Application of RFID Technology in a Senior Design Course

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Abstract

This paper describes the design and implementation of a senior project based on RFID (Radio Frequency Identification) technology. The objective of the project, titled "Real Space Physical Object Tracking System (RSPOTS), was to design a complete RFID system that can physically locate an individual object from anywhere in the world via a secured Internet connection. By incorporating two or more customized RFID readers with location tracking capabilities (with an optional motorized camera system), any tagged object can be traced in a given location with the help of a network connection. The project uses a secured web site to display a 3-D (three dimensional) model of a given location, where a representation of the object is placed to represent its actual location. The paper also discusses the advantages and applications of RSPOTS. The major advantage of RSPOTS is that it can record and keep track of valuable products and visualize their movement over time with a motion-trail like display. A potential application of this system is efficient inventory control. Combined with a standard inventory system, RSPOTS can serve as an efficient tool to minimize yearly inventory variations and required adjustments for corporations, thus helping increase profits by curbing inventory losses. Furthermore, the paper explores the characteristics of "*constructivist*" and "*deep learning*" teaching/learning methodologies, inherent in teamwork, that allow students to gain new insights and competencies for enhancing their problem-solving and analytical thinking skills.

I. Introduction

RFID is an electronic method of exchanging data using radio frequency (RF) signals. A typical RFID system consists of four elements: the RFID tags (transponders), the RFID reader, the antennas and choice of radio characteristics, and the computer network (if any) used to connect the readers. The RFID tag, the basic building block of system, contains a microchip with an antenna. The microchip contains a radio receiver, a radio modulator for sending a response back to reader, control logic, memory, and power system. The tag can be powered by incoming RF signals (passive tag) or by an internal battery (active tag). The RFID reader also has its own antenna that transmits a pulse of electromagnetic energy to the tag and listens for tag's response. The tag detects this energy and sends back a response that contains tag's serial number and other required information. The RFID physical layer consists of actual radios and antennas that couple the reader to the tag. Most RFID systems use the *unlicensed* electromagnetic spectrum.[1-2]

RFID technology has been gaining momentum in recent years and is presently used in a number of applications, such as security systems, product tracking, production-line management, inventory control, product tracking, animal tracking, keyless entry, automatic toll debiting, and smart credit/debit cards.

RFID technology has been around for a while, but its current popularity stems from a tremendous drop in price of the hardware. From the Massachusetts Institute of Technology, several individuals emerged who helped start EPC (Electronic Product Code) Global, an organization that standardized how RFID should be used as a barcode replacement. EPC helped galvanize the industry and standardization helped push down prices. There are several classifications of RFID transponders (tags), which include active tags and passive tags. Table 1 highlights the characteristics of the active and passive tags.[2]

Table 1: Characteristics of Active and Passive RFID Tags

Tag	Range	Application	Cost
Passive	Short or very short 5 meters or less	The tag functions without a battery; these tags have a useful life of twenty years or more.	Less expensive compared to active tag
Active	Long 100 meters or more	Active tag technology also can be used for human subject identification when used in conjunction with a video surveillance system.	Approximately $20 or more.
Source: RFID, Applications, Security, and Privacy, Simpson Garfinkel and Beth Rosenberg, Addison-Wesly (2006).			

Table 2 lists the Electronic Product Code (EPC) global RFID classes. Table 3 presents a summary of RF bands used for RFID physical layer, and Table 4 lists the ISO (International Organization of Standardization) RFID air interface standards.

Table 2: Electronic Product Code (EPC) Global RFID Classes

EPC Device Class	Definition	Programming
Class 0	"Read only" passive tags	Programmed by the manufacturer
Class 1	"Write-once, Read many" passive tags	Programmed by the customer, cannot be reprogrammed.
Class 2	Rewritable passive tags	Reprogrammable
Class 3	Semipassive tags	Reprogrammable
Class 4	Active tags	Reprogrammable
Class 5	Readers	Reprogrammable
Source: RFID, Applications, Security, and Privacy, Simpson Garfinkel and Beth Rosenberg, Addison-Wesly (2006)' p. 19.		

Table 3: RFID Physical Layer: Radio Frequency (RF) Bands and Applications

RF band	Frequency	Wavelength	Application
Low Frequency (LF)	125 – 134.2 kHz	2,400 meters	Animal tagging and keyless entry
High Frequency (HF)	13.56 MHz	22 meters	
Ultra High Frequency (UHF)	865.5-867 MHz (Europe) 915 MHz (USA) 950-956 MHz (Japan)	32.8 centimeters	Smart cards, logistics, and item management
Industrial, Scientific, & Medical (ISM)	2.4 GHz	12.5 centimeters	Item management
Source: RFID, Applications, Security, and Privacy, Simpson Garfinkel and Beth Rosenberg, Addison-Wesly (2006), p. 21.			

