An Indoor Security System with a Jumping Robot as the Surveillance Terminal

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An Indoor Security System with a Jumping Robot as the Surveillance Terminal

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Abstract —*Mobile robots are now widely used in various surveillance and security applications. But most of them are wheeled and tracked robots that can not work well to overcome stairs, doorsills and other obstacles in cluttered indoor environments. This paper presents the design and implementation of a new indoor security system with a jumping robot as the surveillance terminal. The jumping robot, a gateway and some pyroelectric infrared (PIR) sensor nodes form a ZigBee wireless sensor network (WSN). The sensor nodes are installed above the doors and windows of the house to detect intruders and send intrusion detection messages to the robot. The robot can jump to the sensor coverage area to take photos and send them to the gateway and the home server. The remote house owner will get these photos through Internet. A prototype system has been implemented and some performance tests have been done. Experimental results show that the robot can jump up on a desk of 105cm high to perform the surveillance task. A 3k-byte captured photo can be transmitted to the gateway in 3.68s with 0.1% loss rate by 5 hops[1].*

Index Terms —Jumping robot, PIR, WSN, Multi-hop data transmission.

I. INTRODUCTION

With the development of wireless communication technology, the performances of home automation systems and indoor security systems are rapidly improving. Safety and security are two most important issues in the remote monitoring and control of intelligent home environments [1]. Indoor security systems provide safe, reliable and comfortable living and working environments for people. A safety visualization technique is developed for visualizing digital home safety in [2]. Traditional surveillance and security systems mount multiple cameras on walls with different angles of view to track objects. In order to track dynamic objects, the cameras need to hand over tracking tasks. In [3], the authors propose a surveillance and security system using multiple cameras for real time tracking. Multiple cameras in the system can track persons in indoor environments. An intelligent surveillance system using multiple autonomous cameras is proposed in [4]. The system tracks across multiple cameras with both overlapping and non-overlapping fields of view using an automatic topology construction method. In [5], the authors suggest the application of camera array should be based on OSGi (Open Service Gateway Initiative) and UPnP (Universal Plug and Play) security in order to build an effective management style in smart home systems. These systems with multiple cameras are costly and complicated to install and use. They are not flexible to implement monitoring funcitons.

Researchers are beginning to use mobile robots with cameras to monitor indoor environments. The cameras installed in the robots can be moved to more locations to take photos with different angles. These dynamic cameras are more flexible than cameras fixed in one place. Most traditional indoor security robots are wheeled robots [6-13]. The wheel based locomotion manner is more suitable for moving on the flat floor and can overcome small obstacles. When the obstacles are higher than the wheel radius, the robots are not able to overcome.

Most indoor environments are cluttered with stairs, doorsills and other obstacles. These environments limit the use of wheeled robots. So other locomotion manners are adopted by researchers in indoor security robot design. PATROLLER is a tracked robot proposed in [14], which can climb stairs. But it can not overcome obstacles higher than its flippers. Some researchers are designing various kinds of hybrid-structured robots that can be used in many fields. In [15], a hybrid-structured robot of humanoid and vehicle types is presented to perform home security tasks. This robot can change structures between the legged walking mode and the wheeled driving mode. It can move on smooth floors with three wheels and overcome obstacles with two legs. Its capability to overcome obstacles is more powerful than pure wheeled robots.

Inspired by the jumping motion patterns of some creatures such as frogs, locusts, and kangaroos, some researchers are now interested in designing robots that have the similar motion capabilities. It is believed that this kind of bio-inspired robots with jumping gaits will be more efficient in traversing rough terrain. Jumping robots can jump over obstacles higher than several times of its size. These kinds of robot are proposed in [16-21].

This paper presents the design and implementation of a new indoor security system with a jumping robot as the surveillance terminal. Equipped with a camera, the jumping robot can jump over obstacles to take photos. As a mobile node, the jumping robot can communicate with other PIR

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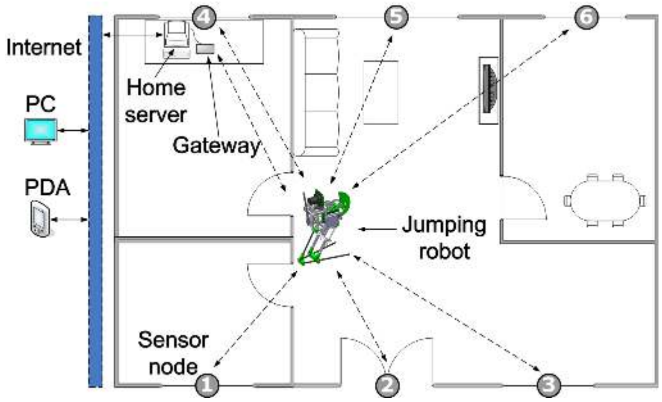

