

DESIGN OF A PASSIVE RFID SYSTEM
FOR ASSET TRACKING

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2010

Abstract

This project focuses on the feasibility of utilizing the lower cost passive RFID technology to track electronic test equipment for Raytheon Company. Although developed for a specific storeroom at Raytheon Company's Network Centric Division's (NCD) laboratory in Goleta, California, the project concepts and design are applicable to many portal-based asset tracking systems. The first part of the project consisted of experimentally evaluating the reliability of passive versus active technologies and selecting the best commercially available hardware offering when applied to asset tracking. The second part of the project consisted of developing a complete asset tracking system. The primary goals of the project were to reduce efforts spent on paper-based processes and gain a better view of asset movement for a significantly lower cost than another division's current active RFID system.

Acknowledgements

Giving credit where it's due: the vision and expertise of Dr. Tali Freed, Larry Rinzel, and Mike Krist made this project more than just a concept. Thank you all for the time and dedication you spent making this project a reality.

I'd like to extend a special thank you to Dr. James Harris. From microcontrollers to this paper, you've had an important and lasting impact on my career as a student at Cal Poly.

A very special thank you is extended to Dr. Tali Freed, Julie Gibson, and my family. I can't even imagine where I'd be without your support.

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I. Introduction

Asset tracking is a very important responsibility for companies and government agencies. Inventorying assets can easily become resource intensive, especially for large organizations whose assets include mobile items shared by numerous users. Misplaced assets coupled with incomplete records can result in loss of productivity and unnecessary expenditures. These issues may be mitigated by identifying assets with radio frequency identification (RFID) technologies. Assets carrying RFID tags enable networked readers to automatically and wirelessly exchange data. When coupled with custom software, the received data may be logged to a database allowing for the generation of event timelines, location reports, and statistical analyses.

A recently completed project by the Cal Poly PolyGAIT laboratory for Pacific Gas & Electric's Diablo Canyon Power Plant in Avila Beach, California provides strong economic justification for tracking low and high value assets using passive RFID systems. The specific project involved tagging thousands of items in a large warehouse and tracking their approximate locations using readers and antennas mounted to the warehouse workers' lift trucks. During the warehouse workers' daily picking activities, the RFID system continually monitors and automatically updates the time and approximate location of each item found. Current figures show that the automated RFID inventory system saves an estimated 1,700 hours per year of manual inventorying and cycle counting procedures^[1]. Additional savings are

realized by utilizing location information to search for lost items and is estimated at an additional 500 hours per year. Based on PG&E figures, this amounts to 105% of a full-time-equivalent employee or approximately \$165,000. With a total system cost of \$240,000 including a one year maintenance contract, PG&E justifies the implementation in approximately 1.5 years of operation.

Raytheon Company's NCD estimates annual mobile asset shrinkage at approximately \$150,000. This shrinkage includes the cost of items that are reported lost or stolen and the cost associated with the labor time used to search for the lost or stolen assets. This figure prompted the division to research alternatives to the current process. This project was driven by the motivation to significantly reduce this shrinkage cost.

This project experimentally characterized the performance of passive and active RFID technologies. Utilizing the low-cost passive technology, a portal-based asset tracking system was developed suitable for tracking equipment in Raytheon Company's NCD laboratory. The best commercially available hardware was employed to reduce the cost of asset shrinkage and labor associated with the paper-based process. Raytheon Company's NCD supported the research and system design through the Cal Poly Laboratory for Global Automatic Identification Technologies (PolyGAIT). The following deliverables were provided to PolyGAIT and made accessible to Raytheon Company:

- Paper summarizing experimental results

- CD containing binary and source formats of the developed software system
- User guide detailing how to install, configure, and operate the developed system

Section II provides background information about RFID technologies and Raytheon Company's NCD inventorying process. The project requirements are outlined in section III. Section IV explains the setup of the passive tag selection experiment and provides a summary of its results. Section V summarizes the setup of the passive versus active tag experiment and its results. The system design is presented in section VI and includes hardware selection and configuration, software platform selection, and an overview of the software algorithms and presentational elements employed. The test methods are summarized in section VII. Section VIII provides information about the tools used to implement the system design. The test results and analysis of the implementation are presented in section IX. A summary of the final system performance future design considerations are provided in section X. References made throughout this paper are listed in the bibliography of section XI. The appendices conclude with an overview of the project costs in A, a "read me" file for the software and user guide CD in B, and an analysis of the senior project in C.

