# DEVELOPMENT OF A CHILD LOCALIZATION SYSTEM ON RFID AND SENSOR NETWORKS IN AN UNDERGRADUATE CAPSTONE SENIOR DESIGN PROJECT

**Chao Chen, Chinwe Aneke, Justin Ebaugh, and Christina Hong**

*Department of Engineering, Indiana University Purdue University Fort Wayne, Indiana*
*Emails: chen@engr.ipfw.edu, {anekcg01, ebaujj01, hongcg01}@ipfw.edu*

## ABSTRACT

Radio Frequency Identification (RFID) and wireless sensor networks are wireless technologies that rapidly emerge and show great potential in the future. Combining the RFID and the wireless sensor networks provides a cost-efficient way to expand the RFID system's range and also enable an RFID system in areas without a network infrastructure. In this undergraduate capstone senior design project, we employ both technologies to build a wireless localization system in a children's theme park. The main purpose of our child localization system is to track and locate children within a certain range near some landmarks in the park. The design experience in this project can be exported to other applications such as object tracking and surveillance.

## 1. INTRODUCTION

In recent years, RFID technology has emerged to be a popular replacement for the Universal Product Code (UPC) barcode system in many industries. Specifically, RFID uses a short-range radio technology to communicate mainly digital information between a stationary location and a movable object or between movable objects. Since RFID does not require line-of-sight communication and offers a longer operating range, RFID outperforms barcode systems in many areas, such as electronic road tolling, supply chain management, and article tracking (Landt, 2005). An RFID system generally consists of simple devices called *tags* (or transponders) and more complex devices called *readers* (or interrogators). The RFID tags are small and inexpensive, and can be deployed economically in very large numbers. Moreover, the RFID tags usually carry a unique identity (UID) and can be attached to the objects to be managed. The RFID readers employ tag-reading algorithms that are capable of identifying tags by the UIDs. Compared with the tags, the readers are more capable and are usually connected to a host computer or a network.

A wireless sensor network consists of many spatially distributed devices called *motes*. These devices use sensors to monitor conditions at different locations, such as temperature, sound, vibration, pressure, motion or pollutants. Since motes are small and inexpensive, they can be produced and deployed in large numbers. Motes are equipped with wireless communication capability to other motes either directly or via multiple hops. The fast-growing research effort in the academia and industry has resulted in many protocols and applications of wireless sensor network (Akyildiz, *et al.*, 2002).

Combining the RFID and the wireless sensor network offers advantages in both sides. First, attaching the RFID readers enables the motes to monitor a wider range of objects than with the traditional sensors. Second, the wireless sensor network can expand the RFID system's range and also enable an RFID system in areas where a network infrastructure (e.g., Internet) does not exist. In this undergraduate capstone senior design project, we employ both RFID and wireless sensor network technologies to build a wireless localization system in a children's theme park.

The rest of the paper is organized as follows: Some related projects on integration of RFID and wireless sensor networks are described in Section 2. The system requirements of the children's theme park and the detailed design of the wireless localization system are discussed in Section 3. Finally, conclusions and the progress of this project are pointed out in Section 4.

## 2. RELATED PROJECTS

In this section, we describe several related projects and products that are taken places in industrial and academic research laboratories.

**Intel Research: Hands-on RFID**

Intel Research Seattle has developed hand-worn RFID readers for detecting intentional touches of objects (Fishkin, *et al.*, 2005). These RFID readers can be embedded in wearable gloves and bracelets, and detect tagged objects through user interaction. The readers are connected to sensor motes, and report sensed events wirelessly to a PC base station that may be 15m to 30m away. The integration of the RFID and the wireless sensor networks serves to support real-time analysis of data stream and to keep the wearable device small and autonomous. The designed hands-on RFID system can be applied to activity-based applications such as health monitoring, factory-floor maintenance and context-sensitive reminders.

