Journal of Mobile Multimedia, Vol. 2, No.4 (2006) 359-370

GUARD: A GUIDE, ALARM, RECOVERY, AND DETECTION SYSTEM ON A WIRELESS SENSOR NETWORK FOR THE BLIND

HUAN-CHAO KEH, KUEI-PING SHIH, CHIH-YUNG CHANG, HUNG-CHANG CHEN, and CHIEN-MIN CHOU

Department of Computer Science and Information Engineering, Tamkang University
Tamshui 251, Taipei, Taiwan
{*kpshih,cychang*}*@mail.tku.edu.tw*

Received May 31, 2006
Revised September 20, 2006

The paper proposes a GUARD (GUide, Alarm, Recovery, and Detection) system for the blind. The main goal of the GUARD system is to construct an obstacle-aware wireless sensor network and provide guide, alarm, recovery, as well as detection functions for the blind to guarantee his safety and convenience at Tamkang University. Some hardware components as well as communication and management protocols are implemented in the GUARD system.

Keywords: The blind, deployment, MICA Mote, sensor, wireless sensor networks (WSNs).

1 Introduction

Wireless communication and MEMS (Micro-Electro-Mechanical Systems) technology have greatly advanced in recent years. As a result, sensor nodes characterized with low power, low cost, small size, and multi-functionalities are widely investigated and employed in academic and industrial fields. Wireless Sensor Networks (WSNs) composed of a large amount of wireless sensor nodes can be used in various applications, such as disaster reporting, military detection and monitoring, location tracking, environmental sampling, healthy monitoring, natural ecology monitoring, and so on. A system for the blind at Tamkang University has been constructed for years and much experience is gained with the development of computer applications for the blind, the construction of guide bricks, and the use of guide dogs. As the development of information technology, more secure, timely, and convenient services can be provided for the blind. This paper tries to utilize the previous experience to conduct the wireless and sensor technologies in order to provide a GUide, Alarm, Recovery, and Detection system (GUARD) on WSNs for the blind. This paper takes Tamkang University as a scenario to construct a WSN and establish the GUARD system. In general, energy consumption of sensors should be taken into consideration when the WSN is constructed. A sensor with an efficient energy consumption policy can perform the sensing tasks as long as possible. Therefore, this paper takes energy efficiency into consideration to construct a WSN with longer lifetime as well. Besides, the GUARD system also provides the blind with accurate location information. When walking around the campus, the blind can be aware of his location at any time and his safety can be guaranteed.

Generally, a WSN is a self-configured network, in which sensor nodes form the network topology automatically. For the different applications, many researches are proposed to meet the sensing requirements. A. Howard et al. [1] assumed that sensor nodes have the moving capability, and tried to maximize the network coverage by the movements of sensor nodes. The sensor nodes can move to the uncovered area and extend the sensing field. L. Li et al. [2] proved that each sensor having at least one neighbour in every 5/6π area of its coverage can not only maintain the network connectivity, but also decrease the power consumption. The lifetime of a WSN, hence, can be efficiently extended. F. Mondinelli et al. [3] localized all sensor nodes in a WSN through the sink. After the topology of a WSN is constructed, the best path for each sensor node to disseminate data can be found. E. L. Lloyd et al. [4] tried to compute the transmission power of every sensor node in order to minimize the total energy consumption in a WSN. H. Gupta et al. [5] proposed a centralized algorithm to solve the problem of area sensing in a WSN. Through the centralized algorithm, a best subset of sensor nodes can be found to perform the sensing tasks. Thus, other redundant sensor nodes can turn their power off to save energy. As a result, this algorithm can reduce the energy consumption of the sensor nodes.

