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# ZigBee Wireless Sensor Networks based Detection and Help System for Elderly Abnormal Behaviors in Service Robot Intelligent Space

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**Keywords:** ZigBee; wireless sensor netowrks; service robot intelligent space; abnormal behaviors
**Abstract.** The detection of abnormal behaviors is one of the most important issues in the health monitoring system. Computer vision based techniques, usually combined with statistics, are labor-intensive, time-consuming and costly. Moreover, only monitoring but no help functions are provided. To overcome this limitation, this paper presents a ZigBee wireless sensor networks based detection and help system for elderly abnormal behaviors in service robot intelligent space. The main components of the system, including abnormal behaviors detection module, localization of abnormal behaviors, ceiling projector for robot navigation and development of ZigBee wireless sensor networks, are addressed in detail. Finally, we conclude this paper and future research direction is given.

## Introduction

With the rapid development of social economy, the increase of elderly population is much faster than ever before. A large number of alone elderly and empty nesters exist in modern society. That is why the development of health monitoring system of elderly people attracts widespread concerns. However, human behaviors understanding, especially the abnormal behaviors detecting and understanding, is one of the most important issues in the health monitoring system, because some abnormal behaviors are closely related to human's healthy problem.

Nowadays, a great many of researchers are attracted to the study of human behaviors understanding and achieve series of important results. However, most of related work is based on computer vision techniques, which are usually combined with the statistics on activities of daily living and activity level over an extended period of time to provide important data for functional assessment and health prediction. However, persistent activity monitoring and continuous collection of this type of data is extremely labor-intensive, time-consuming and costly [1]. Furthermore, only the monitoring function but no help function is provided and implemented in these projects.

In recent years, IMU (Inertial Measurement Unit) based body posture detection attracts a great many interests [2]. In this paper, we present a ZigBee wireless sensor networks based detection and help system for elderly abnormal behaviors in our service robot intelligent space. The abnormal behaviors (now we focus on tumble, which is dangerous for elderly) are detected by IMU module. And then a message indicating the abnormal behaviors, as well as the location where the message is from, are sent to decision-making system of intelligent space through ZigBee wireless sensor networks. Afterwards, intelligent space decides to tell the family or order a robot to help. If the latter is decided, which is in our case, a ceiling projector is used for robot navigation in the intelligent space after the projector receives path planning data. The data of detection, location, robot command and path planning are all transmitted through our ZigBee wireless sensor networks. Fig.1 illustrates how this system works.

The remainder of this paper is organized as follows. Section II introduces our ZigBee wireless sensor networks, including hardware module and software stack. In section III, we describe the design and implementation of the main components in this system, including IMU based abnormal behaviors detection module, locating system based on ZigBee wireless sensor networks and ceiling projector control for mobile robot navigation. Section IV concludes our work and presents the future direction of our research.

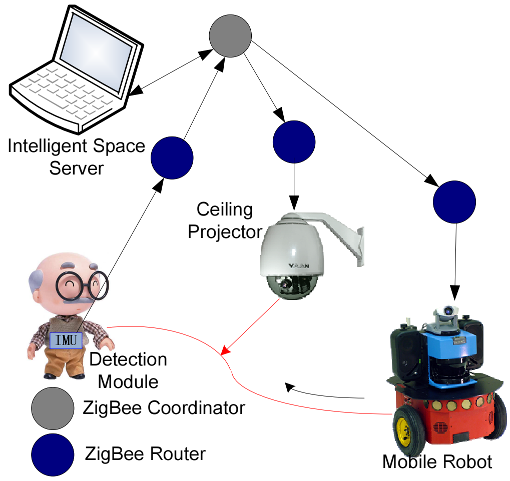


Fig.1 ZigBee wireless sensor networks based abnormal detection and help system

## 1 Implementation of ZigBee Wireless Sensor Networks

In general, Bluetooth (over IEEE 802.15.1), UWB (over IEEE 802.15.3), ZigBee (over IEEE 802.15.4), and Wi-Fi (over IEEE 802.11a/b/g) are four protocol standards for short range wireless communications [3]. As compared with other protocol standards, ZigBee is designed to be applied to low data rate, low-cost, low power consumption wireless communications. In this section, we firstly overview the ZigBee wireless senor networks, and then the implementation of hardware module and software stack are addressed in detail.