**UCLA: The Ragobot**

The Networked and Embedded Systems Laboratory in UCLA has designed coordinated "real action gaming robots" (Ragobots) to form a mobile sensor network. Ragobots are teamed up in robogaming, where they must collaborate to achieve a final goal while navigating a terrain. Specifically, Ragobots use an RFID system to provide a cost-efficient solution to object recognition. All the objects on the game board are tagged and classified. Small RFID readers mounted on the Ragobots can detect the tags and determine the object type based on the information stored on the tag (Lee and Friedman, 2004). Moreover, the RFID system in Ragobots adapts the mobile sensor motes to environment and task dynamics.

**Bluesoft and KidSpotter: Legoland's WiFi Kid Tracker**

In 2004, Bluesoft, Inc. and KidSpotter A/S successfully deployed a full-scale child-tracking application within LEGOLAND Denmark, one of the Europe's largest amusement parks (Bluesoft, 2004). Through this system, park guests can rent the AeroScout Wi-Fi Tags with a wristband that children wear inside the park. If a child becomes separated, the parents simply send a text message (SMS) from their mobile phone, and receive an automated response telling them the accurate location of the child. This kid tracking solution is based on the Bluesoft, Inc's AeroScout System – a real-time location system that can accurately locate both standard Wi-Fi devices and AeroScout's Wi-Fi-based active RFID tags. This project motivated us to combine the RFID technology with the wireless sensor network technology for a tracking application in a smaller-scale children's park.

## 3. SYSTEM DESIGN

The detailed description of our design and implementation in the capstone senior design project is covered in this section. We start with the system requirements and the overview of the child localization system, then describe the system components and design considerations. Finally, we present the overall system architecture.

### *3.1 System Overview*

Indiana University Purdue University Fort Wayne (IPFW) has proposed to build a children's theme park on campus in a location without any existing wired/wireless network coverage. There will be about 14 statues of mastodons (the official mascot of IPFW) located in the park. Our responsibility is to embed the mastodon park with a high-tech architecture on which some interactive games for kids can be easily added.

Based on the requirements, we proposed an underlying wireless localization system. The main purpose of such a system is to enable tracking and locating a child within a certain range (2-3 meters) near some landmarks (Here in this theme park, the landmarks will be the statues of mastodons). Each child playing in the park will wear a wearable RFID tag. When a child is near a mastodon, the RFID reader on or close to the statue will detect the tag and recognize it through the tag's UID. This information can be propagated through the underlying sensor network by wireless communication. One sensor mote can act as a gateway and is connected to a host computer through either wireless or wire-line connection. Therefore, the host computer can track the whereabouts of every child in the park and display the information. Furthermore, some interactive activities can be applied to the park based on this localization system. For example, some display about a mastodon can be activated when a child is close, and a child can have a print-out of his/her experience in the park.

### *3.2 System Components*

The main hardware components of the child localization system are RFID tags and readers, wireless sensor networks, and motion detection sensors. Here, motion detection sensors are used to save energy when no human activity is detected in the mastodon park.

**The RFID system:**
RFID tags are classified by its energy source as *passive* and *active tags*. A passive RFID tag has no power supply of its own. Thus, passive RFID tags have to be in the close range of the reader and make use of the incoming radio waves broadcast by a reader to power the response. Comparatively, an active RFID tag uses its own battery power to perform all operations. Therefore, active RFID tags usually produce a longer read range and higher efficiency.

In our child localization system, we use passive RFID tags for the children to wear. Since passive RFID tags are dormant unless powered by the energy radiated by the reader when they are close, the tags pose no harm to the children. Although the operating distance is limited to the reader's range, this is not a disadvantage of our system; because we want to draw children close to the mastodons to make the upper-level applications more interactive. Moreover, passive tags don't need battery replacement and thus are low cost, where the cost ranges from 50 cents to about 2 dollars.