Fig. 1. Conceptual architecture of the proposed indoor security system.

sensor nodes in the indoor security system. When a sensor node finds an intruder and sends an alarm message to the robot, the robot will jump to the surveillance area of the sensor node and take a photo. The photo will be sent to the house owner through Internet. The owner can see this photo in any user terminals with Internet connections, such as PCs, PDAs or mobile phones.

The rest of this paper is organized as follows. Section II introduces the overall architecture of the indoor security system based on the proposed jumping robot. The robot design, the PIR sensor node, and the local wireless communication and control are presented in Section III. The experimental results on detection performance of the PIR sensor, jumping performance of the robot, multi-hop data packet transmission, and photo retransmission are given in Section IV. Concluding remarks are given in Section V.

II. System Overview

The conceptual architecture of the indoor security system based on the proposed jumping robot is shown is Fig. 1. The system is composed of two networks: a remote Internet based communication network and a local wireless sensor network. The remote Internet based communication network consists of a home server, a PC, and a PDA. The information of the indoor environment can be sent to the remote PC or PDA by this network.

The local wireless sensor network consists of a gateway, a jumping robot, and several sensor nodes. The sensor nodes are static nodes with PIR sensors. These sensor nodes are mounted above the door and windows. They can detect a person passing through the door or the windows and send the alarm message to the jumping robot. The jumping robot will jump to the surveillance area of the sensor nodes and take a photo. The photo data will be sent to the gateway. The gateway is connected with the home server. The photo will be transmitted to the house owner through Internet and displayed in a PC or a PDA. The house owner also can control the robot in remote places using a PDA or a mobile phone conveniently.

III. System Design

A. Robot Design

Fig. 2 is the CAD model of the proposed jumping robot. It is 120mm×67mm×122mm in size and composed of a mechanical body and a control system. The mechanical body contains a body frame, a jumping mechanism, a self-recovery mechanism, and a set of driving mechanisms. The control system consists of a camera, a control board and a lithium battery.

Inspired by the sudden jump locomotion of locusts, we select torsion springs as the energy storage components. The torsion springs are installed between the main leg and the

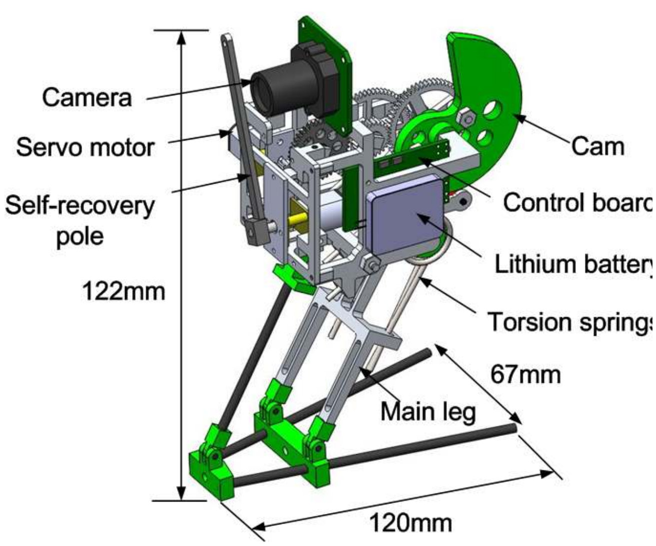

Fig. 2. CAD model of the jumping robot.