II. DeVry University's Senior Project Capstone Course Sequence

DeVry University's Electronics Engineering Technology/Computer Engineering Technology (EET/CET) program senior project is a two-semester course sequence in which students synthesize knowledge and skills learned in the previous courses. In the first course (EET-400, Project management), students research, plan and develop a project proposal. And in the second course (EET-410L, Senior Project Laboratory) students implement the project plan by building and testing a prototype. A typical project involves a solution to a software/hardware-based engineering problem. The process of developing and implementing a solution to the problem offers a learning opportunity for students to gain new insights and competencies as a result of "*constructivist*" and "*deep learning*" teaching/learning approaches.

According to the *Thesaurus of ERIC Descriptors,* [3] *constructivism* is a "viewpoint in learning theory which holds that individuals acquire knowledge by building it from innate capabilities interacting with the environment." The constructivist approach is based on recent research about the human brain and what is known about how learning occurs. It is an approach to teaching and learning based on the premise that cognition (learning) is the result of "mental construction." In other words, students learn by fitting new information together with what they already know. Weigel[4] has identified the attributes of *deep learning* as a methodology in which learners (i) relate ideas to previous knowledge and experience, (ii) look for patterns and underlying principles, (iii) check evidence and relate it to conclusions, (iv) examine logic and argument cautiously and critically, (v) are aware of the understanding that develops while learning, and (vi) become actively interested in the course content.

The senior project course sequence also presents an opportunity to directly measure the competencies (program objectives) of EET/CET graduating students. In both courses, assessment rubrics are used to evaluate students' accomplishments of various tasks of project design, planning and implementation phases.

III. Senior Design Project: Real Space Physical Object Tracking System (RSPOTS)

Over the course of two semesters (30 weeks) at DeVry University, Addison, IL, the RSPOTS team planned and implemented a project to locate objects in real space. The project pooled the resources and skills of five students. The team, which spent many hours researching, planning, and developing this project, divided the group into a software team and a hardware team. The plan required the creation of an RFID system that would be able to find the exact or approximate coordinates of any object tagged with a transponder. By building and placing three or more customized RFID readers, a motorized camera system, and an interface to the Internet in a single room, any tagged object could be located in that room and visualized. The user interface was developed with the idea of a simplified search engine that any computer with Internet access could use without the need of additional software or browser plug-ins. On the secured web site, the user is presented with a 3-D (three dimensional) simulation of a given space (room/store/warehouse), and a representation of the object within this 3-D space to represent its actual location.

IV. Project Background and Objectives

Locating a product in a timely manner is a challenge many customers face everyday. When one walks into a store and does not find the desired product on the shelf, one might ask the nearest employee if it is in stock. Then employee proceeds to the computer terminal to research the store's inventory. After a lapse of twenty minutes or so, that same employee returns stating that he or she was unable to locate the product even though there were a few in stock somewhere in the store. Had there been a device/system that could actually pinpoint the exact location of the product, the store could generate more revenues and hence enhance profit.

RFID technology became popular recently due to a decline in prices. It offers a swift and efficient way to determine what is in stock, but it does not allow one to pinpoint the location of an object. GPS (Global Positioning System) has the potential to be a good tracking system, but has the shortcoming of working only for outdoor locations that can pick up satellite signals. Companies track products through a hybrid system that is mainly based on barcodes, so they do not always know the exact location of a package/object at a specified time. They can only estimate where the package is located. The only company that has developed a system for tracking physical inventory for retail stores and warehouses with RFID tags is a very young company located in South Africa. The company, Trolley Scan Ltd., has shipped its first line of products to European retailers in March 2006. It is a modified RFID system that can physically locate objects using a proprietary software and hardware solutions.

An RFID reader consists of a reader and tags. The reader sends out an illumination signal (induction coupling or propagation coupling) to the tags, and the tags transmit their data back to the reader. The project plan was to implement passive tags or active tags using UHF (Ultra High Frequency) frequency, based on EPC Global Generation 2 standards. Passive tags have no internal power source, and derive their power from the radio signal which generates an electromagnetic field around the tag. The tags then have enough power to transmit their data. The choice for UHF signals as opposed to low frequency and very high frequency signals was made because of the longer signal propagation distance.

A budget and guideline for the project was created during the initial phase. These guidelines were formulated by a series of “use cases” for the overall project. They define the objectives initially intended to be accomplished in the development of the project.

1. The device should have low production cost to make it affordable to individuals/small companies.

2. The device should offer immunity to external interference source.

3. A high level of security is required in data transmission and access.

4. The device should enable a user to either search for a specified object or space (room).

5. The RFID reader should be able to read tags within proximity of 20 meters.

6. The design should be user-friendly with detailed instructions for easy troubleshooting.

7. A simulated 3-D view and an optional panning camera should be included to focus on the object visualized within a web browser.