II. Background

An RFID system consists of four components: reader, antenna, tag, and computer. The reader is a small, typically microcontroller or microprocessor driven, communications device that intelligently decodes and logs transmitted data received through one or more external, directional antennas. The tag is a smaller communications device that includes a built-in antenna that identifies a unique item under observation. There are currently three types of RFID technologies: active, passive, and semi-passive. The primary difference between these technologies is the presence of an internal battery or lack thereof. The active and semi-passive technologies contain an internal battery while the passive technology does not. The active technology draws power from the internal battery to transmit the desired data to the reader. The passive and semi-passive technologies draw power from a signal broadcast by the reader to transmit the desired data back to the reader. RFID tags are programmed with a unique number that is transmitted with all data messages. However, having an internal battery, active and semi-passive tags are capable of continually powering the internal circuitry in the absence of a reader enabling complex operations such as calculating GPS coordinates, temperature sensing, and extended logging to memory. Although more complex and creative applications are being developed for passive tags, their typical use involves tracking the unique, programmed number.

Raytheon Company currently employs active RFID tags and readers to track the

location and movement of high value assets. The active RFID tags cost anywhere from \$10 to \$100 depending on the selected feature set. Unfortunately, these higher costs are prohibitive for employing an active RFID asset tracking system for low value assets. Raytheon Company's NCD is interested in tracking electronic test equipment using the lower cost passive RFID tags that can typically be obtained for less than 25 cents each when purchased in bulk. The equipment ranges from \$10 probes to \$100,000 oscilloscopes and is housed in a specific storeroom. Employees have been asked to register when and what items are checked in or out of the storeroom. This registration was completed via paper forms kept on a desk near the portal, or the entrance and exit. The form includes fields for the employee's badge number, the equipment serial number, and the current date and time. The employees' failure to consistently complete the paper form continually presented challenges as the incomplete records made tracking lost equipment difficult. In addition, management had to perform laborious analysis on the paper form entries to determine if particular items are in high demand warranting additional purchases to increase productivity. A floor plan of the equipment storeroom is provided in Figure 1.