Besides, there are many researches focusing on irregular hierarchical WSNs. Generally, this kind of researches tries to construct clusters in WSNs. How to select the appropriate cluster heads, how to prolong the lifetime of the WSN, and where to put a sink are the main challenges of this kind of researches. G. Gupta et al. [6] proposed an algorithm to control the topology of a WSN. Because sensor nodes elected as cluster heads consume energy rapidly, [6] tries to balance the number of cluster members between clusters. Consequently, every cluster head will have about the same life time after balancing the number of cluster members. However, [6] does not consider how to elect cluster heads. W.-R. Heizelman et al. [7] proposed an algorithm to solve this problem. Every sensor node will be the cluster head in turn. Hence, the energy consumption of sensor nodes becomes roughly equal.

The rest of this paper is organized as follows. Section 2 is the overview of the GUARD system. In Section 3, the deployment method of the GUARD system is described. Section 4 is the implementation of the GUARD system. Section 5 concludes this paper.

Figure 1 A scenario of a WSN at Tamkang University

2 Overview

Figure 1 shows a scenario of the GUARD system at Tamkang University. In the system, a WSN is constructed at Tamkang University. When walking around the campus, the blind can use a walking stick embedded with sensor node to receive the information from the GUARD system. In addition, through the communication among sensor nodes, the user (such as security guards and system administrators) can know the locations of the blind. Figure 2 shows the protocol stack of the GUARD system. The detailed functionalities of the GUARD system are described as follows:

- When walking around the campus, the blind can set his destination where he wants to go. During the initialization of the WSN at Tamkang University, the location of every sensor node can be known by either the capability of localization in the LLC sub-layer or robots after the sensor deployment. The GUARD system can estimate the location of the blind through the localization algorithm in the network layer. Therefore, the GUARD system is able to find the shortest path to quickly **guide** the blind to his destination.

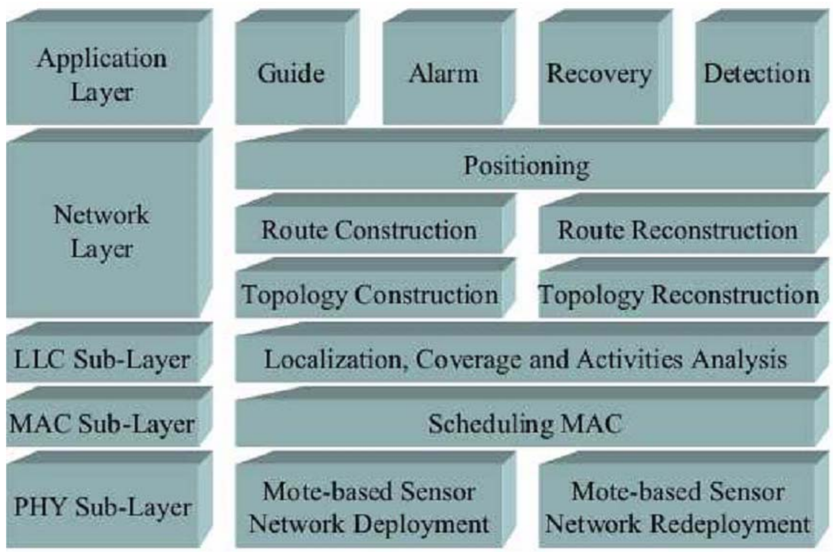

Figure 2 Protocol stack of the GUARD system

- When an object (a car or something else) is moving around the campus, sensor nodes can sense the object by means of their sensing components. The object should be viewed as an obstacle to the blind. When an obstacle is sensed by a sensor node or set by a user, the GUARD system can locate the object through the localization algorithm. Afterward the GUARD system will immediately **alarm** the blind of the danger of the nearby obstacle. Accordingly, the blind can keep away from obstacles for his safety.
- Since sensor nodes are not rechargeable, some sensor nodes will become malfunctioned after a period of working time. The GUARD system can detect the failed sensor nodes. The GUARD system will reconstruct the topology of the WSN if perceiving that some sensor nodes are failed to work. Consequently, the walking path of the blind will be quickly recalculated when the topology changes. In the GUARD system, a topology reconstruction algorithm is used in network layer to reconstruct the topology of the WSN. After the topology is reconstructed, all the routing paths will be rerouted and the walking paths of the blind will be recalculated again. Hence, the **recovery** of the activities for the blind can be performed in the GUARD system.