8. A simplified user Interface should be incorporated:

    - User logs into tracking website www.rspots.com with a password.
    - High level access user can setup database table with room, object or building information from website.
    - Any privileged user can search for an object within a text box. Pull down menus can be used to search by building, floor, or room.
    - The search will list the results where the user can highlight one or more objects to be tracked and click on the button labeled *Track*.

- The website will pinpoint the object which allows the user to view history of position/location records of the object.

V. General Approach

After developing project guidelines, a broad overview of the actual project implementation was created. The block diagram of the project is shown in Figure 1. As indicated, the user first logs on and fills in the object to be tracked in a search field. The user has the option to either specify the exact location(s) if it is known, or not. The location information will be gathered from the database as illustrated in Figures 2. After completing this step, the user is connected to the RFID reader in that location via a microprocessor across the network. The reader is then activated and sends out illumination signals to every RFID tag in that location. These tags are already mounted on every object of the room (and their respective information is contained in a database). RFID tags are powered by the RF signals. As soon as they receive RF signals from the reader, they send out data stored in the memory.

Several tags with transponders from Alien, Texas Instruments, and Analog Devices were tested. These tags had a frequency range of 900-920 MHz. This range is within the EPC Global Generation 2 standard, and also falls under the ISM (Industrial, Scientific, and Medical) band in the United States. To address the problem of interference caused by outside sources, reference tags were created. The reader is calibrated with the reference tags via their signal timings and strength. The three readers then mark the time when the signal is received back from the tags, and the time when the illumination signal was sent to the tag. A single master reader sends the illumination signal while all three synchronized readers read the signal from actual tags. The tag data captured by the readers is sent back to the server where the user is logged on. Coordinates are calculated by the server (this process involves triangulation and probability analysis), and stored in the database. The readers update the database on a user specified interval. The user logged onto the website can now initiate a simple search to find objects in the room.

The website takes advantage of PHP (Hypertext Preprocessor) and MySQL programming for the website interface, database, and searches. The user is able to view a 3-D image of the object and the exact physical location which is coded with java and X3D. The security issues of the project were addressed by creating SSL (Secure Socket Layer) access on the website (see Appendix A) with a variety of user levels allowing permission to change different settings. The data transmission between the Rabbit semiconductor microprocessor and the network was also encrypted.

