Remote Wireless Face Recognition Employing ZigBee

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ABSTRACT
This paper presents the design of an image transmission system using the ZigBee™ sensor network environment which is based on the IEEE 802.15.4 standard. Further, the implementation of a face recognition application using this system is discussed. Wireless communication is a very attractive mechanism to transmit data and gradually enlarges potential application area. In particular, ZigBee has more advantages pertaining to low-power consumption than other wireless protocols. It also can be applied to the security realm for use in image based surveillance systems. However, a general embedded system employing ZigBee sensor modules has the problem of limited resources. As a result, there is potential difficulty in handling large amounts of data or computations such as those inherent in image processing. In this paper, we present the design of our image capturing environment and data transferring mechanism which is suitable for image sensor networks. Our results of implementing a face recognition system using images transferred from ZigBee wireless nodes are presented, including analysis of transmission speed and power consumption.

Categories and Subject Descriptors
C.3 [**Real-time and embedded systems**], C.2.2 [**Network Protocols**]: Applications (ZigBee), I.4.8 [**Scene Analysis**]: Object recognition

General Terms
Design, Security, Measurement

Keywords
camera sensor network, power consumption, face detection, face recognition, IEEE 802.15.4, ZigBee

1. INTRODUCTION
Sensor networks based on embedded system are emerging as a new paradigm in computing area. Small size and easily portable sensor's properties make tremendous computing is possible when it is connected to the network. Typically, various sensors are used to improve the life of human beings. Most of all, CMOS camera technology has changed our life dramatically by emerging in the form of digital cameras, cellular phones with cameras, web cameras, and so on. As a result, small size and low-power cameras requiring minimal setup time are possible.

In this paper we present a face recognition surveillance system using a wireless embedded camera sensor network. There is little previous work on wireless camera sensor networks [1~3] because of their high computing requirement for image processing. We designed a proper wireless vision sensor network based on the IEEE 802.15.4 protocol, so called ZigBee, and demonstrate a face recognition surveillance system. As a matter of fact, a camera sensor network on ZigBee is not an ideal configuration in view of low power consumption because of its large data processing requirement. On the other hand, a camera image has significantly more information than any other sensors. Thus, when it is combined with a low duty rate of requirements, we can get more advantages by using an image with wireless. Our wireless vision sensor network consists of three architectural parts. One is the sensor node as a data collector, another is the agent node as a data transmitter, and the third is the transaction server as an image processing node for face recognition.

This paper organized as follows. In Section 2, we discuss background and related work and describe our face recognition via ZigBee system in detail in Section 3. Section 4 discusses experimental results of our system and Section 5 concludes.

2. RELATED WORK
ZigBee uses IEEE 802.15.4 MAC and PHY layers aimed at simple, low-cost wireless communication networks, and lower power consumption than other wireless protocols such as Bluetooth due to its small size stack (about 28Kb). It also supports ease of installation, reliable data transfer, and short-range operation. Depending on the application, a system network can be designed as either a star or peer-to-peer topology which can be implemented as a mesh networking topology. They are determined by the controller, called the PAN coordinator. Detailed ZigBee protocol is described in the literature and is beyond the scope of this paper [4]. ZigBee has been used in medical [5], industrial and commercial, home automation, PC peripherals, consumer electronics, and toy and game [6] applications.

Meanwhile, face recognition is one of the well-known personal identification systems among biometric systems. Because of the uniqueness and ease of facial data collection, this method is widely used by researchers. It is more convenient and user friendly than other identification systems in a wireless environment. It has several processes as shown in Figure 1. Among them are two significant processes, face detection and face recognition. Only the face region should be identified from the input image before recognition. As a result, it is necessary to normalize the size, orientation, and pixel intensity of the clipped face for better recognition.

There are several approaches for face detection and recognition. Geometrical feature based approaches [7, 8], appearance based approaches [9, 10], and hybrid approaches [11, 12] have been pursued.

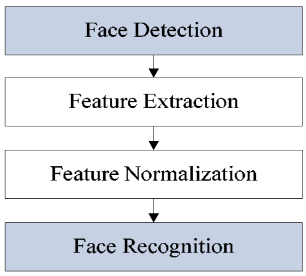


Figure 1. Face recognition processes.

3. FACE RECOGNITION VIA ZIGBEE

We designed a gate access control system in a wireless environment. It is not suitable for the implementation of face recognition system directly on the currently utilized ZigBee modules due to their resource limitations. Thus, we designed a proper face recognition system with performance adequate for the ZigBee wireless sensor network.