- The **detection** in the GUARD system is used to detect the blind, the obstacles, and the malfunction of sensor nodes. It relies on the sensing and communication components of sensor nodes. For this reason, the GUARD system communicates with the blind through wireless communications. The GUARD system will react immediately according to what sensor nodes sense. The locations of obstacles and the blind will be immediately shown on the GUI of the GUARD system. Therefore, the GUARD system can detect obstacles and the blind through sensing components and wireless communications, and react in order to serve the blind seamlessly.

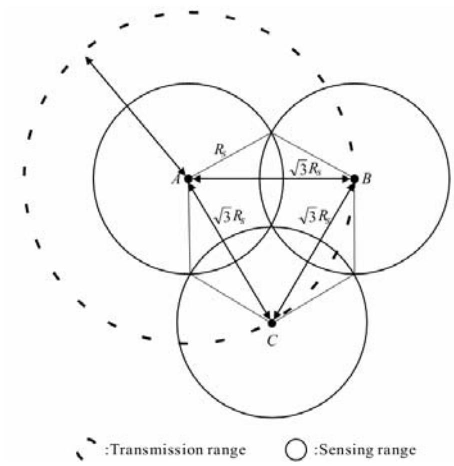

Figure 3 Distance between the sensor nodes is $\sqrt{3}\ R_s$.

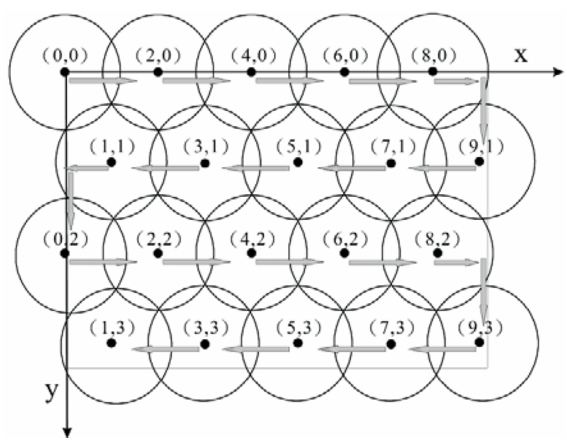

Figure 4 Coverage of the sensing field can be maximized with the fewest sensor nodes.

3. Deployment by Robots

The throughput of WSNs is highly dependent on the coverage status of sensor nodes. In order to achieve full coverage and save the hardware cost of sensor nodes, it is necessary to decrease the coverage overlap as much as possible. Figure 3 shows how three sensors cover an area with the minimum coverage overlap. Let R_s and R_c be the sensing and transmission ranges of a sensor node, respectively. R_c is assumed to be equal or larger than $\sqrt{3}\ R_s$. The sensor nodes will have the maximum coverage when the distances between the sensors are all $\sqrt{3}\ R_s$. In the conditions, sensor node *A* can communicate with sensor nodes *B* and *C*. The relation is used to design the senor deployment algorithm for robots in the GUARD system. Robots move in a snake-like manner to deploy sensor nodes during the sensor deployment. Robots will begin from the corner of the sensing region and place sensor nodes in turn. While placing sensor nodes, the robots also set the coordinate for each sensor node. Figure 4 shows the coordination system of WSNs. The coordination system is a two-dimensional system, and the coordinate of the starting point is (0, 0). Figure 5 shows that robots can circulate the obstacles by the snake-like algorithm. Consequently, every area in the sensing region can be covered by sensor nodes. The detailed description of the approach please refers to [8].