Figure 1: System Block Diagram

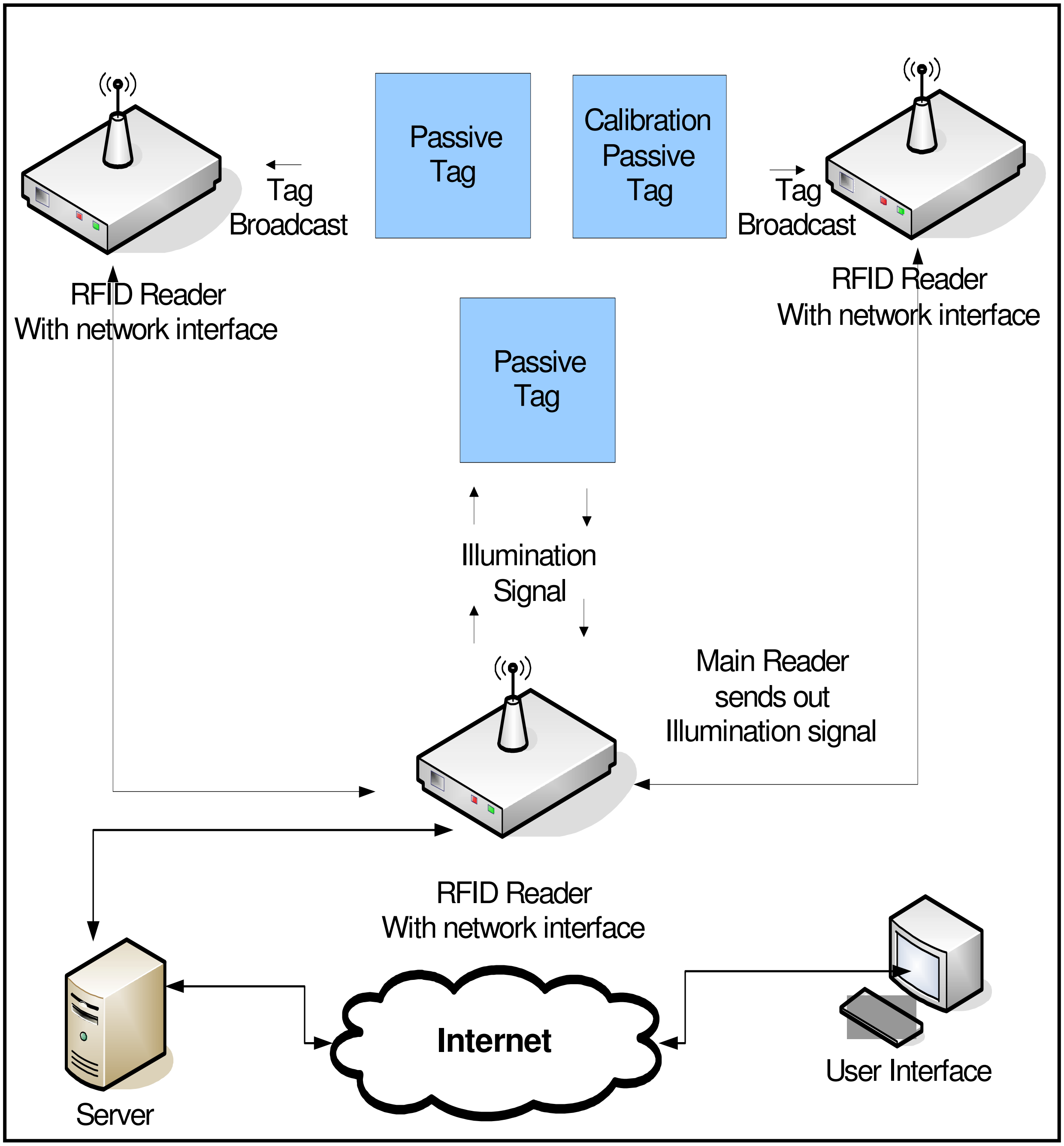
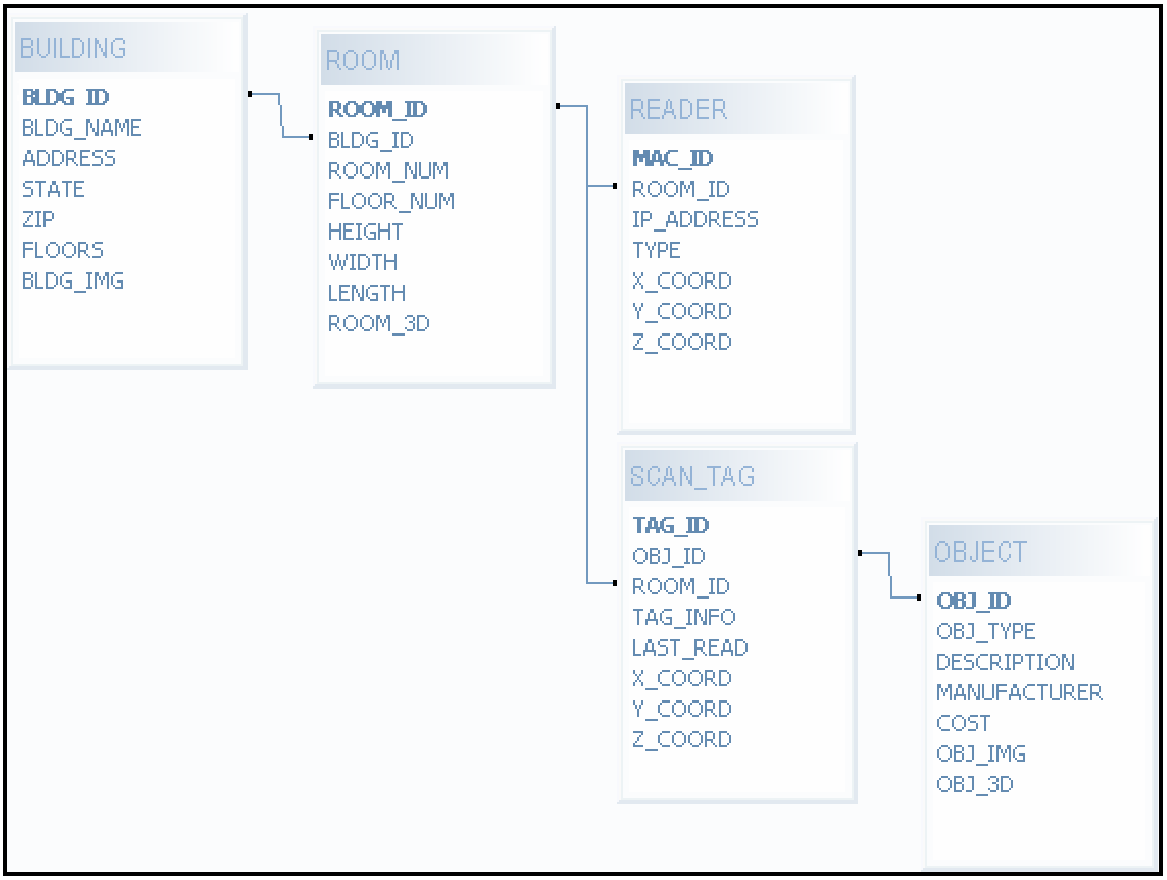