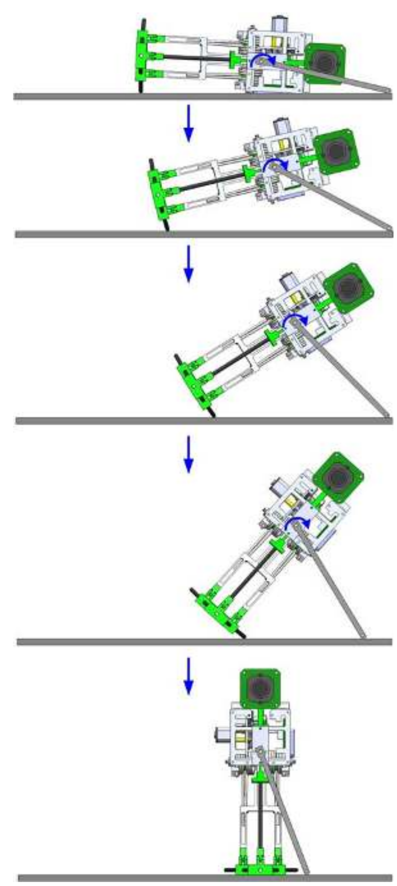

Fig. 3. Self-recovery principle of the jumping robot.

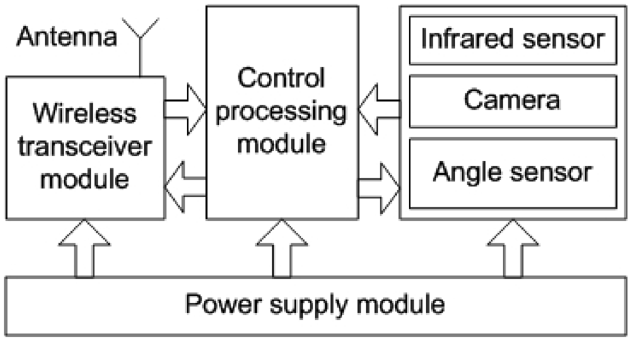

Fig. 4. Hardware components of the control board.


Fig. 6. A prototype of the PIR sensor node.

body frame of the robot. There is a bearing on the main leg, which is tangential to the cam. We use a DC motor with the reduction gear mechanism to obtain high torque to drive the cam to rotate. The cam compresses the torsion springs to store elastic potential energy. The contour shape of the cam is specially designed with quick-return characteristics. It allows sudden release of the elastic potential energy to drive the robot to take off. The detailed mechanical design work is presented in [22].

The self-recovery mechanism consists of a DC motor and a self-recovery pole, as shown in Fig. 2. Fig. 3 shows the self-recovery process when the jumping robot falls on its left side. An angle sensor can provide posture angle information for the robot. The self-recovery pole rotates clockwise and the robot body will be propped up. The robot detects its posture angle periodically. When standing up, the robot will stop rotating the pole and fold it up. If the robot falls on its right side, the pole only needs to rotate in the opposite direction for recovering.

The control board includes a power supply module, some sensors, a wireless transceiver module, and a control processing module, as shown in Fig. 4. The power supply module provides 5V voltage for the servo motor and 3.3V voltage for the control processing module. The infrared sensor can detect the rotating position of the cam. The camera can capture photos of the house. The angle sensor can detect the posture angle of the robot. The control processing module is used to control the robot to complete various functions. The wireless transceiver module can receive commands from the gateway and send requested data back.

B. PIR Sensor Node

Fig. 5 shows the CAD model of the PIR sensor node. It is composed of a PIR module, a ZigBee wireless communication module, a control board, and a Ni-MH battery group. Fig. 6 shows the implemented prototype of the PIR sensor node. The PIR sensor nodes are used to detect whether there is a person passing through the door or the windows of the house. The nodes periodically sample the output voltage of the PIR module. When finding the voltage is in a high level, the ZigBee module will send this message to the robot.

C. Local Wireless Communication and Control

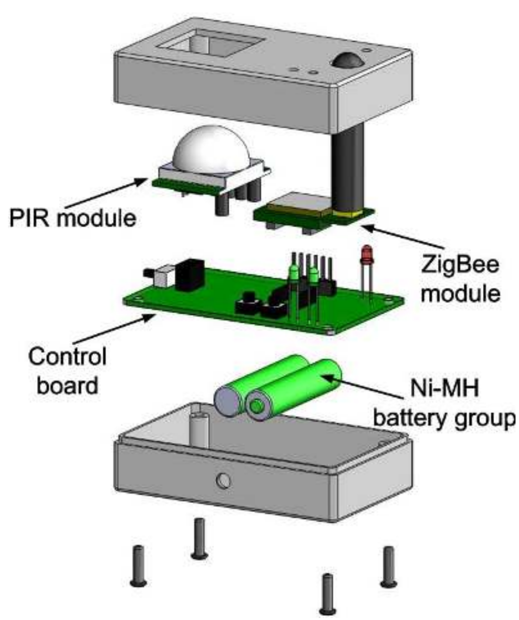

Fig. 5. CAD model of the PIR sensor node.