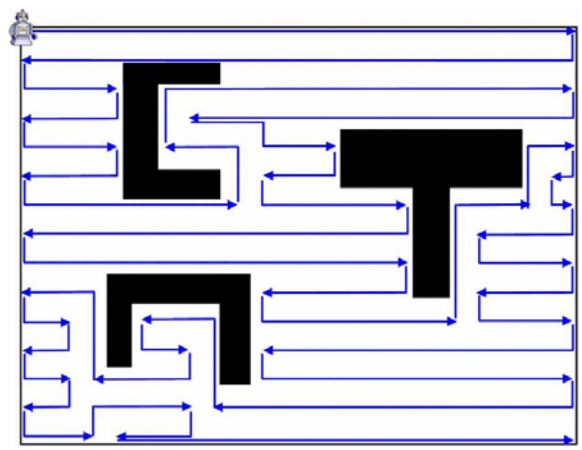

Figure 5 A robot can deploy sensor nodes in a snake-like manner.

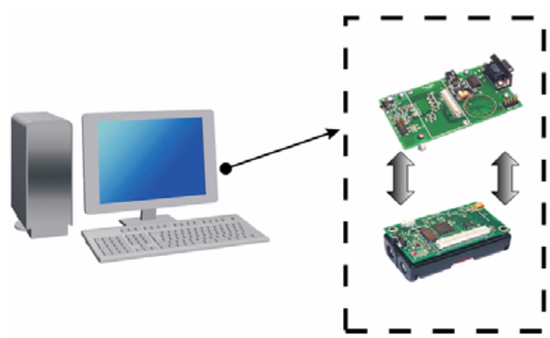

Figure 6 Basic components of a sink.

4. Implementation of the GUARD System

4.1. The Sink and Sensor Nodes

MICA2 Mote [9] modules connected to one or more personal computers play the role of the sink. When connecting to autonomous vehicles, MICA2 Mote can also play a part of mobile nodes. Figure 6 shows the concept of constructing a sink. MICA2 Mote modules are also used as the sensor nodes.

When sensing an environmental variety, a MICA2 Mote can transmit the information to another MICA2 Mote through an analog to digital converter (ADC). Figure 7 shows the basic component of a sensor node. The basic components of a sensor node are a Micro Control Unit (MCU), an RF module, sensing components, a power unit, and an I/O interface. The MCU is a micro processor responsible to compute and process the received and sensing data according to the application requirements. The RF module is the wireless communication module used for sensor nodes to communicate with other sensor nodes. Sensing Components are used for environmental sensing. Through different sensing components, sensor nodes can get different information from the environment. The I/O unit is the basic input and output device in a sensor node. The power unit supplies power to all other components in a sensor node.

4.2. Mobile Sensor Nodes

In addition to using MICA2 Motes as sensor nodes, a MICA2 Mote and an autonomous vehicle are combined as a mobile sensor. Mobile sensors can move within some region in order to substitute for malfunctioned sensor nodes. Mobile sensors can also patrol to find the malfunctioned sensor nodes.

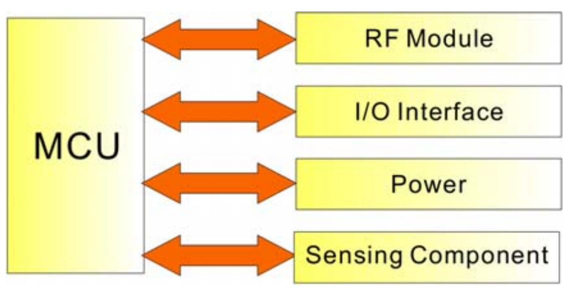

Figure 7 Basic components of a sensor node [9].

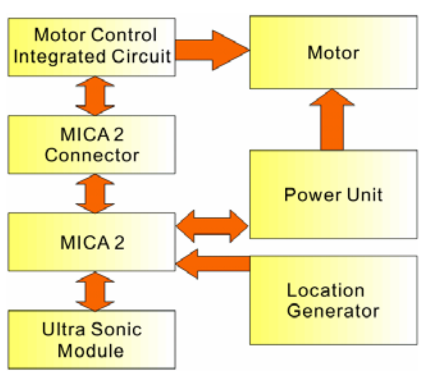

Figure 8 Components of a mobile sensor.