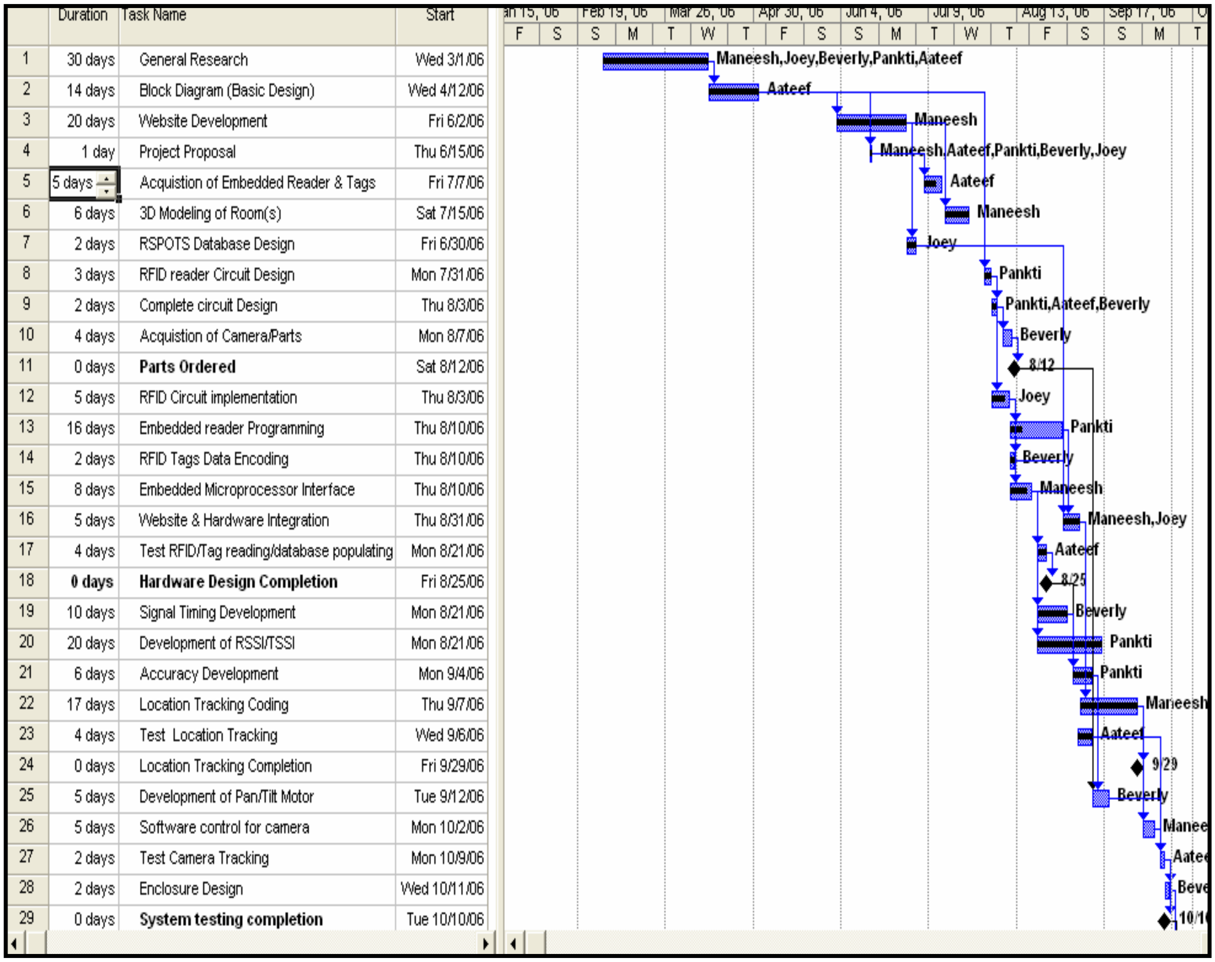
Figure 2: Software Database Design



VI. Schedules

Figure 3 illustrates a list of tasks, resources, milestones for the project schedule.

Figure 3: Project Gantt Chart



	Duration	Task Name	Start
1	30 days	General Research	Wed 3/1/06
2	14 days	Block Diagram (Basic Design)	Wed 4/12/06
3	20 days	Website Development	Fri 6/2/06
4	1 day	Project Proposal	Thu 6/15/06
5	5 days	Acquistion of Embedded Reader & Tags	Fri 7/7/06
6	6 days	3D Modeling of Room(s)	Sat 7/15/06
7	2 days	RSPOTS Database Design	Fri 6/30/06
8	3 days	RFID reader Circuit Design	Mon 7/31/06
9	2 days	Complete circuit Design	Thu 8/3/06
10	4 days	Acquistion of Camera/Parts	Mon 8/7/06
11	0 days	**Parts Ordered**	Sat 8/12/06
12	5 days	RFID Circuit implementation	Thu 8/3/06
13	16 days	Embedded reader Programming	Thu 8/10/06
14	2 days	RFID Tags Data Encoding	Thu 8/10/06
15	8 days	Embedded Microprocessor Interface	Thu 8/10/06
16	5 days	Website & Hardware Integration	Thu 8/31/06
17	4 days	Test RFID/Tag reading/database populating	Mon 8/21/06
18	**0 days**	**Hardware Design Completion**	Fri 8/25/06
19	10 days	Signal Timing Development	Mon 8/21/06
20	20 days	Development of RSSI/TSSI	Mon 8/21/06
21	6 days	Accuracy Development	Mon 9/4/06
22	17 days	Location Tracking Coding	Thu 9/7/06
23	4 days	Test Location Tracking	Wed 9/6/06
24	0 days	Location Tracking Completion	Fri 9/29/06
25	5 days	Development of Pan/Tilt Motor	Tue 9/12/06
26	5 days	Software control for camera	Mon 10/2/06
27	2 days	Test Camera Tracking	Mon 10/9/06
28	2 days	Enclosure Design	Wed 10/11/06
29	0 days	**System testing completion**	Tue 10/10/06