3.1 System Configuration

Our system consists of three major components, the ZigBee Node(ZN), the ZigBee Agent(ZA), and the Transaction Server(TS). It has a two-step data transmission mechanism. As a data collector, the ZN is equipped with camera and PIR sensors for capturing images. To achieve low-power consumption, the PIR sensor detects an object regularly while the camera is in its idle state. If there is an object, the ZN captures an image with its camera. Then the ZA, a data transfer agent between the TS and ZN, receives data from the ZN and transmits this to the TS via an RS-232 interface. After that, the TA manipulates the image from the ZA for face detection and recognition. Figure 2 presents our hardware system configuration. As the figure indicates, the system could be expanded for multiple gates using a star topology.

A sequence diagram for the access control system using face recognition over ZigBee is shown in Figure 3. For low power consumption, ZN tries to find an object by monitoring its PIR sensor. Image capture logic is triggered when object is detected by the PIR sensor.

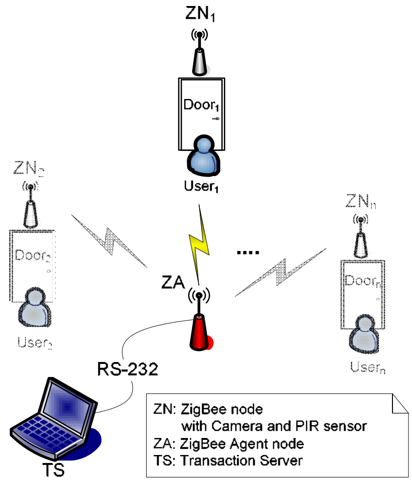


Figure 2. System H/W configuration.

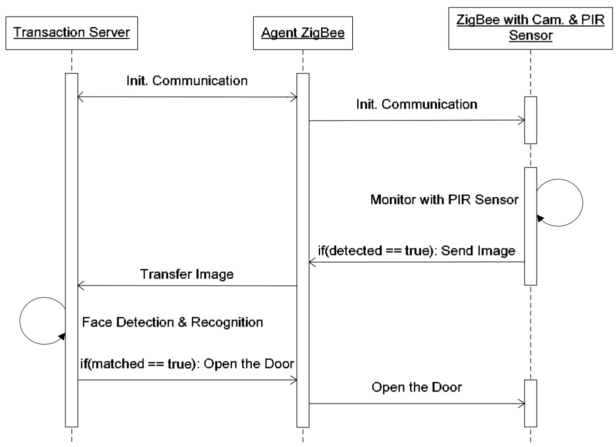


Figure 3. Sequence diagram for access control using face recognition via ZigBee.

3.1.1 *Resources on the ZigBee module*

The PAN802154 is a full modem communication module for the 2.4 GHz ISM band. It is designed to be in full compliance with the IEEE 802.15.4 radio standard; and the ZigBee protocol layer [13]. It is a low rate and low power communication device based upon the Freescale™ ZigBee sensor application reference design (SARD) development platform [14]. It consists of a microcontroller unit - Freescale part number: MC9S08GT60CFB. It has an 8-bit microprocessor, 60Kb Flash, 4Kb RAM, RS-232 interface, and 10 bit A/D converter. It requires between 3.0-3.4VDC when using RS-232 capability. It operates using 35-60mA DC current.

3.1.2 Resources of Camera module

We employed a C328 CMOS camera module [15] for capturing an image. This component is designed for low cost, and low power solutions for high resolution image capture. It supports VGA/CIF/SIF/QCIF/160x128/80x64/3-20x240 image resolutions. It also supports JPEG data compression for transmission efficiency and can be controlled with an RS-232 interface for setup and data transfer. The unit has 115.2Kbps bandwidth for transferring JPEG still pictures or 160x128 preview at 8bpp with 0.75-6 fps. It is operated using 3.3V, 60mA, and low standby current 100 µA. For purposes of experimentation we mainly considered images of size 160x128 and focused on transmission rate and face recognition rate.

3.2 Face Recognition

Our face recognition approach has three main processes: face detection, face normalization, and face recognition. A feature extraction process is implied within the face recognition stage since we use eigenface based feature. The sequence of face recognition is illustrated in Figure 4.

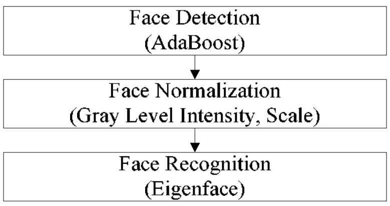


Figure 4. Flow chart for face recognition system.