Components of a mobile sensor include an ultra sonic module, a MICA2 Mote, a MICA2 Mote connector, a motor control integrated circuit, a motor, a power unit, and a location generator. Figure 8 shows the components of a mobile sensor. A mobile sensor will use the ultra sonic module to detect the existence of obstacles and to determine the distance between an obstacle and itself. The information will be sent to MICA2 Mote. A MICA2 Mote is the data processing center of a mobile sensor. All received data and sensing information will be processed in the MICA2 Mote. The RF module can be used to transmit processing data and sensing information to neighboring static sensor nodes. The MICA2 connector is the interface between the MICA2 Mote and the motor control integrated circuit. The MICA2 mote can control motor control integrated circuit through a MICA2 connector. The location generator is used to calculate the location of a mobile sensor.

4.3. Communication Module

All software on MICA2 Mote is developed in compliance with TinyOS [11] (designed by University of California, Berkeley). TinyOS is a small component-based operating system. Instead of managing the processes, TinyOS uses a scheduler to manage tasks and events. Virtual memory is not available in TinyOS, neither. TinyOS configures memory statically. Therefore, TinyOS can efficiently reduce the energy consumption. The programming language, nesC, is used to write programs for TinyOS. NesC is a component-based and event-driven programming language. The components include two parts, **Modules** and **Configurations.** Modules can be modified to control the components in MICA2 Mote according to the application requirements. Configurations can be used to define the relations between every component. Figure 9 shows an example of a Configurations program segment.

```
//Blink.nc
configuration Blink {
}
implementation {

  components Main, BlinkM, SingleTimer, LedsC;

  Main.StdControl -> SingleTimer.StdControl;
  Main.StdControl -> BlinkM.StdControl;
  BlinkM.Timer -> SingleTimer.Timer;
  BlinkM.Leds -> LedsC;
}
```

Figure 9 A Configurations program segment.

After finishing the programs of Configurations, we begin to write the programs of Modules. What interfaces Modules declare and what functions these interfaces define before the Modules are written should be checked. In Figure10, three commands are implemented: init(), start(), and stop(). Because Modules supply *Std Control* interface, commands can be implemented in the interface.

Some components designed for the GUARD system are described as follows.

- IntToRfm: IntToRfm is a component which can receive output value from the I/O interface. IntToRfm can also transmit the output value to other components in the MICA2 Mote.
- RfmToInt: RfmToInt is a component which is used to receive packets from the radio module. After a packet is received, MICA2 Motes will check the command in the packet. If it is designated for other MICA2 Motes, the packet will be sent out immediately. Otherwise, the packet will be sent to the components through the RfmToInt module.

- Broadcast Module: When receiving a packet, a MICA2 Mote will check the command in the packet. If the packet has been received before, the MICA2 Mote does nothing. Otherwise, the MICA2 Mote broadcasts the packet to other MICA2 Motes by the Broadcast Module.
- Environment Parameter Module: When the sensing component senses the variation of the environment, Environment Parameter Module will transfer the analog signals to digital values. Then, the digital values can be sent to the GUARD system to verify the change of the environment.

```
//BlinkM.nc
module BlinkM {
 provides {
  interface StdControl;
 }
 uses {
  interface Timer;
  interface Leds;
 }
}

implementation {
 command result_t StdControl.init() {
  call Leds.init();
  return SUCCESS;
 }

command result_t StdControl.start() {
  // Start a repeating timer that fires every 1000ms
  return call Timer.start(TIMER_REPEAT, 1000);
 }


command result_t StdControl.stop() {
  return call Timer.stop();
 }

event result_t Timer.fired()
 {
  call Leds.redToggle();
  return SUCCESS;
 }
```

Figure 10 A Modules program segment.

4.4. Graphic User Interface

Macromedia FLASH™ [10] is used to design the GUI (Graphic User Interface) in the GUARD system (Figure 11 to Figure 14). The main considerations are as follows.