VII. Resources

Various hardware and software components which were used in the building of this project are listed below:

Hardware Components

1. Range Master 2 and Range Master 5 (RFID Reader) evaluation kits from Anadigm

2. Embedded RFID Tags from Allien Technology

3. Rabbit 3700 and 4010 Microprocessors

4. ADF7010 Transmitter from Analog Devices

5. Resistors, Capacitors, and Inductors

Software Components

1. Lunar Pages website – Provided reliable and affordable web hosting services.

2. Programming in C – A general purpose, widely used language; and assembly languages – low-level language used in the writing of computer programs.

3. Matlab – Numerical computing environment and programming language.

4. Multisim – An electronic schematic capture and simulation program.

5. MySQL – A multithreaded, multi-user SQL database management system.

6. PHP – (Hypertext Preprocessor), a reflective programming language mainly used in server-side scripting.

7. X3D for 3D model – The ISO standard for real-time 3-D computer graphics.

VIII. Development and Testing of Prototype

The unified process (UP) method was used to develop this project. The UP method is generally deployed in software development environments, but can be applied to both hardware and software development. This process combines the incremental process model and iterative processes

Another process defined by the UP method is the development of 'use cases' that detail how a user will interact with a part of the system. They are developed with the idea that computer systems/people will interact with hardware and software in predefined ways. With this formalized and adaptable method, the project was broken down into several planned phases. The preliminary timeline of project is outlined in Figure 3.

The first development phase involved the creation of an embedded RFID reader that can communicate to the project website. Implementation of the circuits, microprocessors, and software to read passive tags in a room was required. The data was then sent out to a web server to be stored in a database.

Phase two involved the heart of the project, location tracking. This involved additional circuitry and computer programming to track objects in real space through a secured website. Since this is an adaptive process, certain individual features of the project may change based on system testing.

The third phase originally involved implementing the camera, but the project plan was modified and instead time was spent to implement the RFID reader. The project's focus was originally on the "big picture," but after discovering many implementation challenges the completion of the RFID reader section became team's primary focus (see Appendix B).

The final phase of system development involved the design of an enclosure for the complete RFID reader and the testing of the entire system in varying environmental situations. Each phase led the team to a testable product and each had “use cases” that defined how the user interacts with the system. Using the experience gained from each phase, the team learned how to gauge the amount of time and skills required to finish the next phase of the project. Table 4 illustrates the testing plan and the challenges encountered during conducting actual testing.[5-11]

Table 4: Test Plan vs Actual testing

	Test Plan	**Actual testing**
1	Test RFID tag-reader connectivity.	Problems encountered in testing RFID tag – reader connectivity.
2	Test RFID reader – microprocessor connectivity.	RFID reader – microprocessor connectivity successfully established.
3	Populate database with simulated tags.	Successfully populated database with simulated tags.
4	Test RFID tag signal strength.	Problems encountered with passive tags. So active tags were incorporated.
5	Test web interface and tracking.	Successfully tested web interface and tracking by resolving software issues.
6	Implement system prototype and test in various simulated environments.	Encountered RFI / EMI problem in testing phase. The problem was solved by using a higher gain antenna and this led to successful implementation and testing of system prototype in various simulated environments.
Appendix C presents an array of images illustrating various phases of project testing and implementation.		

IX. Encountered Problems and Solutions

Designing various phases of the project was relatively easy, but the actual implementation of the project was difficult due to a variety of issues. Table 5 sums up the problems encountered and the solutions adopted during various phases of the project.