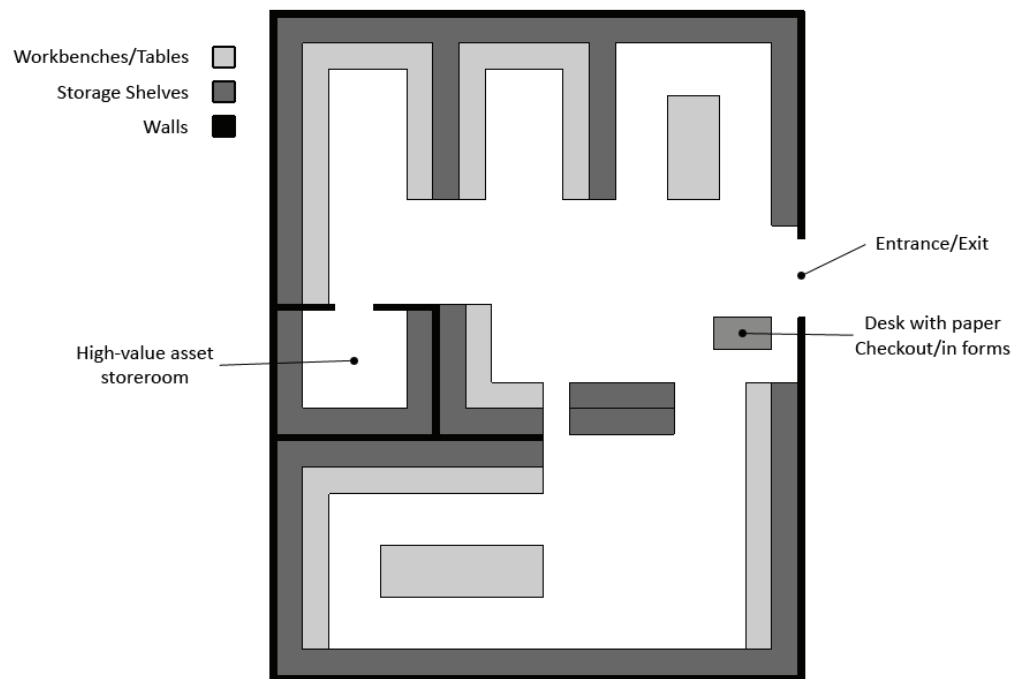


Figure 1. Floor plan of Raytheon Company's storeroom (not drawn to scale).

III. Requirements

The first project requirement included experimentally determining the best commercially available passive RFID tag brand and model. The passive tags had to operate in the UHF frequency range and conform to the Electronic Product Code Generation 2 (EPC Gen 2) standard^[2]. The second project requirement included experimentally determining if any statistical differences exist between the read rates of active and passive tags when applied to an asset tracking system. The active tags had to be similar to those already in use at Raytheon Company. The final project requirement included developing a complete asset tracking system. The system requirements are outlined in Table I.

Table I. ASSET TRACKING SYSTEM REQUIREMENTS.

Identify equipment using passive EPC Gen 2 RFID tags
Identify employees using the Raytheon Company's existing HID near-field RFID badges
Use off-the-shelf hardware components to ensure corporate support options
Minimize costs without sacrificing reliability experimentally determined
Automatically log when an item passes through the portal
Provide check out and in processes for employees with a workflow similar to the paper form process
Allow multiple items in a single transaction
Provide an intuitive interface with instructions enabling employees to check out and in equipment
Check out and in workflow must be similar to the paper form process
Provide an access-limited interface for management to review equipment history and each item's current status
Mount the antenna above the storeroom's doorway

IV. Passive Tag Selection Experiment

Alien Technology's 925 MHz passive ALR-9800 Enterprise Reader was connected to an ALR-9611-CR antenna and used to evaluate the leading RFID tag manufacturers' best flagship products^[3]. The ALR-9611-CR is a flat panel directional antenna that utilizes circular polarization to minimize the effects of multi-path interference. The following list of tags were evaluated:

- Symbol (Matrics) UHF Passive Tag with Dual Dipole Antenna
- Alien ALL-9354-02 "M" UHF Tag
- Alien "Squiggle" UHF Passive Tag
- Sokymat UHF Passive Tag

Most items in the storeroom are expected to contain or be enclosed within metal. The small skin depth of metal proves to be a significant obstacle for RFID operating at UHF frequencies^[4]. In addition, reflected radio waves off metallic surfaces can cause interference with a tag's transmission. These issues required the tags to be tested standalone, mounted directly to a metal chassis, and insulated from the metal chassis. Three types of insulation were tested: 3 ply cardboard approximately 5/16 inches thick, 2 ply Plexiglas approximately 1/4 inch thick, and rubber foam weatherseal tape approximately 5/16 inches thick. The Alien Gateway demonstration software was used to test the read distance. The software interface provides a real-time, graphical listing of the tags found in the antenna's field. Each tag was held close to the reader and walked slowly away until it disappeared from

the interface's listing. The distance at which it disappeared was recorded as the read distance.

The results of the experiment showed most favorable read conditions when the tag was by itself. The tags were capable of read distances averaging 20 feet. Least favorable read ranges were obtained when the tags were mounted directly to a metal chassis. All tags were incapable of being read under this condition except the Symbol UHF tags which could be read at an average distance of 2 inches. Insulating the tags with Plexiglas proved to be least effective, and cardboard insulation provided slightly better read ranges than the Plexiglas insulation. Insulating the tags with the rubber foam proved to be most effective, and the read distances are summarized in Table 2. Table 2 also includes an entry for the active tag used in the active versus passive tag experiment of the next section. Comparing average read distance, physical size, and cost the Alien ALL-9354-02 "M" UHF tags were selected as the best available passive tag.

