assisted-living and residential monitoring. In this work, infrared (IR) motion sensors are employed to gather information about a person's activity. AMON[5],Wireless Body Area Sensor Network System[6]and GlucoWatch G2[7] use WSN to research wearable personal health system that will monitor and evaluate human vital signs.

In this paper, we are presenting a wireless sensor application for e-Health which is based on a very simple RSSI algorithm and special sensor data that positions the mobile node by calculating the RSSI of its neighbors and some fix position sensors. The idea with the proposed WSN application is to monitor and localize the person within a home environment in order to fast provide home assistants, nurses, healthcare centers and relatives information about the person current health conditions. Alarm set off when they need. History body and action data provide for the necessary.

Besides the proposed position algorithm, the difference with our work compared to previous mentioned work on WSN applications for e-Health, is that this work considers tracking and localization in multiple rooms.

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The rest of the paper is organized as follows. In Section 2, a general overview of the system design is giving, including hardware design, network architecture design and software design. In Section 3, the proposed position algorithm is described and its implementation. Finally in Section 4 we conclude our work.

2. System Description

The complete system design includes three different parts: hardware design, network architecture and software design. In the following subchapters we will describe the different parts to give an overview of the working system

2.1. Hardware Design

The node works as a small computer with limited CPU, memory and battery, and it needs different driver programs when different sensors or other hardware attach to it.

The node we used in our system is MicaZ of Crossbow company, which is a 2.4 GHz, IEEE/ZigBee 802.15.4 board used for sensor networks, which owns a microcontroller ATmega128L and a RF chip CC2420. Multi-sensor board MTS310 and data board MDA300 are used in our system.

Here introduces some sensors we used.

Pressure sensor connecting to air bed with vacuum pipe is used to test if there are person on the bed or chair. Fire sensor puts in kitchen. Pulse sensor is used to measure heartbeat rate and bind on the wrist of the person acting as the mobile node (beacon node).Emergency button on person also attaches to mobile node for the emergency situation.

2.2. Network architecture design

After hardware design, network architecture is given here to show a big picture of the system.

As figure 2 shows, the network in E-Healthcare is composed by wireless and wired part. Wireless part in person home collects environment and person parameters, while wired part processes and transfers data to remote computer or PDA. Basestation with computer is the device that can either take as one node in wireless network or a node in wired network. Here we take it with gateway (a computer on internet) together as one part of wireless network.

In figure 1, wireless is expressed by dash lines, and wired part solid lines. In the wireless part, there is one mobile node and many fix location nodes. All data of them are transmitting to a basestation by wireless. The gateway receives the data from basestation and saves them in database. This part is implemented by our experimental system.

Furthermore, the gateway forwards data to the internet. Health care center, hospital and assistant will receive the data on the internet if they ordered. This will is under developing by our group.

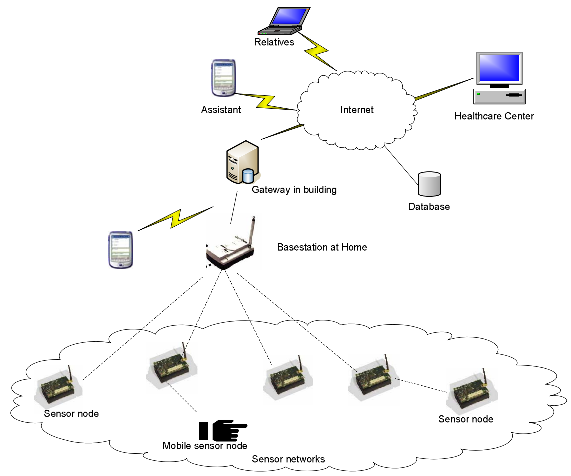

Figure 1 System architecture of wireless sensor networks for E-Healthcare

2.3. Software Design

Message flows from nodes to computer using one format frame which keeps the consistence of the software design--- node embedded programming and computer programming. Message format definition is the key of the software design.

The network uses multi-hop routing protocols. Two types of message are transmitted. One is beacon for RSSI positioning algorithm, one is message for sending all kinds of sensor data named surge message inheriting the name of sample program surge of Crossbow.

The SurgeMsg fields and bytes are described in the following tables.

Our program is changing based on the example program surge, it use MTS300 board, but we use MTS310CA and MDA300. For compatibility, microphone data fields are added in SurgeMsg fields. When MDA300 is used, *Mag* and *Accel* fields are reused for pressure or heartbeat or etc. depending on the sensor it connected.

To know which room the person is, the mobile node on the person will broadcast beacon periodically. Every node received the beacon will calculate the signal strength (RSSI) and forward the signal strength to the basestation.

