Real-Time Sink Node Architecture for Active Healthcare USN with Service Robots

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Abstract
This paper proposes a real-time sink node system architecture for healthcare USN with a mobile service robot, which provides active service for elderly persons. Embedded sensors in USN monitor periodically user’s mental and physical condition and transfer logged data to the sink node on main controller of a mobile robot through wireless channel where data analysis is performed. For the purpose of handling emergency situations, it needs real-time processing on gathering variety sensor data, routing for sensor networks to a moving sink node and processing of logged data. This paper realized multi-hop sensor network for biometric data transmission and performed algorithms on XENOMAI, a real-time embedded Linux. In order to verify the usefulness of the proposed system, performance of data transferring and processing on a real-time OS is also evaluated.

1. Introduction

USN gathers much attention for home service[1], environmental protection[2], military purposes[3] etc. Due to the problem of aging society, there are lots of discussions over using USN for elderly people. USN will be able to provide healthcare services for them with its technology. UIUC suggested I-Living system, which includes open-softwares and hardwares to provide daily life support for the elderly people[4]. Also, AlarmNet, a system which monitors vital signs and activity patterns of the resident in homes via sensors to provide a healthcare service, was suggested [5]. I-Living system mainly focuses on the ease in use, prevention of interference in communication by other devices, and encryption of data. The system also sends out information to outside systems in order to prevent the loss of information via WLAN and bluetooth communication modules, in case if the gateway malfunctions [6]. However, the bluetooth module is expensive and consumes relatively much electrical power, so that it is disadvantageous to be used as a sensor node. Since sensor nodes must be installed independently in various locations of environment, there is a need for small amount of electrical power usage, in order to reduce the cost in forming infrastructures and to provide convenience for maintenance. Furthermore, there are several researches currently ongoing to link mobile service robots and the sensor network, in order to provide a more active service based on the data collected by sensor network, rather than passive services[7][8].

This paper proposes a sensor network structure which will provide active service using service robots. This network will be able to process various vital signs according to appropriate priorities, and provide real-time response to emergency situations of the user. The network does not have a separate stationery server, while the main control board of mobile robots performs the task of collecting data from the sensor nodes and transmitting them to the outside network, working as a gateway as well as a sink node. Also, to guarantee real-time data processing, the main boards used the Real-time Embedded Linux XENOMAI, the newest open source project, as the operating system [9]. This paper will explain the structure of the proposed system in part II, experiment results of routing methods of sensor network and the structure of real-time sink node in part III, experiment results in using mobile robots in part IV, and conclusion in part V.

2. Structure of the proposed system

In this section, we will explain the structure of Healthcare/Life-support USN system with service robots. As written before, service robot system based on the Healthcare/Life-support USN must provide (1) an efficient connection via network of the data collected by the sensor nodes, (2) less power consumption of sensor nodes but high economic efficiency, (3) sink node system which transmits various information sent from the sensor nodes to the main control, (4) and a real-time software structure to make active response to emergency situations and to process data in order of the priority. To meet such requirements, this paper proposes the USN with service robot as the follows: Sensor nodes will evaluate the health status of an elderly, while the transmission will take place on the sink nodes built within the mobile robot. The transmitted data will be transferred to the main control, which will then process it with the task provided by the real-time operating system. During the process, the mobile robot will confirm the location of the sensor nodes, and will move to the location to provide more active services such as visual monitoring or voice chatting etc. The sensor nodes, which will be spread across the living environment, will transmit the collected data to the sink nodes via the method of single hop or multi hop. To provide
more active services in this system, the sink node controller is installed on the control board of the mobile robot. The sink node will hand over the data to the main board through RS-232 interface. The data gathered on the control board will then be processed accordingly to its priorities in real-time. For example, the vital signs, such as pulse will be processed first, while other less important information will be processed later. When the system finds out an emergency situation based on the gathered data, the robot will approach the user to capture a visual image and send it to the system manager in the outside network or try to chat to the user. The collected sensor and visual data of the user in an urgent occasion will be sent to the monitoring system in near distance using broadband WLAN communication network. These data will be used to create a health record database.