Table II. COMPARISON OF PASSIVE TAGS AND THE RF CODE MANTIS II ACTIVE TAG.

Reader	Symbol UHF	Alien ALL-9354-02 "M" UHF	Alien "Squiggle" UHF	Sokymat UHF	RF Code Mantis II
Average Read Distance (Feet)	7.25	8.41	0.8	8.87	> 30
Insulation	Rubber Foam	Rubber Foam	Rubber Foam	Rubber Foam	None
Cost (Quantity)	No Quote Available	\$0.44 (2000) \$0.22 (7500)	\$0.20 (2000) \$0.149 (14500)	\$4.00 (100) \$3.30 (1000) \$2.80 (5000) \$2.60 (10000)	\$24.00 (1)
Size (Inches)	4 x 4	3.87 x 1.375	3.87 x 0.48	9.06 x 0.59	2.44 x 1.25 x 0.4
Life Span	Indefinite	Indefinite	Indefinite	Indefinite	5-7 Years

V. Passive Versus Active Tag Experiment

The purpose of the experiment was to compare the read rates of active and passive tags passing through a portal to determine if passive technology is sufficient for tracking both low and high value assets. An environment similar to Raytheon Company's NCD storeroom was setup in the PolyGAIT laboratory. The active and passive tags were fixed to various pieces of electrical test equipment that were expected to be found in the storeroom. The items were randomly chosen to leave and enter the room at specific time intervals while being tracked by hand and by a computer. The movement simulated the checking in or out of an item.

The experiment utilized the passive Alien ALR-9800 Enterprise Reader and ALL-9354-02 "M" UHF tags and RF Code's 303 MHz Mantis II active tags and reader^[5]. The ALR-9800 Enterprise Reader was attached to an ALR-9611-CR antenna and mounted to a post above the PolyGAIT laboratory entryway. The ALR-9611-CR was mounted at a downward angle of 30° measured from the vertical wall. The passive tags were mounted to rubber foam weatherseal tape, and the rubber foam and active tags were fastened to each item using plastic ties. The Mantis II reader included two helical antennas and was mounted approximately 12 inches from the passive reader with antennas upright and parallel to the vertical wall.

The experiment was run twice. During the first run, the tags were purposefully obstructed from the view of the reader's antenna by the carrier's body simulating a worst case read scenario. During the second run, the tags were given an

unobstructed view of the antenna held away from the carrier's body to simulate a best case read scenario. For both runs, the speed was varied between the carrier walking very slow and very fast. In addition, the number of tags passing through the portal at once was varied between one and two. The order in which the items entered the portal was determined by a randomization produced by Minitab. The specific item each tag was affixed to was determined using an online pseudo-random number generator. During the experiment, tag events generated by the reader were sent immediately to an electronic database via software.

The experiment result showed that the passive tags read anywhere from 85% of the time during the worst case scenario to 100% of the time during the best case scenario. The experiment also confirmed that the active tags read 100% of the time. Although not statistically insignificant, the worst case scenario is expected to play very little into the actual reliability of the system implementation. It is expected that reads in Raytheon Company's storeroom will occur under the best case scenario as employees will be purposefully stopping and moving equipment in front of the antenna to fulfill the software interface's check in and out procedure. It was decided that passive tags were reliable enough and significantly less expensive justifying the system design and implementation.

VI. Design

The system design included in four steps: hardware design, software platform selection, employee interface design, and manager web site design. These four steps have been separated into the following sections.