Table 1 Fields of Surge message format

Byte #	Field	Description
0	Type	The type of message that indicates the action
1-2	Reading	Does not appear to be used
3-4	Parent Address	The address of the Parent Node
5-8	Sequence Number	The upper 9 bits represent the battery voltage.The remaining bits count the number of packets sent since the application was last reset
9	Light	The raw light sensor reading
10	Temp	The raw thermistor reading
11	Mag X	The raw sensor reading for the x-axis magnetometer
12	Mag Y	The raw sensor reading for the y-axis magnetometer
13	Accel X	The raw sensor reading for the x-axis accelerometer
14	Accel Y	The raw sensor reading for the y-axis accelerometer
15	MicHigh	The raw sensor reading for microphone high
16	MicLow	The raw sensor reading for microphone low

The beacon format is like this.

Table 2 Fields of beacon format

Byte #	field	Description
0-1	CountId	Beacon id
2-3	hsourceaddr	Moving node address

CountId uses to avoid the node receiving same beacon many times. Hsourceaddr is left for identifying the person. Now in our experimental system there is only one moving node, so this field sets same value.

The mobile node not only sends beacon packet but also sends sensor data packet (like heatbeat rate of the human). To distinguish the beacon packet from other packets, the message parameter is defined different to the normal surge message's, by which the receiver can guarantee the right interface to be active (The system is a real distribute one that program on the distributing nodes run by its own, and the message is the only fact to active the program).

Table 3 Fields of message after beacon received

Byte#	field	Description
0-16	surgemsg	Surgemsg fields
17-20	Signal strength	2 bytes for CountID 2 bytes for signal strength

In our experimental system, the mobile node is the beacon node that sends beacon. Other nodes receive it, get the RSSI valued and recompose the value in their next surgemsg. As table 3 shows, 2 bytes signal strength is filled in after calculating and 2 bytes CountId is copied from beacon message, and field before them is the normal surge message fields which saving sensor data and etc. CountId considered here is used to cancel the message disorder of the networks (later message may arrive earlier).

If there is no beacon message received, *Signal strength* part of the fields to be empty.

When computer reads the message, source node address in surge message fields will point out signal strength belong to mobile node and which node.

All the information for positioning algorithms is prepared.

3. Positioning algorithm

In healthcare system, we more concern where the person is and what he is doing to judge if he is ok. To positioning him, two methods are used in our experimental system. First judgment is made on some special sensor data, and if there are no sensor data to use, a simplex RSSI positioning algorithm is used.

3.1. Positioning on Sensor Data

As the hardware design introduced, several sensors are used in our system. First decision made by the special sensor value.

Definition: Given a random process $X(i) = (X_0, X_1, X_2, ..., X_{N-1})$. If the mean of the random process $m = (\sum_{i=0}^{n-1} X_i)/n$ and $\sigma_i^2 = (m - X_i)^2$.

For easy implementation, $\sigma^2 > test$ is the judge condition. $test$ is the value gotten from normal sensor test.

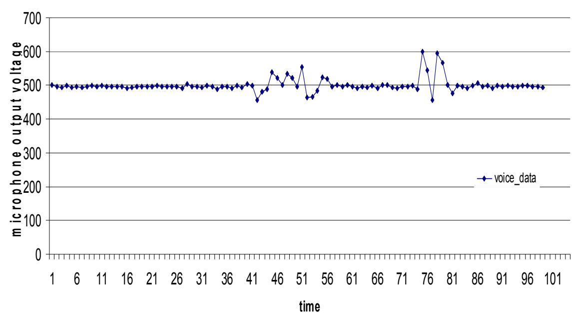

Figure 2. Water sound capture when tap opening and closing.

Take microphone to be an example, we attach the microphone of MTS310CA with MicaZ on the sewer pip. When the tap is opened, the water flows over the sewer pipe. The sound of water affects the microphone. After test, we get the water sound character in figure 2. The voice data is X(i) and m=499.7.

Most σ^2 in two times sharp change are higher than 160. Those consist with the actions opening tap.

According to the test, $\sigma^2 > 160$ is used to be the judge condition. In program, |avr_micphone-SMsg.get_micphone())|>40 is used . Here, SMsg.get_micphone() is the current voice value. avr_micphone is the average value of the test. avr_micphone must be gotten in learning stage.

The same tests are done by pressure sensor, light and others. The value of pressure sensor attaching on the air-bed on the chair is over the limit means that the person is sitting on the chair, then the decision is made that the person on the chair in the sitting room; Same will made by the pressure sensor on the bed; light sensor putting in the refrigerator to judging opening the refrigerator; moisture sensor on the MDA300 in bathroom predicting if the person in shower.

But if there are no such sensor data to give position, a simplex RSSI based positioning algorithm is executed.

3.2. Proposed RSSI Positioning algorithm

Figure 3 shows a wireless sensor network system for location estimation, where there are *N* fixed nodes and *M* target nodes. Communication along all the fixed nodes and the target nodes is based on IEEE std 802.15.4. The received RSSI vector **R** from the base station can be described as follows

$$R = [r_{1,} r_{2,} .., r_N] \qquad n = 1,2,..., N$$

where *n* is the total number of nodes within the network. Each fixed node measures the RSSI for the target node *j (j=1,...,M)* and sends the information to a sink node. The signal strength between mobile node *j* and its neighbor *i* in a particular room is given by R_i .