- FLASH is a vector based drafting system. The pictures in the FLASH system will not lose its reality when it is enlarged or shrunk.
- FLASH performs well for multimedia files. The animation effects and information can be easily involved in a dynamic map.

- FLASH can be fully integrated with the database system. Users can be authenticated through FLASH as well. Moreover, the user can also manipulate the GUARD system through the network in a real-time manner.

In the system, the user is authorized to access the GUARD system. Each user is assigned an account with a priority. The user can access only the data of the priority. The user is classified into three types, including administrators, operators, and the blind. The administrator has the highest priority and is responsible for managing systems. The operator has an average priority and is responsible for guiding or alerting the blind. The priority of the blind is the lowest. The system only enables the blind to receive guiding information through the wireless communication. By giving different priorities, the privacy of the blind is protected accordingly.

In general, the aforementioned functions are provided via a graphical user interface. The interface can be used to display the sensor status and the location of the blind, to command sensors to reply sensing data or report their statuses, to alert the blind, and to plan the walking paths of the blind.

The main user interface of the GUARD system is shown in Figure 11. The interface can be divided into two parts: the control panel and the campus map. In the control panel, the user can issue the commands to the system. The configuration will be shown in the map according to the setting of the user. As shown in Figure 11, the blue points and human-like symbols respectively represent the sensors and the blind at Tamkang University. When clicking a blue point, the user can obtain the information of the sensor, such as the remaining energy, the location, and the number of the blind the sensor senses. When clicking a human-like symbol, the user can view the information such as the name or the destination of the blind. Such information will be listed on the right side of the interface.

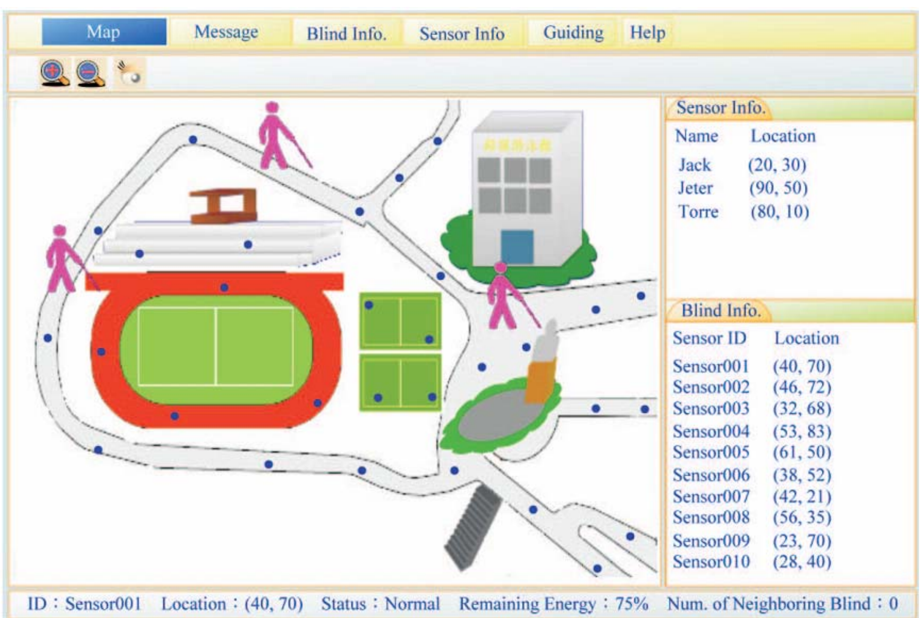

Figure 11 GUI of the GUARD system- Main interface.

Figure 12 is the interface for commanding sensors to reply sensing data or report their statuses. The left side of the interface lists all of the sensors in the campus. The sensors are divided into multiple groups according to their deployed locations. The user can issue commands to either the individual sensor or a group of sensors on the left side of the interface. The commands can be sent at once or by schedule depending on the requirements of the user.