Hardware

The first step was to develop a high-level system concept specifying hardware components, inputs and outputs, and physical transports. It was decided to identify items with Alien Technology's UHF devices used in the previous experiment, specifically the ALR-9800 Enterprise Reader, ALR-9611-CR antenna, and the ALL-9354-02 "M" UHF tags. The reader costs approximately \$1500. Each antenna costs approximately \$150. Each tag costs approximately \$0.22 when purchased in bulk. This homogeneous brand utilization helps minimize Raytheon Company's dependency on external hardware vendors. It was determined that employee identification should be performed by reading the existing RFID proximity badges. The employee badges are manufactured by HID Global and operate on 125 kHz^[6]. A simple approach was developed using RFIDEas pcProx near-field reader^[7]. This reader provides a USB connector and emulates an ASCII keyboard sending keystrokes matching a scanned badge's card and site numbers. To interface with both readers, a PC workstation with Ethernet and USB adapters is required. The block diagram of Figure 2 shows the resulting design with details about the physical connections.

The PC workstation and UHF reader are locked inside a cabinet of the desk

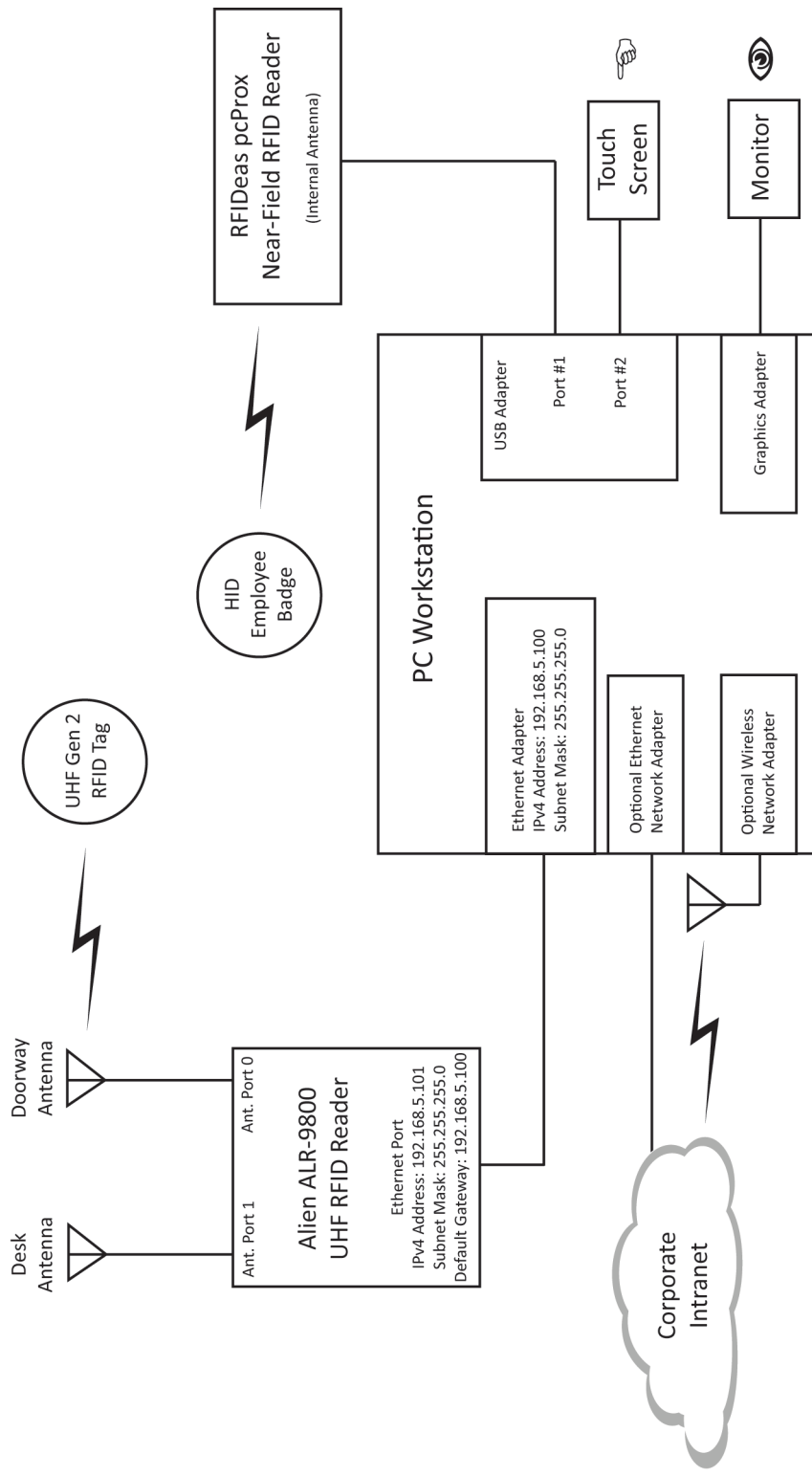


Figure 2. Block diagram of hardware components and interconnections.