3.2.1 Face Detection

Face detection is an initial step towards face recognition. After an image is captured, it is scanned by the face detector over the entire image. We use Viola and Jones cascaded Haar-like face detector [16] for fast and high detection rate.

Weak classifiers are trained by the AdaBoost learning algorithm [17] using Haar-like features [18] over the sample face and non-face images. These are then boosted into a strong classifier. This algorithm uses the so-called integral image representation which enables the features to be computed very quickly. Further, this algorithm is a method for combining increasingly more complex classifiers in a cascade which allows background regions of the image to be quickly discarded while spending more computation on promising object-like regions.

If a face is detected from the input image, the face region is cropped out for further processing. This makes real-time detection possible.

3.2.2 Face Normalization

Cropped images from the face detector may vary from the registered database images in image size and pixel intensity. For face normalization, this is transformed into a 64x64 image size and equalized histogram of pixel intensity. We did not consider face orientation, because we used only frontal and non-orientated (or oriented within just 5 degrees) facial images.

3.2.3 Face Recognition

After the face image is normalized, it is possible to compare the normalized face to registered faces for recognition. We used the eigenface algorithm [9] which is one of the most popular face recognition algorithms. The eigenface method is based on Principle Component Analysis (PCA), commonly used to reduce the dimensionality of a face class, which is depicted in Figure 5.

In the training stage, an average image (Ψ) is obtained from training sets (Γ). Then eigendata, eigenvalues (μ) and eigenvectors (ν), which represent the characteristics of the training sets are calculated from the covariance matrix (C) could be obtained from the differences (Φ) between average images and training sets. Eigenvalue projected images (ω) are very similar to face images, hence, so-called eigenface. Similarly, in the recognition stage, an eigenvalue projected image is calculated from the difference image between the test and average images. Then, recognition is possible by measuring the distance between this projected image and trained eigenspaces.

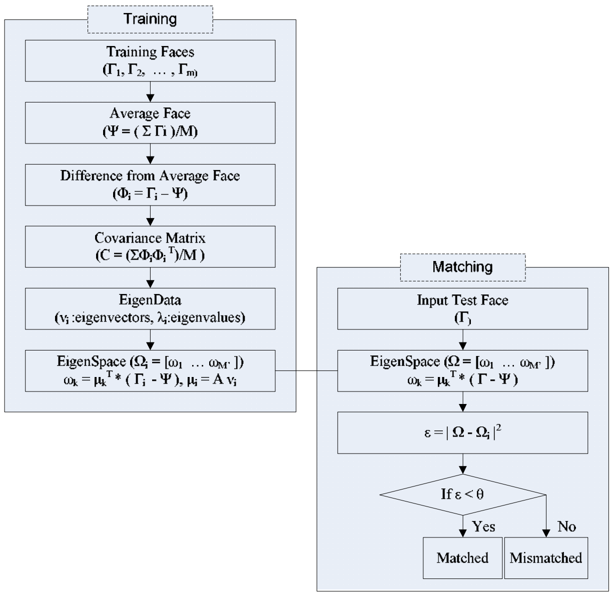


Figure 5. Eigenface algorithm for face recognition.

4. EXPERIMENTAL RESULTS

We experimented on an INSPIRON 6000 notebook computer from DELL as our TS. This is connected to ZA by a RS-232 interface connected via Keyspan[19], USB serial adapter which supports RS-232 asynchronous communication at data rates up to 230Kb, to communicate with the notebook computer. ZN and ZA are implemented with Panasonic PAN802154HAR00 communication modules. The PAN802154HAR00 is a 2.4GHz, WPAN module that fully supports IEEE 802.15.4 or simple MAC.

For an image capturing device, we adapted a C328-7640 JPEG compression module with serial output made by Comedia Ltd. We mainly used 160x128 resolution for the transmission speed test and recognition ratio analysis. For face recognition, a database was composed of 106 images from 4 persons. Each registered face image was normalized in 64x64 resolution. It focuses on frontal face and forward and backward scaling variation without facial expression.

This system consists of two significant parts, registration and matching. Those parts commonly use the same face detection algorithm to detect a face. To determine a match or not, we used tolerance-added Euclidean distance between database and input eigenface projected images.

All the following tests were executed and analyzed on the face containing images. Head orientation was fixed smaller than 5 degrees. Forward and backward scale variation was also considered. Viola et. al's face detector resulted in 98.3% successful performance as showed in Table 1.

Table 1. Face detection result.

frames	detected	Ratio
1002	985	98.3

Face Recognition based on eigenface resulted in about 87.7% acceptance ratio. PCA is excellent in reducing the dimensionality, but it is not sufficient in identifying a face class among others. In the case of image-based face recognition, pixel intensity and pose variations are the main obstacles when using eigenfaces. Face recognition results are tabulated in Table 2.