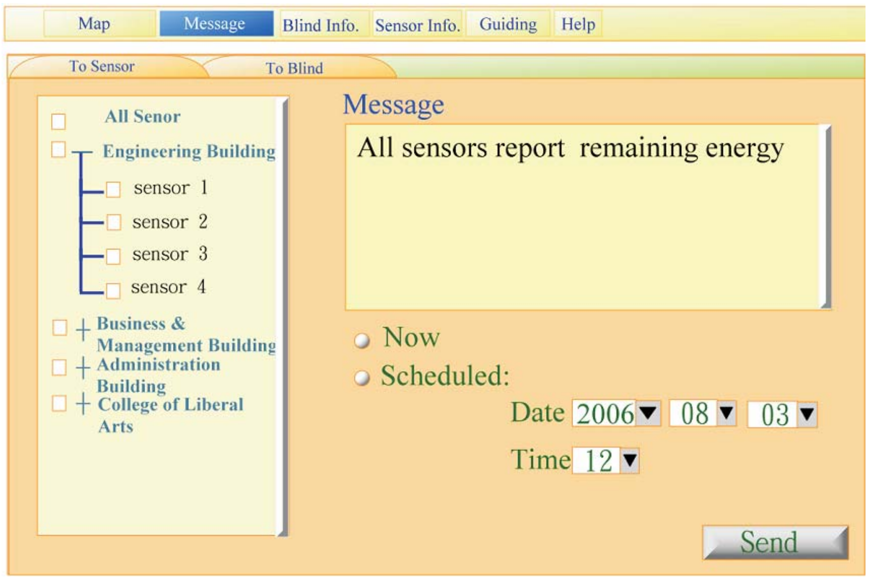

Figure 12 GUI of the GUARD system- Interface to command sensors.

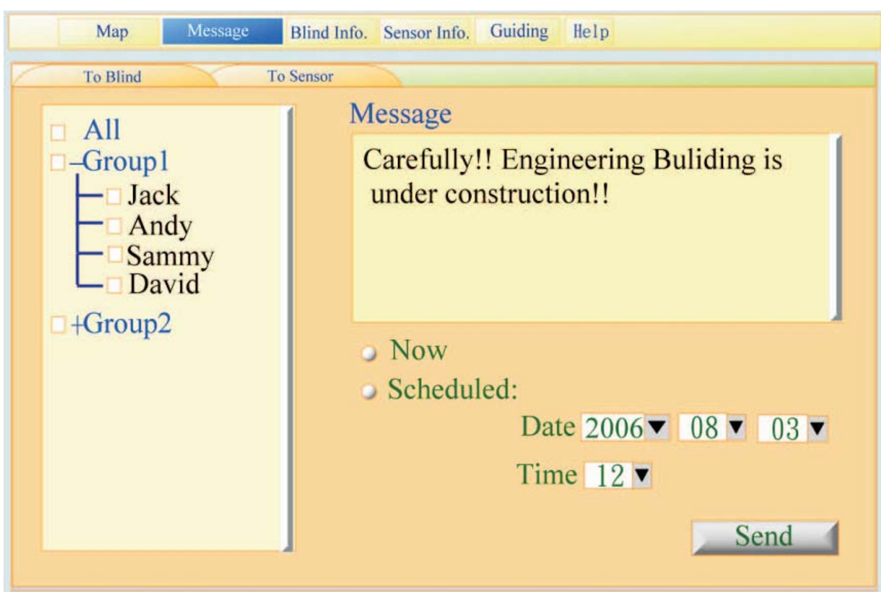

Figure 13 GUI of the GUARD system- Interface to send messages to the blind.

Figure 14 GUI of the GUARD system- Interface to query the information of the blind.

The interface of alerting the blind is illustrated in Figure 13. The user can send information to the blind by unicasting or boardcasting through the interface. The information includes the danger or road conditions on the way to their destinations. Users can select the blind from the list on the left side of the interface as the information receiver. One or many blind people can be also informed at a time. The blind can be classified into many groups. For example, the blind having the same class can be classified to a group. Similar to the setting in Figure 12, the user can determine whether the commands should be immediately sent or be scheduled to send.