Table 5: Summary of problems encountered and solutions adopted

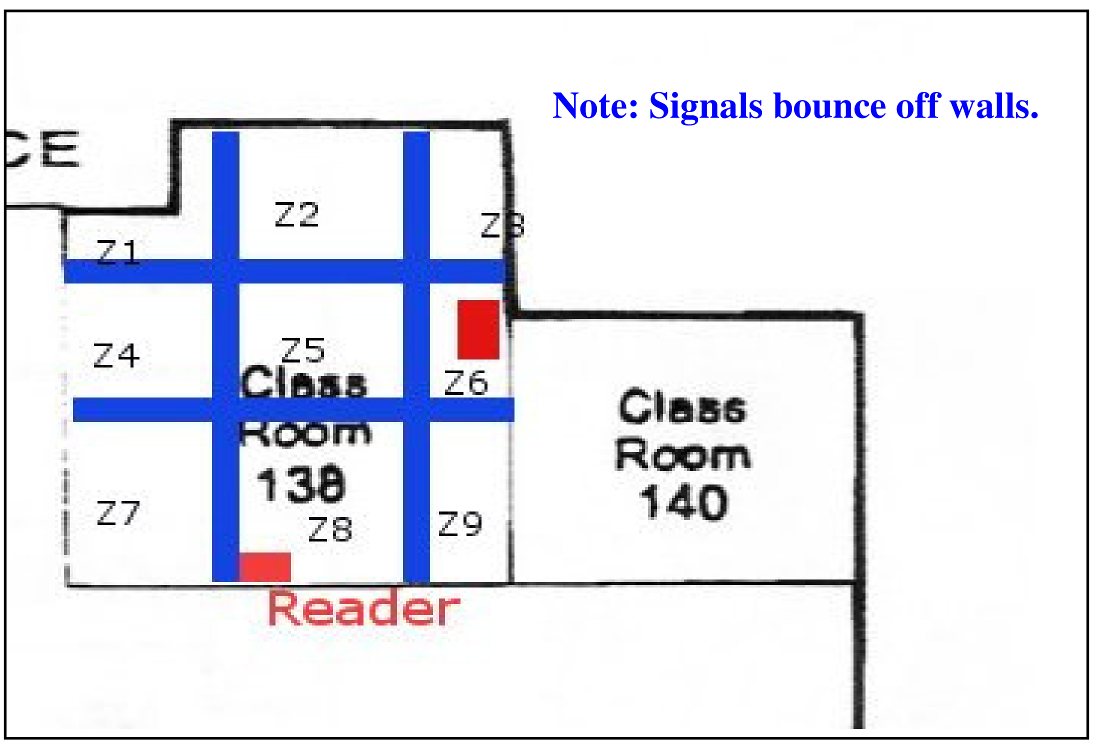
	Problems Encountered	Solutions Adopted
1	Multipath interference caused erroneous readings.	Multipath interference problem was rectified by incorporating time delay.
2	Difficulty encountered in ordering/acquisition of parts	Researched for more companies and developed backup options for alternate parts
3	Soldering of very small components/parts	Developed expertise to perform soldering of very small components/parts
4	Integration of Hardware and Software	Group members researched and implemented various options to test system integration

Figure 4(a) shows how the RFID reader detection capabilities are shown without the implementation of DSP (digital signal processing). If another reader was added, (a total of 2 readers in a room) Figure 4(b) shows how it would enhance the resolution of the tracking (with UHF signals bouncing off walls). The more complex matrix formulas required for triangulating the tags position with signal timings and strength were dropped (meant for passive tag tracking), but the team ended up with a functional project.

The project website (see Appendix A) requires a registered user to login to initiate the object search. It prompts either for an object description to be searched for or a room number. The results page lists all the tags found (the reader continually polls the tags and updates the database). Choosing a tag displays a three dimensional model of the room along with a two dimensional map of the room. The object is represented by a transparent yellow cube to indicate its general region. Appendix C contains a series of images illustrating various phases of project testing and implementation.

Figure 4 (a): Reader signal strength

Figure 4(b): Signals from the reader



X. Synthesis of Learning

The EET/CET program provided a solid educational experience that allowed the development of the RSPOTS project to yield viable results. Each course in the sequence has proven useful in the development process of the project. Since the team consisted of three electrical engineering technology (EET) students and two computer engineering technology (CET) students, the team members had the opportunity to learn outside of their field. Team members thus learned how to integrate electrical engineering theories with the computer engineering concepts. The project also enabled the team to incorporate concepts learned in the introductory classes of electronics, like the construction of a voltage regulator and a timer circuit using a 555 timer. Knowledge and skills gained in courses like communication systems and network communications enabled team members to build and test the transceivers and transponders. Programming classes such as Distributed Computing with Java taught the development of networked applications in Java. Database Design provided the crucial know-how in developing the online database that connected our hardware and software application. The Technology and Ethics course brought up the realization that there are many privacy issues associated with this technology, and its regulated use would help set up a positive technology. The project has widened the scope of learning and knowledge in the electronics and computer fields for the team members. The project also helped the group to develop higher levels of knowledge by learning totally new items that were not covered during the course work (for example, the different types of RFID tags and their applications).