For such system to perform efficiently, it is essential to have a quick data processing procedure. If the data processing is delayed, the quick response will not take place, therefore leaving the user in a dangerous situation. Also, the response to the situation by the robot will be too slow to provide the adequate service to the user.

3. Multi-hop network and the structure of real-time sink node

In this section, we will explain the structure and communication method of multi-hop, a method used to efficiently transmit the data in a sensor network. In addition, a real-time sink node structure is proposed in order to process the data gathered by sensor network in real-time.

3.1. Multi-hop Sensor Network

In order to ensure an efficient transfer of data collected by the sensor nodes, the multi-hop method, which has the Zigbee protocol, is chosen. The Zigbee has its very own protocol within the PHY/MAC class, hence preventing RF signal collision for smooth transmission between the nodes. Also, each node must reduce its power consumption for the convenience of maintenance, thus shortening the distance of data transmission range. Therefore, there is a limit for the wireless transmission of the sensor node in rage, and a single-hop transmission will not be efficient enough to transmit the data. To resolve this, there is a need for the multi-hop method, as shown in the Fig. 2, when sink node tries to collect the data from the sensor node in a long distance.

For the multi-hop data transmission, the configuration of network route to sink node from the sensor node must be set before the transmission of the data. The network route configuration must constantly be fixed accordingly to the movement of the user and the mobile robot. TinyOS provides components for multi-hop configuration, and uses packet structure shown in the Fig. 3 for network route configuration and data transmission [10-11]. In this paper, two packets are used in network route configuration and data transmission in each, hence making the efficient data processing possible. There are two kinds of message packets in multi-hop data transmission methods: the BeaconMsg, used in the configuration of network route, and the DataMsg, which is used to transmit data from the sensor nodes. The ID of the parent node of the receiving node, link cost from the sink node to parent node, and information on number of hops from sink node to receiving node are recorded on the BeaconMsg. The receiving node will configure the route to the sink node with such information (Fig. 3). DataMsg is a message structure used to transmit the collected data from the sensor node to sink node.

The route configuration algorithm provided by the TinyOS uses minimum cost policy. Here, the link cost is calculated using RSSI(Received Signal Strength Indication) and LQI(Link Quality Indication). Fig. 4(a) is the routing algorithm based on the minimal cost. In the figure, each circle indicates nodes which form the sensor network. Also, number 0 represents the sink node, number 6 denotes the sensor node, and number 1~5 are the relay nodes on the...
route.
Each node goes through initialization for the configuration of network route. Except the sink nodes, other nodes cannot create BeaconMsg independently. When sink node transmits the BeaconMsg, other nodes in the perimeter will receive the data and calculate the link cost to the parent node. The calculated cost will be compared with the previous cost, and the route will be set for the one which spends less cost. After this process, BeaconMsg will be adjusted and sent again, repeating this process until the data reaches the final node. With such process, the route with minimum link cost can be found, and sensor node will be able to transmit the data to the sink node in DataMsg.

Mobile service robot has both sink node and the main control board. Roles of the robot are listed in the following:
- Sink Node: Gathers the data received from the sensor node and hands over it to the main control board
- Active Agent: Provides an active service for the user during an emergency situation
- Gateway: Transmits the data collected and analyzed to outside monitoring network via WLAN for database

In order to perform such tasks, the service robot must be equipped with the functions listed in the following:
- Sink nodes to receive data from the sensor nodes
- Network camera to obtain the visual image of the user during the emergency
- WLAN access for remote monitoring system