An interface for users to edit the profile of the blind is also implemented, as shown in Figure 14. Through clicking the push-down list on the left side of the interface, the users can view the information, including the name, the telephone number, the student ID, the picture and the locations of the blind, on the left side of the interface. The right side of the interface shows the school timetable of the blind. The timetable can be used to predict the destination of the blind. Hence, the walking path of the blind can be scheduled in advance to prevent the blind in danger.

5. Conclusions

The system for the blind at Tamkang University has been built for years. A lot of experience is gained by developing the computer applications for the blind and constructing guide bricks. As the advancement of information technology, low power, low cost, small size, and multi-functionalities wireless sensor nodes can be realized and be widely used. Wireless sensor nodes have been adopted in many applications. Therefore, the GUARD system with wireless sensor nodes is constructed in order to provide security, real-time, and convenient services for the blind. The capabilities of the GUARD system include guide, alarm, recovery, and detection. In the system, the fewest sensor nodes are used to fully cover the whole campus. Besides, the lifetime of the WSN can be extended due to the efficiently usage of the sensor's energy by turning off the energy of the off-duty sensors. The relation between the sensing range and the transmission range of a sensor node is also analyzed when deploying sensor nodes by robots. Therefore, sensor nodes at Tamkang University can be deployed by robots without the blocking caused by obstacles. Because the functions of the sensor nodes currently provided by vendors can not meet our needs, sensing and communication modules are designed and implemented in present sensor nodes. In order to build the GUARD system at Tamkang University, the buildings and paths are surveyed to implement the GUARD system according to the realistic application scenario. Through the GUARD system, the location of the blind can be shown on the GUI in the GUARD system. The blind can be guided to his destination properly, safely, and quickly.

Acknowledgements

This work was partially supported by the National Science Council of the Republic of China under Grants NSC 94-2213-E-032-014 and NSC 94-2745-E-032-005-URD.

References

1. A. Howard, M.-J. Marari'c, and G.-S. Sukhatme (2002), *An incremental self-deployment algorithm for mobile sensor networks,* Autonomous Robots, Vol. 13, pp. 113-126.
2. L. Li, J.-Y. Halpern, P. Bahl, Y.-M. Wang, and R. Wattenhofer (2001), Analysis of a cone-based distributed topology control for wireless multi-hop networks, in *Proceedings of the Twentieth Annual ACM Symposium on Principles of Distributed Computing.*
3. F. Mondinelli and Z. K. Vajna (2002), Self localizing sensor network architectures, in *Proceeding of the 19th IEEE Instrumentation and Measurement Technology Conference.*
4. E. L. Lloyd, R. Liu, M. V. Marathe, R. Ramanathan, and S. S. Ravi (2002), Algorithmic aspects of topology control problems for ad hoc networks, in *Proceedings of the 3rd ACM International Symposium on Mobile Ad-Hoc Networking and Computing.*
5. H. Gupta, S.-R. Das, and Q. Gu (2003), Connected sensor cover: Self-organization of sensor networks for efficient query execution, in *Proceedings of the 4th A CM International Symposium on Mobile Ad-Hoc Networking and Computing.*
6. G. Gupta and M. Younis (2003), Load-balanced clustering of wireless sensor networks, in *Proceedings of the IEEE International Conference on Communications.*
7. W.-R. Heinzelman, A. Chandrakasan, and H. Balakrishnan (2000), Energy-efficient communication protocol for wireless microsensor networks, in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences.*
8. C.-Y. Chang, C.-C. Hsieh, and H.-R. Chang (2005), Obstacle-free robot deployment algorithm for wireless sensor networks, in *Proceedings of the Workshop on Wireless, Ad Hoc, and SensorNetworks (WASN 2005).*
9. Crossbow Technology Inc. website. [Online]. Available: http://www.xbow.com/
10. The official macromedia website. [Online]. Available: http://www.macromedia.com
11. TinyOS. [Online]. Available: http://webs.cs.berkeley.edu/tos/