RFID readers generally fall into two categories – high frequency (HF) and ultra-high frequency (UHF). Besides the operating frequency, HF and UHF readers also differ in the read range, the read rate, the memory size, and the power source. We select UHF RFID readers mainly because they have a longer read range (>1m). Moreover, UHF RFID readers have faster reading speed and larger memory size.

Our RFID system chooses the ISO 18000-6B UHF RFID tags. This type of tags employs technologies developed in modern telecommunications resulting in efficient and limited use of frequency bandwidth. Specifically, our system uses the SkyeTek M8 UHF 900MHz reader (SkyeTek, 2005) as the RFID readers. Such a reader with snap-on antenna can read a range as far as 2m. The SkyeTek M8 has a 20-pin flex cable connector, from which a host system can supply power and communication. Three types of microcontroller host interfaces (UART, $I^2C$, and SPI) are supported for ease of integration into existing systems. Through any of the supported host interfaces, the M8 reader operates under host control via the SkyeTek Protocol. In addition, the M8 has a small form of 3×2×0.4in (see Figure 1) and consumes low power. Moreover, the M8 is equipped with an internal antenna, and can install an external antenna.

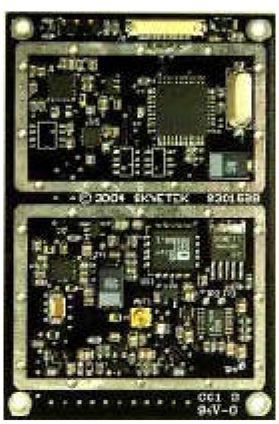


Figure 1: SkyeTek M8 RFID UHF reader (SkyeTek, 2005).

**The wireless sensor network:**
The main purpose of the wireless sensor network is to gather data in each reader and relay the data to a PC base station located in farther distance. The sensor mote that we use is Crossbow's Mica2 410 mote platform (Crossbow, 2005a), which is a 433 MHz radio transceiver including an ATMega128L microcontroller, an RF transceiver, and an RF antenna. The ATMega128L has 128KB flash memory, 4KB configuration EEPROM, and support programmable UART and $I^2C$ interfaces, and 38.4Kbps data rate. The $I^2C$ interface enables Mics2 410 sensor motes to connect to the SkyeTek M8 RFID reader directly. The Mica2 410 mote is very small in size (2.25×1.25×0.268in) and is shown in Figure 2(a). It also supports power-down mode, which can be used to conserve power consumption when no child is near any mastodon. Moreover, a Mica2 410 sensor mote can report sensed events either directly or multi-hop via wireless channel to a Crossbow's Stargate gateway SPB 400 (Crossbow, 2005b). The Mica2 mote implements such communication through a 51-pin connector that can be connected to Stargate gateway as a programming interface. The Stargate gateway (see Figure 2(b)) has both a standard RS-232 serial port and an AmbiCom Wave2Net wireless 802.11a/b card, which can transfer signals to a PC base station through either wired or wireless connection.

(a) Mica2 mote processor and radio platform.

(b) Stargate gateway SPB 400.

Figure 2: Crossbow wireless sensor network devices (Crossbow, 2005a, 2005b).

**The motion detection sensors:**
The main purpose of including motion detection sensors in the design is to conserve energy. When there is no human activity, thus no motion, in the park, the RFID readers are in dormant state. Whenever motion is detected close to a mastodon, the motion detection sensor will activate the RFID reader. It's important that the read range of the RFID reader be shorter than that of the detection range of the sensor, so that there will be a short interval after the RFID reader is enabled and before it's ready for tag reading. We select the AMB315920 sensor manufactured by Panasonic in our child localization system. The AMB315920 is an area reflective type motion sensor and has a detection range of 2m.

**The software components:**
The Crossbow sensor motes are operated by the TinyOS system, which is an open-source event-driven operating system designed specifically for wireless embedded sensor networks. TinyOS is written in nesC, a language supported by many micro-controllers and includes the necessary features to interface with hardware. In addition, the SkyeTek M8 RFID reader can communicate with any host software that sends commands according to the SkyeTek Protocol (SkyeTek, 2004).