located by the portal. The antenna is connected to the reader via shielded coaxial cables terminated with a BNC connector. The antenna is mounted above the doorway at a downward angle intended to catch any tagged item passing through the portal. Figure 3 illustrates the location of the portal antenna and its approximate field pattern.

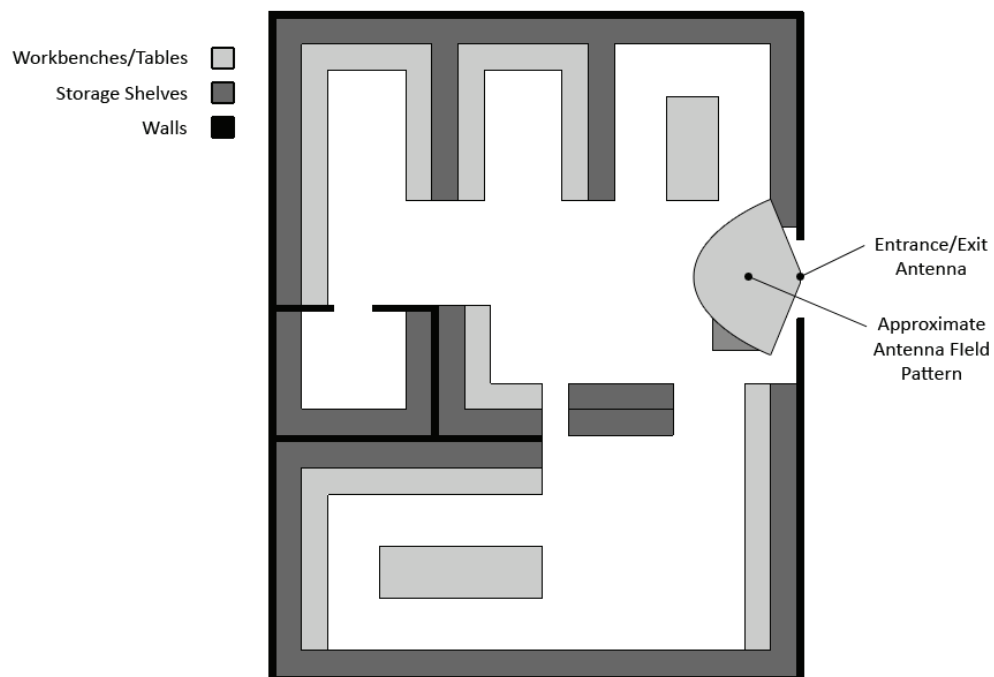


Figure 3. Doorway antenna location and approximate field pattern (not drawn to scale).

The experimental results showed that tag reads were negatively impacted when the antenna field was obstructed by the carrier's body. A second antenna has been included in the design to help ensure the occurrences of this scenario are minimized. The current check in and out process forces employees to set down

their equipment as they complete the paper form. Although not required, it is expected that employees will continue this practice by resting items on the desk during the check in and out procedure. To ensure the second antenna's read field remains unobstructed by the employee's body it should be mounted to the desk and positioned slightly higher than its surface. This may be achieved by mounting the antenna to a pole that is bolted to the rear of the desk. This second antenna is optional but recommended for extending the read field during check in and out procedures and boosting the expected reliability of the system for minimal cost. Figure 4 illustrates the location of the optional desk antenna and its approximate field pattern.