Table 2. Face recognition result.

total	match / ratio (%)	mismatch / ratio (%)
985	887 / 90.1	98 / 9.9

We also considered the JPEG image transmission speed in the laboratory environment. RS-232 was set to 38,400 baud rate. Image size was set to 160x128. Table 3 shows our experimental results related to transmission speed.

For the highest data transmission strategy, we adopted a UDP-like connectionless protocol without handshaking for QoS between ZN(Tx) and ZA(Rx). At first, we tested on the serial communication speed of TS. Then, the transmission speed between ZA and TS was tested. Finally, ZN to TS was measured. As we expected, transmission speed between ZN and TS was lowest. We could also find explore the potential for data loss between ZN and ZA. Most importantly, nearly 0.7 frames could be transmitted from camera to host computer. This is not so fast but acceptable for our access control surveillance system.

Table 3. Data transmission speed (168x120).

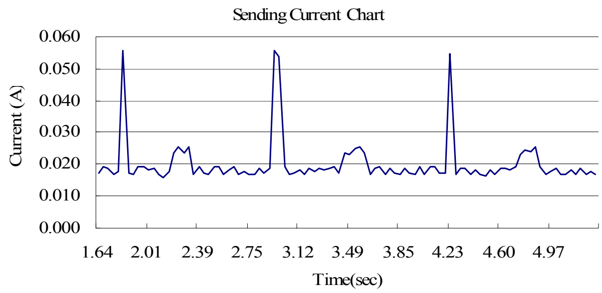
item	frames / fps	time (sec)	data(byte) / avg/frame	rate (byte/sec)
RS-232 on TS	1,007	1,000.64	2,625,220	2,623.5
	0.61		2,607.0	
ZA↔TS	851	1,000.10	2,548,753	2,548.5
	0.85		2,995.0	
ZN↔TS	689	1,000.05	1,821,225	1,821.1
	0.69		2,643.3	
	Data losses: 0.097 %			

We also considered 320x240 size frames for comparison with 160x128. It resulted in lower frame rates, however, it could be considered in low duty rate camera sensor networks.

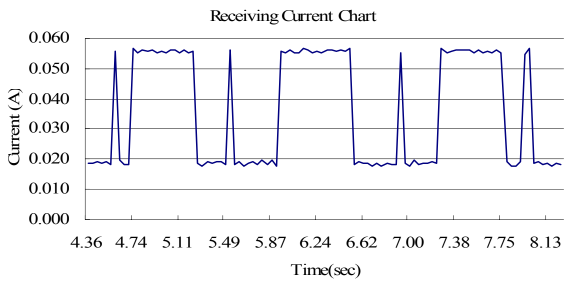
Table 4. Data transmission speed (320x240).

item	frames / fps	time (sec)	data(byte) / avg/frame	rate (byte/sec)
ZA↔TS	311	1,001.10	2,429,553	2,426.9
	0.31		7,812.1	
	Data losses: 0.037 %			

Figure 6 describes energy consumption of our ZigBee modules. We measured the currents while sending an image (a) and receiving the data (b) using the LabTracer2 with model 2400 general-purpose SourceMeter from Keithley Instruments [20].



(a) sending current on the ZN



(b) receiving current on the ZA

Figure 6. Power consumption of ZigBee modules.

Sending current has three kinds of interesting spikes on the graph (a). The highest points on graphs (a) and (b), in the range of 50mA and 60mA, are from the radio sending and receiving. The second highest points, between 20mA and 30mA, are the current while accessing RS-232. The lowest points, nearly 20mA, are the current in the processor itself. Thus, as expected, the ZigBee unit consumes most of the power while transmitting or receiving the data.

5. CONCLUSIONS

In this work, we designed an embedded camera sensor network system for surveillance in a wireless environment. In general, computer vision processes require prohibitively large amounts of memory resources and computation costs. However, embedded systems based on wireless sensor nodes typically cannot provide large memory capacity and high CPU performance. Thus, we added a host system, named transaction server, for image processing, such that wireless sensor nodes only play a role as a data collector, reducing the overall power consumption and computation overhead. With this configuration, we implemented a face recognition system for gate access control and experiments within ZigBee wireless environment. We considered image transmission speed and power consumption. We found that most power is consumed on radio sending or receiving and transmission speed is reasonable for a system not requiring a high frame rate such as ours.

Future work includes increasing the number of nodes within our sensor network as well as scalability considerations.

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