### 1.1 Overview of ZigBee Wireless Sensor Networks

ZigBee is a novel radio frequency (RF) communications standard based on IEEE 802.15.4. It defines the application layer and network layer, utilizing the IEEE 802.15.4 standard as the communication protocols of medium access control (MAC) layer and physical (PHY) layer.

The ZigBee wireless networks consist of one coordinator, several end devices and routers [4]. The coordinator is a special FFD (full function device) responsible for creating and maintaining the whole ZigBee PAN (personal area network). The end device can be an FFD or RFD (reduce function device). An FFD is able to act as anyone of the three roles, while an RFD can only act as the end device. Router is an optional device for ZigBee wireless sensor networks when the PAN covers a large area and routing is necessary. In addition, the topology of ZigBee wireless sensor networks includes simple star network, reliable mesh network and large scale mesh-tree network. Considering the easy expansion of the whole system, all of the devices in the implemented ZigBee wireless sensor networks are FFDs and they form a mesh-tree network.

### 1.2 Hardware module

Up to now, several companies have introduced their own ZigBee protocol compatible hardware platform and corresponding software stack package, such as CC2430 from Texas Instruments (Chipcon), MC13192 from Freescale and EM250 from Ember. The System-on-Chip CC2430 and Z-Stack from Texas Instruments (Chipcon) are widely used in the implementation of ZigBee wireless sensor networks. CC2430 combines the excellent performance of the leading CC2420 RF transceiver with an industry-standard enhanced 8051 MCU, and enables ZigBee nodes to be built with very low total bill-of-material costs.

Our ZigBee hardware module consists of CC2430 and very few external components. The PCB layout of hardware module is based on the CC2430 EM reference design recommended by Chipcon. When using an unbalanced antenna such as a monopole, a balun should be used in order to optimize performance. The balun can be implemented using low-cost discrete inductors and capacitors. The recommended balun shown in Fig.2 (a) , consists of C341, L341, L321 and L331 together with a PCB microstrip transmission line (λ/2-dipole), and will match the RF input/output to 50 Ω. Moreover, an F-antenna is a complement for some short distance and small package cases. An external 32 MHz crystal, XTAL1, with two loading capacitors (C191 and C211) is used for the 32 MHz crystal oscillator. And XTAL2, as an optional 32.768 kHz crystal, is also implemented on board. The reference design provided by Chipcon is very compact and Fig.2 (b) shows our ZigBee hardware module.

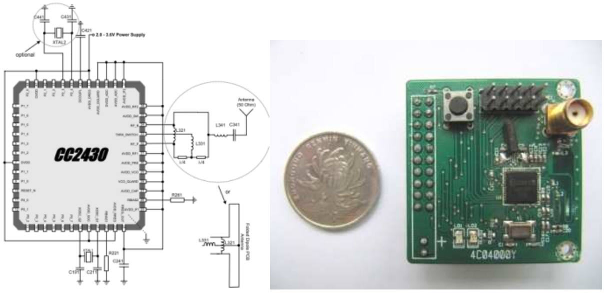


Fig.2 (a) CC2430 application circuit, (b) ZigBee hardware module

### 1.3 Software stack

Z-Stack is TI's ZigBee compliant protocol stack for growing IEEE 802.15.4 products and platforms. Z-Stack is compliant with the ZigBee 2007 (ZigBee and ZigBee PRO) specification, supporting ZigBee and ZigBee PRO feature sets on the CC2430 System-on-Chip [4]. Z-Stack consists of application layer, network layer, security layer, MAC layer and physical layer. Z-Stack is easy for developers to use and what the developers have to do is programming in application layer.

In Z-Stack, the device type is usually determined at compile-time via compile options. Generally, compiler option NV_RESTORE should be enabled for the final ZigBee wireless sensor networks after developing and debugging. This compiler option makes the Z-Stack to save some important network related information in nonvolatile storage in case of the unexpected reset or reboot after power down.

For convenient extension, we design a general software frame in application layer based on example projects. Few events are responded in current frame. Firstly, when ZDO_STATE_CHANGE event occurs, such as a new device join the network, the device sends its extended address to coordinator, so that an extended address table is established for short address explanation, because the short address is used in ZigBee wireless networks. In addition, some operations indicating current state of devices are triggered, for example, LED’s blink, set on or off. AF_INCOMING_MSG_CMD event, indicating new received messages, is the most important event in this frame, but the response operation is very simple, that is any received messages are sent out via serial port for further processing. The response of HAL_UART_RX_FULL event, triggered by serial port interrupt, is specific in different devices. For instance, detection module connected ZigBee module sends the data received from serial port to coordinator, and coordinator sends the data transmitted via serial port from PC to devices according to their short addresses after above address explanation.