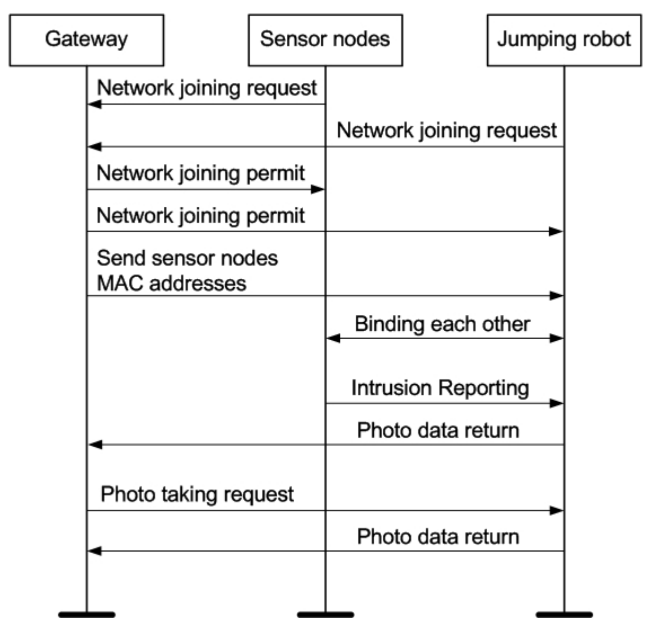

Fig. 7. Network registration procedure of the proposed local wireless sensor network.

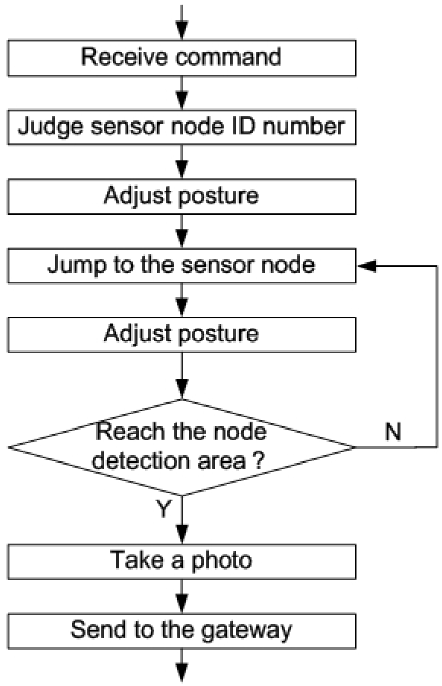

Fig. 8. Photo taking software flow chart of the jumping robot.

We use the ZigBee low speed wireless communication technology to perform local network data transmission. Fig. 7 shows the network registration procedure of the proposed local wireless sensor network. When the robot and sensor nodes are powered up, they will request to join the network established by the gateway. After joining into the network, the sensor nodes send their Media Access Control (MAC) addresses to the gateway. The gateway will send their identification numbers and MAC addresses to the robot. Then the robot requests to bind with the sensor nodes in order to receive the intrusion reporting messages from the sensor nodes. The sensor nodes are static nodes which are mounted above the door and windows of a house. The sensor nodes monitor if there is an intruder passing through the door or the windows. When finding a person, they will alarm and send this message to the jumping robot. A photo will be taken by the robot and transmitted to the gateway. As shown in Fig. 8, the jumping robot will follow the photo taking procedures when a photo taking command is received from the gateway or one of the sensor nodes.

Header: 0xAA 1Byte	Packet length: 0x36 1Byte	Packet number : 1Byte	photo data 50Byte	Trailer: 0x55 1Byte

Fig. 9. Photo data packet format.

Because of the low speed and limited bandwidth of the ZigBee communication technology, a photo should be compressed before being transmitted. In our work, we use a camera which can provide compressed JPEG photos. The captured photo is about 3000 bytes. We split the photo data into dozens of data packets with 50 bytes in each packet. If the data length is not integral multiple of 50, the last data packet will be filled with photo data and some 0 bytes. The format of the data packet is shown in Fig. 9. One data packet is 54 bytes in length with 50 bytes of photo data and one byte of packet number, which begins with 0xAA and ends with 0x55mber. The packet number is useful for the gateway to find lost packets. When finding lost packets, the gateway will send retransmission commands to the robot. By this method, the gateway can receive complete photo data packets. The flow chart of the photo transmission algorithm is shown in Fig. 10.