*3.3 System Architecture*

Figure 3 shows the system architecture of the child localization system. In this system, there are two types of nodes in the localization system: *a server gateway* and several *client nodes* (one for each mastodon). The server gateway connects to a host computer and also has an RF antenna to communicate with the client nodes. A client node has the following components: a sensor mote, an RFID reader, a motion detection sensor, and battery supply. The detailed schematics for the client node and the server gateway are shown in Figure 4.

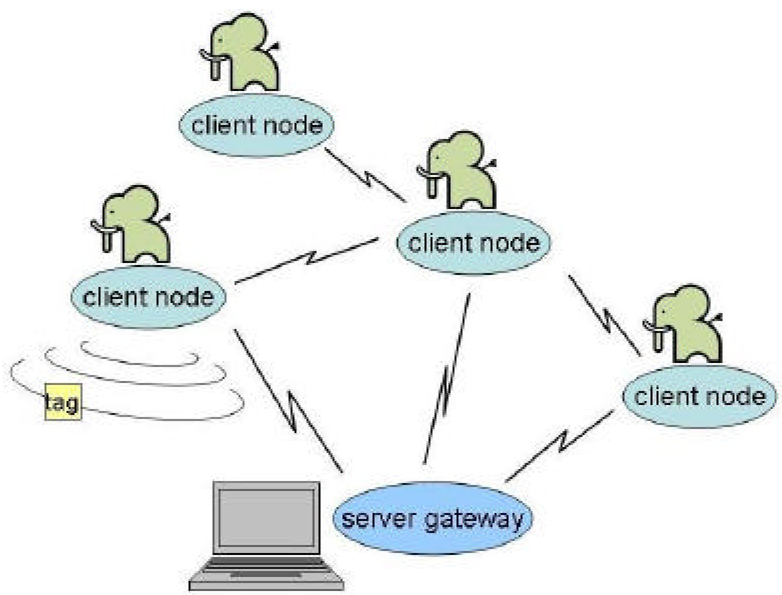
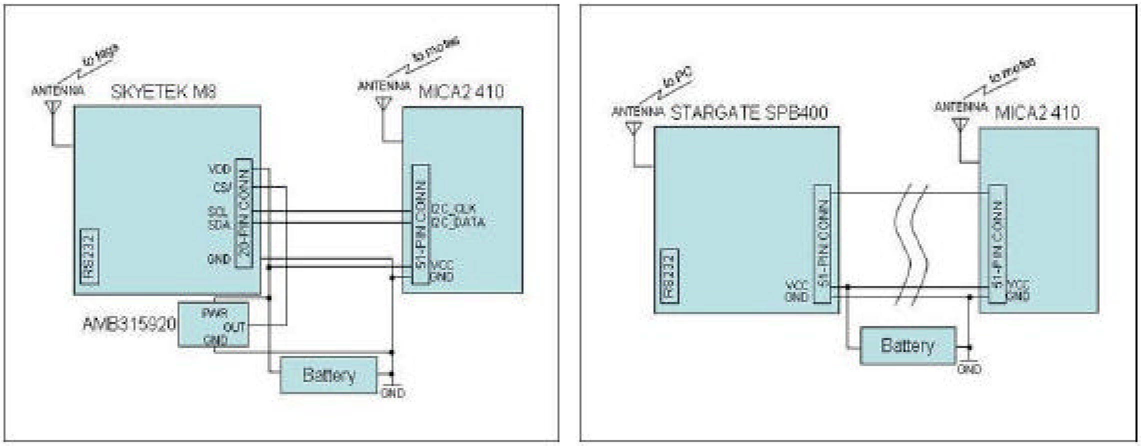



Figure 3: System architecture.