## 2 Detection and Help of Elderly Abnormal Behaviors

### 2.1 Detection module

The detection module consists of two biaxial MEMS gyroscopes (LPR530 and LPY530), one three-axis MEMS accelerometer (MA7260), two biaxial magnetometers (HMC1022) and ARM controller (STM32F103C8T6), as well as few signal processing circuits, such as high-frequency filtering, signal conditioning, and some interface with other modules (e.g. ZigBee module). The block diagram of detection module is illustrated in Fig.3 (a), and Fig.3 (b) shows the real detection module.

The ARM controller with embedded real-time operating system μC/OS-II is used for IMU signal acquisition. Quaternion expression is used to obtain attitude of Gyro by integration. At the same time, absolute attitude is obtained from direction cosine. When some abnormal event occurs, now we focus on fall detection, alarm signal is sent to ZigBee module via serial port and then the alarm message and position of the alarm (addressed in next section) are transmitted to coordinator.

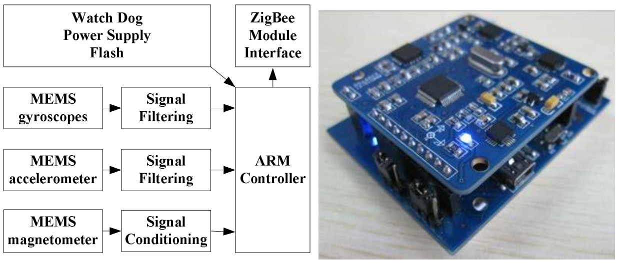


Fig.3 (a) Block diagram of detection module, (b) Detection module

### 2.2 Localization of Abnormal Behaviors

Localization is one of the most important tasks in the service robot intelligent space and necessary for abnormal behaviors, because detection of abnormal behaviors without location is meaningless. RSS-based localization is used in this paper considering its lowest complexity and cost.

The static nodes in ZigBee wireless sensor networks are used as reference node in the localization system. These nodes are configured with $X$ and $Y$ values corresponding to their physical location. A blind node is a node to be positioned and the MCU used on the blind node is CC2431 [4], which is an advanced CC2430. This chip includes a location detection hardware module (i.e. location engine) that can be used to receive signals from nodes with known location and calculates an estimate of a blind node's position. The location engine is based on RSSI distance measuring and triangulation.

Firstly, the coordinator sends the configuration request command to record the configuration parameters of the reference nodes and blind node. Then, the blind node sends RSSI blast and request command to acquire the RSSI between the blind node and each reference node. Meanwhile, the static reference nodes send their location to the blind node through messages, and the blind node store the RSSI carried in the packet. After that, eight maximal RSSI values and corresponding location coordinates are imported to the location engine to calculate its own position. As can be seen from the above description, the existing static nodes in the ZigBee wireless sensor networks are used as reference node, and no specific nodes are used for localization system. This makes the whole localization system easy to implement as long as little modification on the Z-Stack. The work process of the localization system is illustrated in Fig.4 (a) and Fig.4 (b) illustrates some representative raw results, which shows that most localization error is less than two meters. Better localization result can be achieved after some process of the raw localization data (e.g. Kalman filter).

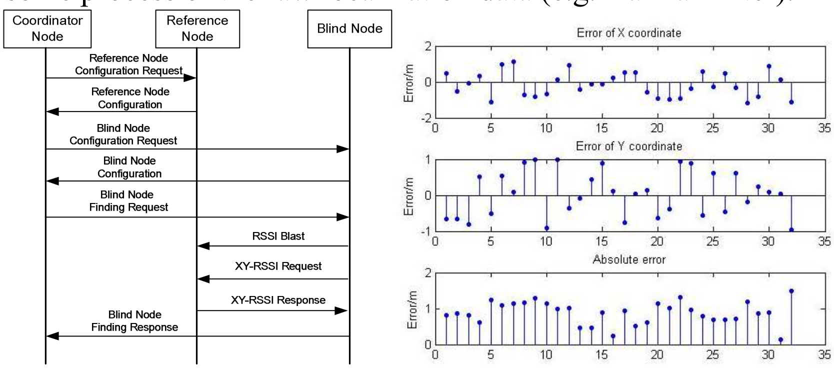


Fig.4 (a) Work process of the localization system, (b) Statistic of localization error