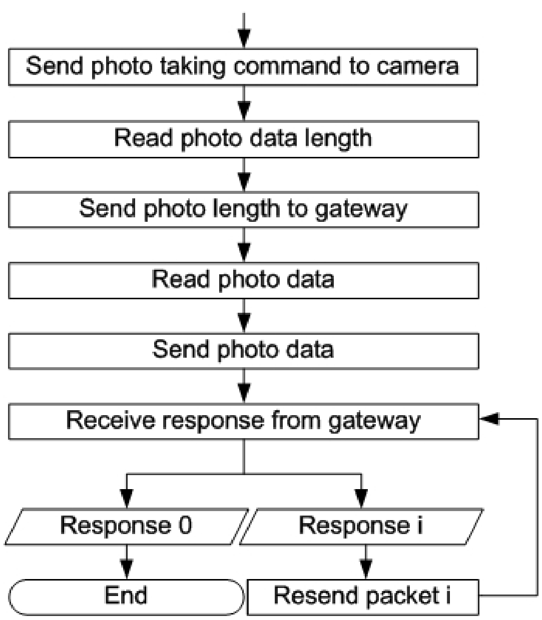

Fig. 10. Flow chart of the photo transmission algorithm.

IV. Experimental Results

We designed several experiments to test the functions of the proposed system. The surveillance function of the PIR sensor node, the jumping capability of the robot, the multi-hop data transmission, and the photo transmission function were tested respectively.

A. PIR Sensor Performance

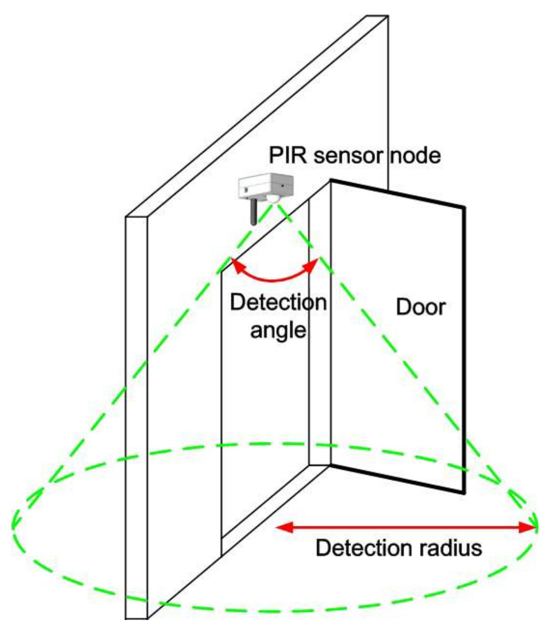

Fig. 11. Schematic diagram of the PIR sensor performance test.

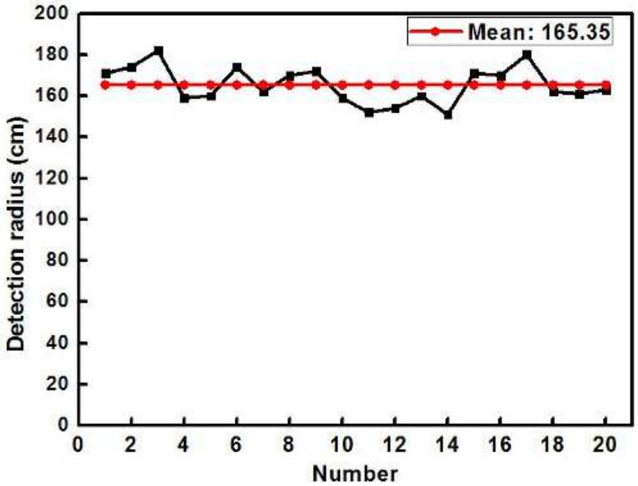

Fig. 12. Performance of the PIR sensor node.

Fig. 11 shows the schematic diagram of the PIR sensor performance test. The PIR sensor node is mounted above the door in 2m height. Fig. 12 shows the performance of the sensor node. The horizontal axis is the number of the tests. The vertical axis is the detection radius at which the sensor successfully detects a person. The results show that the average detection radius of the sensor is 1.65m. So the calculated surveillance angle is about 79 degrees. It can meet the requirements of our system to implement security monitoring.