In this paper, the Intel/IBM compatible i386 single board is chosen as the main controller for the mobile robot. Also, the sink node has CC2420, the wireless communication module, to receive data from the sensor nodes. Using the wireless ethernet port, the main controller is connected to the outside server which monitors every data transmitted. Within the USN, sink node will gather data from the sensor nodes via wireless network and analyze it before sending it to the remote administrator. Also, the sink node checks the network routing status frequently to provide a smooth data communicating environment. In addition, the sink node must compose a complete data from the information sent by other various devices, and then send the data in the order of importance in real-time. To have real-time data collecting and processing system in this paper, the real-time embedded Linux XENOMAI is installed on the main controller, using it as a real-time operating system. The above Fig. 5 is the structure of the sink node proposed in this paper.

The proposed system is composed of the main control board, which processes data, and the sink node, which receives information from the sensor nodes. The sink node uses TinyOS to efficiently manage limited resource. TinyOS is an appropriate operating system to provide an efficient performance within a limited hardware memory capacity. The sink node operated by TinyOS received data from the sensor nodes via Zigbee wireless communication, and relays the data to the control board through RS-232 interface. The control board uses a high-performance processor, and uses XENOMAI patched Embedded Linux as the real-time operating system. The XENOMAI and Linux kernel used in the control board are executed by HAL (Hardware Abstract Layer) for interface with the hardware. Before executing XENOMAI and Linux, HAL starts RT_Task within XENOMAI first, and Linux kernel with the lowest priority. Here, RT_TASK means the operating function registered as a real-time task within the executing program. Hence, the real-time programs are executed in priority, and when these processes are not working, the programs within Linux kernel and Linux kernel itself will be activated [11][12]. On the control board, the data from the sink node are handed over by real-time serial device driver, and processed with RT_TASK, thus enabling quick response to emergency situations.
4. Experiment and Consideration

As written before, the real-time data processing is very important within the service robot system based on the active Healthcare/Life-support USN. In order to check the validity of real-time sink node structure in this paper, the following experiments are conducted: the sink node, linked via sensor network, samples the data in 100ms range to hand over 180 parts of data in one cycle of sine curve. The sink node will communicate with control board in speed of 57,600bps through RS-232 interface. The control board activates readTask() in 100ms unit to read the received data. The read data will be sent to the dataTask() by message que, and data will be processed to be drawn into a curve. While these processes are put into work, many calculations are executed to purposely give computational loads to the processing unit. The readTask() and dataTask() are compared of their data receiving and processing capability in real-time or in non-real-time.

It takes approximately 18 seconds to draw the data, received from the transmitting nodes, into a single cycled sine curve. Fig. 6 is a comparison of data processing time in real-time(RT) and non-real-time(NRT). In real-time case, the data processing is done in definite time even if the number of load tasks increases. On the other hand, in non-real-time case, the data processing time increases as the load of tasks increase. Fig. 7 shows the data loss according to the number of load tasks. In non-real-time processing, there is a distortion in the processing time and curve. However, for real-time, there is no distortion regardless of the number of load tasks. The reason is because when the real-time serial device driver is used to process the data in real-time, the priority of the process is very high, hence preventing ISR or other processes from interrupting its process. However, the non-real-time serial device driver cannot perform the task quickly due to ISR or other processes.

![Figure 6. Data processing time according to the number of load task](image)

![Figure 7. Data distortion according to the number of load tasks](image)

5. Conclusion

This paper proposed a robot sink node structure for an active Healthcare USN which will send the vital signs of the user via sensor network and process work according to the priority to deal with emergency situation. There is no fixed server for data acquisition, but the main control board on a mobile robot will act as the sink node and gateway to outside network. To meet the requirements for mobile sink node on the robot, the routing algorithm was used to form a multi-hop sensor network. Also, embedded Linux and real-time embedded Linux XENOMAI were used to insure the real-time data processing. Also, with the experiments of gathering and processing of data collected by the sensor nodes, the comparison of performance between real-time sink node and non-real time sink node was conducted.

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6. References