### 2.3 Ceiling Projector Control

The ceiling projector is used for robot navigation in the service robot intelligent space. In the service robot intelligent space, the information is gathered and integrated to plan a reasonable path for the mobile robot [5]. The path data are sent to the controller of the ceiling projector through ZigBee wireless sensor networks, which casts a spot along the path. Then, the mobile robot follows the moving spot by using its onboard sensors (e.g. CCD camera). This navigation method reduces the sensors for navigation carried on mobile robot.

The ceiling projector consists of a pan-tilt and a laser projector installed at the end effect, which is shown in Fig.5 (a). $\{X_0, Y_0, Z_0\}$ is the base coordinate system, $\{X_1, Y_1, Z_1\}$ and $\{X_2, Y_2, Z_2\}$ are the joint coordinate system, respectively. $\{X_E, Y_E, Z_E\}$ is the laser coordinate system installed on the pan-tilt. Fig.5 (b) illustrates the D-H kinematic parameters of the laser projector.

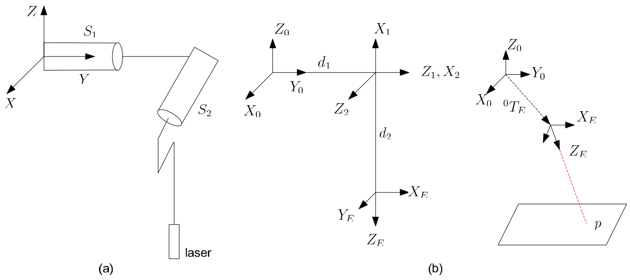

Fig.5 (a) Structure of Ceiling Projector, (b) D-H Model of the Ceiling Projector

Further, we can get the Jacobian matrix representing the joint speed and the spot velocity as,

$$\begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \end{bmatrix} = -({}^{E}Z + d_2)\begin{bmatrix} s\theta_2/s\theta_1 & 0 \\ c\theta_2 c\theta_1/s\theta_1 & 1/s\theta_2 \end{bmatrix}\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} = J\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}.$$

Where, $J$represents the Jacobian matrix, ${}^{E}Z$ is the $Z$ coordinate in $\{X_E, Y_E, Z_E\}$. The input of the system is the velocity of spot in base coordinate, and the control law is selected as,

$$\dot{\theta} = -kJ^{-1}\left(\begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \end{bmatrix} - \begin{bmatrix} \dot{x}_0^* \\ \dot{y}_0^* \end{bmatrix}\right).$$

## 3 Conclusion and Future Work

To overcome the disadvantages of computer vision based abnormal behaviors detection techniques, a ZigBee wireless sensor networks based detection and help system is presented. The design and implementation of main components in the system is described in detail. In the future, we will pay more attention to the information utilization method, especially information fusion and decision-making algorithms, to improve the abnormal behaviors detection and help system.

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## References

[1] Anderson D, Luke RH, Keller JM etc, in: *Modeling Human Activity from Voxel Person Using Fuzzy Logic. IEEE Trans. on Fuzzy Systems*, 2009, 17(1): 39-49.

[2] Peter H. Veltink, Henk Kortier, in: *Sensing Power Transfer Between the Human Body and the Environment. IEEE Trans. on Biomedical Engineering*, 2009, 56(6): 1711-1718.

[3] Jin-Shyan Lee, Yu-Wei Su, and Chung-Chou Shen, in: *A Comparative Study of Wireless Protocols: Bluetooth, UWB, ZigBee, and Wi-Fi. Proceedings of 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON)*, Taipei, Taiwan, 2007, pp. 46-51.

[4] B.-Y. Song, in: *Research of the key technologies in wireless sensor network. Dissertation submitted to Qingdao University of Science and Technology*, 2008.

[5] Xue Ying-hua, Tian Guo-hui, Wu Hao etc, in: *Path planning for service robots in an intelligent space. CAAI Trans. on Intelligent Systems*, 2010, 5(3): 260-265.