B. *Jumping Capability*

A prototype of the jumping robot is shown in Fig. 13. It is 150g in weight and 122cm in height. The jumping trajectories of the prototype robot have been recorded by a high speed camera running at 420 frames per second, as shown in Fig. 14. It can jump 105cm high and traverse 60cm far at a take-off angle of 74 degrees. This test verifies that the jumping robot has powerful obstacle overcoming capabilities. The jumping height can be changed by using different numbers of torsion springs. In this test four torsion springs have been used.

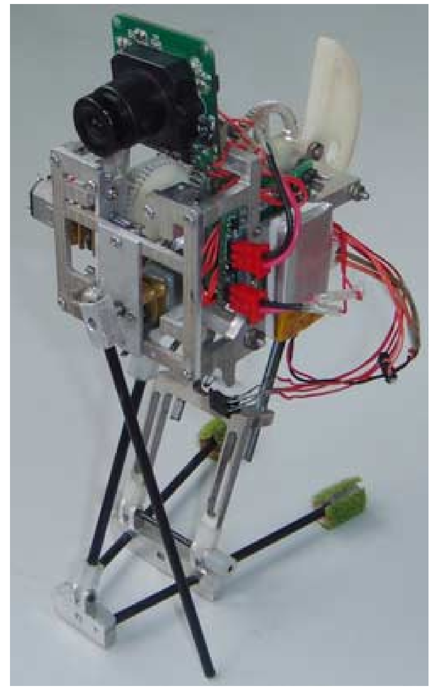

Fig. 13. A prototype of the jumping robot.

C. *Multi-hop Data Transmission*

In a typical indoor environment, many obstacles can decrease the wireless signal intensity, such as walls, ceilings, and furniture. Our system uses the ZigBee wireless communication protocol to transmit data. It allows multi-hop data packet transmission when one-hop transmission is not possible. As shown in Fig. 15, a testbed has been setup for multi-hop photo data transmission test. Because the distance between every two sensor nodes is in one-hop range, we set the max children node number of the gateway and sensor

Fig. 14. Jumping sequence of the prototype robot.

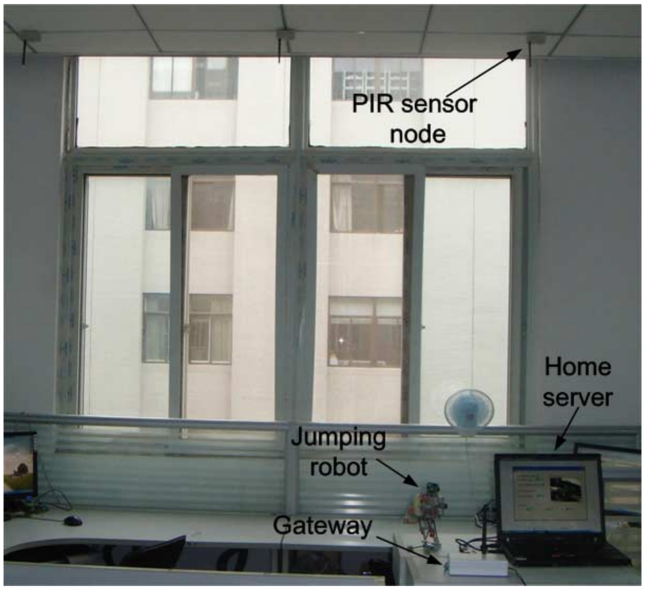

Fig. 15. Testbed setup for multi-hop data transmission test.

nodes to 1 to implement mandatory multi-hop transmission. Then we power on the gateway first, the sensor nodes one by one, and the robot node last to ensure that a multi-hop chain network topology can be established.

In order to test the multi-hop transmission performance of the network, the robot node sends 3000 bytes of photo data with fixed-size. The sending interval of every data packet is set to 60ms. So the total sending time of 60 packets is more than 3.6s. The tests have been repeated 20 times for every different hop count. The result of the time delay in multi-hop transmission is shown in Fig. 16. The time delay of 5 hops is about 3.68s. It is 47.5ms longer than the time delay of 1 hop transmission. The result of data packet loss test is shown in Fig. 17. There are no lost packets in 1, 2, and 3 hops. There are several packets lost in 4 and 5 hops with a loss rate of 0.1%. When the hop count increases to 6, the loss rate will increases to 40.8%. It is not acceptable for photo data transmission. By increasing the data packet sending interval, the packet loss rate will be decreased. But the time delay is increasing accordingly. So it is necessary to balance the time delay and hops of transmission to meet the requirements of the system.