The main characteristics of our child localization system are summarized as follows:

- *Real-time detection:* Whenever a child (with a tag) is within an RFID reader's read range, the reader can detect the child instantly and retrieve the UID from the tag. The RFID reader will also send the UID to the sensor mote that it is connected to via the $I^2C$ interface. The communication through the $I^2C$ interface is guaranteed for speeds up to 400 kHz data rate. The TinyOS operating system in the sensor mote handles hardware event asynchronously, thus support real-time data fetching from the RFID reader. Moreover, anti-collision algorithms can be implemented to enable a single reader to read more than one tag in the reader's field.




(a) Client node. (b) Server gateway.

Figure 4: System schematics.

- *Remote data collection:* With the help of the wireless sensor network, the detected UID information can be sent to the server gateway. A client node has the capability to communicate with the sensor mote in the server gateway. If the client node is out of range of the server gateway, some other client nodes can forward its data to the gateway. Furthermore, the Crossbow Stargate gateway board accesses to the PC base station with high speed via the wireless 802.11 card. Therefore, the PC base station can monitor the RFID detection in the park remotely.
- *Power conservation:* All components in the system are built to consume low energy. For example, operating at 5V, The SkyeTek M8 draws a current of 250mA to 700mA in active mode and as low as 100µA in sleep mode, making it appropriate for use in battery operated devices. The Crossbow Mica2 mote uses 2 AA batteries and draws current of 8mA in active mode and <15µA in sleep mode. The Crossbow Stargate gateway operates at 5V and its power consumption is less than 500mA. Moreover, the motion detection sensor can further reduce the power consumption when no motion is detected in its range.

## 4. CONCLUSIONS AND REMAINING WORK

In this undergraduate capstone senior design project, we employ both the RFID and the wireless sensor network technologies to build a wireless localization system in a children's theme park. Specifically, we have proposed using passive RFID tagging devices coupled with UHF RFID readers to detect children in the park. The wireless sensor network helps deliver the detection information remotely to a PC base station. Meanwhile, the adding of motion detection sensors further reduces the overall energy consumption of the system. This senior design project started from August 2005 and will end in May 2006. The project design and evaluation phase has finished, yet the implementation and testing phase is still on-going. The design and testing experience in this project can enrich the students with the most-recent technologies in a practical application. The gained experience of the child localization system can be exported to other applications such as object tracking and surveillance.

REFERNCES

Akyildiz, I.F., Su, W., Sankarasubramaniam Y., and Cayirci E. (2002). A survey on sensor networks. *IEEE Communications Magazine*, **40**, (8), 102–114.

Bluesoft, Inc. (2004). World's largest Wi-Fi location network at LEGOLAND® Denmark. *MobileTechNews*, http://www.mobiletechnews.com/info/2004/04/27/011106.html.

Crossbow, Inc. (2005a). MPR/MIB mote hardware users manual (document 7430-0021-07). http://www.xbow.com/Support/manuals.htm

Crossbow, Inc. (2005b). Stargate developer's guide (document 7430-0317-13). http://www.xbow.com/Support/manuals.htm

Fishkin, K.P., Philipose, M., and Rea, A. (2005). Hands-on RFID: Wireless wearables for detecting use of objects. *The Proceedings of Ninth IEEE International Symposium on Wearable Computers*, 38-43.

Landt, J. (2005). The history of RFID. *IEEE Potentials*, **24**, (4), 8-11.

Lee, D.C. and Friedman, J. (2004). Robust object recognition for mobile sensor nets. *Technical Report #TR-UCLA-NESL-200406-04*, Networked & Embedded Systems Laboratory, University of California, Los Angeles.

SkyeTek, Inc. (2005). SkyeRead M8 reference guide (document version 1.6). http://www.skyetek.com/downloads.php

SkyeTek, Inc. (2004). SkyeTek Protocol v.2.2. http://www.skyetek.com/downloads.php