XI. Conclusion

This paper described the design and successful implementation of a senior project titled "Real Space Physical Object Tracking System" (RSPOTS). The designed system can physically locate an individual product/object from anywhere in the world via a secured Internet connection. It can also record and keep track of valuable products and visualize their movement over time with a motion-trail like display. A potential application of this system is the efficient inventory control. Moreover, the paper discussed the details of EET/CET senior project capstone course at DeVry University, Addison, IL. The capstone course requires students to work in a team environment to design and implement a software/hardware-based solution to an engineering problem, and thus enables students to gain new insights and competencies as a result of "*constructivist*" and "*deep learning*" teaching/learning methodologies.

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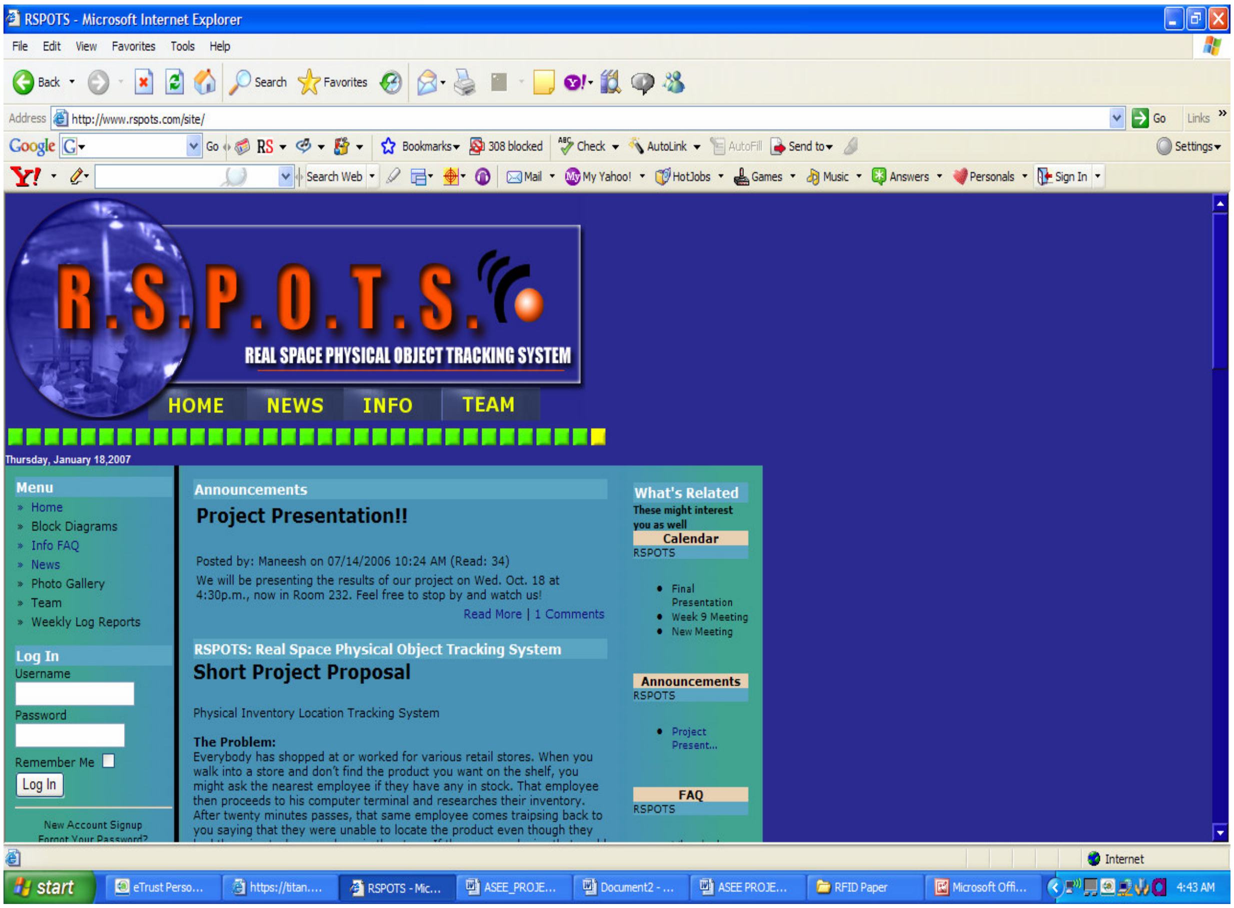
Appendix A
R.S.P.O.T.S Website Highlights

Project website www.rspots.com was created for client-server support to track and locate any tagged object from anywhere in the world.



DESCRIPTION:

The website consists of the following sections:

- Secured Log in for each user
- Object search box
- Search results (3-D view of object)
- User feedback
- FAQs

The website was also used to develop, design and track progress on various phases of project implementation. The website also displays the following sections related to project development:

- Project Proposal
- System Block Diagram
- Gantt Chart
- Weekly progress reports
- Weekly progress presentation
- System testing images

Appendix B
Circuit Diagram of RFID Reader.