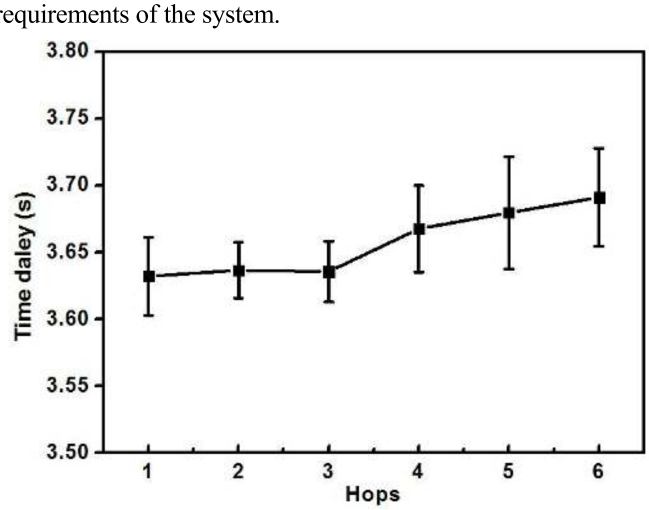

Fig. 16. Time delay of wireless multi-hop data transmission.

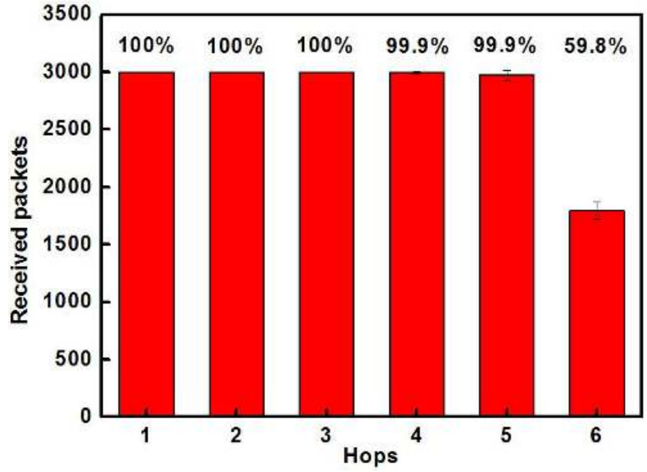

Fig. 17. Packet receiving performance of multi-hop data transmission.

D. Photo Transmission

In this test, we control the robot to move to a PIR sensor node covered area to take a photo. In the software interface of a PDA, we set the number of active inquiring sensor node to 1 and push the photo taking button. The robot receives this command and moves to the covered area of sensor node 1. When reaching the area, the robot will take a photo and send it to the gateway. The gateway is connected to the home server. So the photo can be seen on a PDA connected with Internet, as shown in Fig. 18.

In order to solve the problem of photo data loss in multi-hop transmission, we use the lost packet retransmission mechanism. Fig. 19 shows the difference between two photos got with and without retransmission of lost packets. In Fig. 19 (a), the photo is 5054 bytes with 2 packets lost. In Fig. 19 (b), the photo is 5145 bytes with no packet lost.

Fig. 18. Captured photo displayed on a PDA-based user interface.

(a)

(b)

Fig. 19. Photo qualities. (a) Without retransmission of lost packets. (b) With retransmission of lost packets.

V. CONCLUSION

We have presented the design and implementation of an indoor security system with a jumping robot as the surveillance terminal. Some PIR sensor nodes and a jumping robot can form a ZigBee wireless sensor network and communicate with each other. Jumping test results show that the prototype robot can jump over obstacles up to 105cm in height. It greatly helps the robot navigate freely in cluttered indoor environments when performing surveillance tasks. The multi-hop photo transmission test shows that the time delay of data transmission increases little with communication hops. But the packet loss rate increases markedly after more than 5 hops.

Future work will focus on improving the control precision of the jumping robot and multi-hop photo transmission performance. We plan to add more sensors to detect obstacle height and design a take-off angle adjusting mechanism. New multi-hop communication protocols will be studied for decreasing time delay and packet loss rate.

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