Now we adds the variables *p, t* and *m* into the received vector **R** in (equation) and we get $R = [p, r_{1,} r_{2,} .., r_N, t, m]$. *p* is the label of the room (bathroom, living room etc.), *t* is defines a counter of the number of non-zero RSSI values and *m* is the position sum of all non zero signals in the vector. *t, m* are used to improve the distinguish ability of the algorithm.

There are two stages for this algorithm. One is learning stage, another is decision stage. In learning stage, all the vectors are saved to form a matrix. After learning stage, the saved vector matrix should look like this,

$$\left\{ \begin{array}{lllll} p_1 & h_{11} & h_{21} & \dots h_{1n+2} \\ p_2 & h_{21} & h_{22} & \dots h_{2n+2} \\ \dots & \dots & \dots & \dots & \dots \\ p_m & h_{m1} & h_{m2} & \dots h_{mn+2} \end{array} \right\}$$

$$h_{ij} \in \{RSSI_{ij}, t, m\}$$

At decision stage, the vector matrix is read from the database.

When a new vector is gotten,

$(RSSI_1 \quad RSSI_2 \quad RSSI_3 \quad \dots \quad RSSI_n)$

It changes to $(RSSI_1, RSSI_2, ..., RSSI_n, t, m)$, we take it as $(RSSI_1, RSSI_2, ..., RSSI_n, RSSI_{n+1}, RSSI_{n+2})$

The distance algorithm is:

Calculate the $dist_i = \left\{ \sum_{i=1}^{n+2} \sum_{j=1}^{m} \left| RSSI_i - h_{ji} \right| \right\}$

In which the vector can get $\min \left\{ \sum_{i=1}^{n+2} \sum_{j=1}^{m} \left| RSSI_i - h_{ji} \right| \right\}$,

p_i is the room that the person is.

Example:

In learning stage, if $(bathroom, 23,44,6,0,0,2,0,0)$ is the raw data gotten from the program, there are 4 no zero numbers in the vector, then $t = count(if(RSSI <> 0)) = 4$, and $m = \sum_{if(RSSI_i <> 0)} position(RSSI_i) = 1+2+3+6 = 12$.

And the room name is added, the vector changes to $(bathroom, 23,44,6,0,0,2,0,0,4,12)$.

Suppose we get the matrix as following:

$$\left\{ \begin{array}{llllllll} livingroom & 0 & 23 & 340\ 0 & 0 & 0 & 0\ 2\ 4 \\ livingroom & 0 & 25 & 360\ 0 & 0 & 0 & 0\ 2\ 4 \\ bathroom & 23 & 44 & 6\ 0\ 0 & 2 & 0 & 0\ 412 \\ kitchen & 23 & 0 & 0\ 020 & 60 & 0 & 52420 \end{array} \right\}$$

If current vector we gotten is $(23,44,7,0,0,3,0,0,4,12)$, the minimal distance is: $dist_3 = 2$, 3rd vector will be the match one, and the decision will be given that the person is in *bathroom*.

3.3. Positioning implementation

To implement the proposed RSSI algorithm, it requires cooperation between the software running in both the sensor nodes and at the BS. The mobile node is periodically broadcasting beacons, all the other nodes receive beacon will needs to gather information received from the beacon and forward the signal strength to the BS, and BS forward them to the computer.

At the computer, the array containing beacon-id, node-id and signal strength is continuously monitored, updated and stored. The program waits 5 seconds to guarantee a collection of all signal strength coming from the same beacon-id and after that a new RSSI vector of *n* dimensions will be created. If the correspondence node has no signal strength (equal to 0) or that the signal strength is too large (lower than -20 dB), a 0 will be inserted into the position belonging to the node. Otherwise, we insert signal strength +100 to get a positive integer.

4. Concluding Remarks

In this paper, we have implemented and evaluated wireless sensor applications suitable for e-Health, which uses simple, distributed sensors that can easily be attached to a persons body or within an apartment for example, to easily track and monitor a persons localization in order to provide nurses, home assistants, healthcare centers and relatives information about the current status (position, hart rate etc.) of the person. A full scale implementation consisting of hardware and software design has been done in order to show the usefulness of the sensor applications. To keep track on the person’s localization, a new simple positioning algorithm based on the RSSI measurement and special sensor data is proposed.

To evaluate the performance of the proposed wireless sensor network, we have done full scale experimental tests within an indoor environment. Totally there are 12 nodes distributed within the test apartment with 6 rooms. In the test, the system can almost correctly tell the position of the person and alarm automatically when dangerous condition happened.

The sensor applications tested in this paper are localization, voice and humidity. The data can either be transmitted immediately over the wireless sensor network to a healthcare center or store on a local database for further analysis later on. Our test results show that the simple proposed position algorithm can, achieve 89% accuracy in finding the correct localization of the person in the particularly used indoor environment. However, it should be mentioned that this ratio will be much better with the use of multi-sensor analysis which will be implemented in future tests.

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