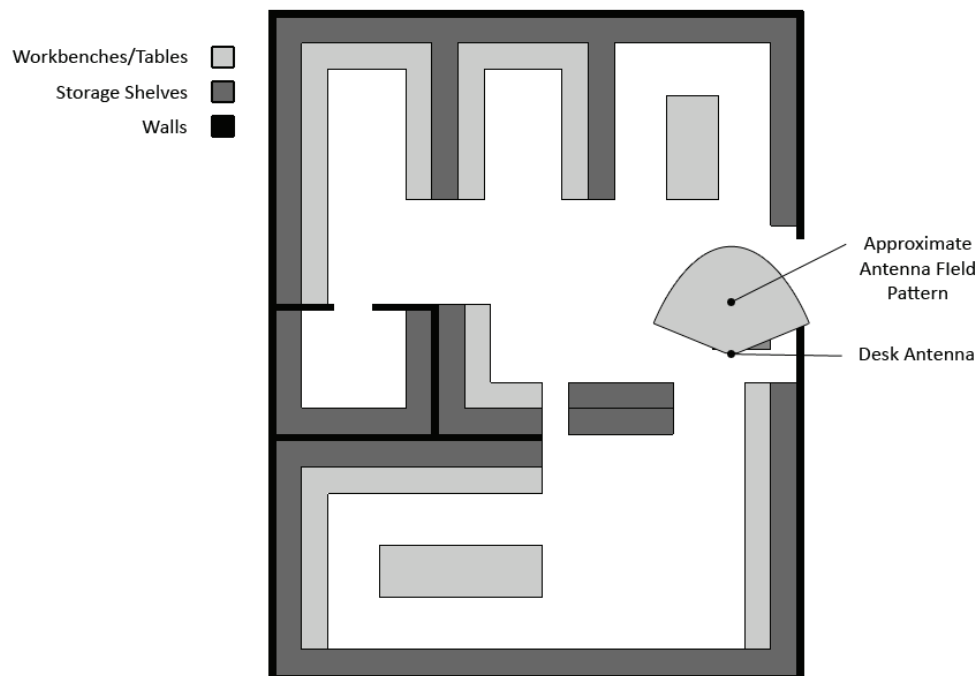


Figure 4: Optional desk antenna location and approximate field pattern (not drawn to scale).

An Ethernet crossover cable is connected between the reader and an Ethernet adapter in the PC workstation. The cable allows the devices to form a private network, and each device must be statically configured with an IP address from an Internet Assigned Numbers Authority (IANA) reserved IP address range for private networks as described by the best current practice published by the Internet Engineering Task Force (IETF) Request for Comments (RFC) 1918^[8]. This physical transport enables software on the PC workstation to communicate with the reader. Figure 2 includes example TCP/IP configuration settings for this Ethernet adapter and the reader. The second Ethernet adapter is optional but recommended for providing a physical transport layer to the corporate intranet. With the correct corporate intranet configuration settings, this second Ethernet adapter can provide remote access to the manager web site's reporting and analysis tools. Alternatively, the second Ethernet adapter can be replaced with a wireless networking adapter to wirelessly connect the PC workstation to the corporate intranet.

The near-field RFID reader is mounted to the top of the desk and connected to the first USB port of the PC workstation. This reader has an internal antenna and is capable of reading the employee badges from an approximate distance of 2 inches. It emulates a USB keyboard, and for each badge read sends ASCII keystrokes to the PC workstation's operating system corresponding to the programmed card and site number. The reader is configurable and supports sending a preamble, the badge data, and a postamble. It is important that any additional keyboard devices be left

disconnected from the PC workstation to ensure false authentication data is not received.

A touch screen monitor resting on top of the desk serves as the second human interface device. The graphics adapter of the PC workstation is connected to the monitor via a VGA or DVI-D cable. The monitor renders a graphical user interface produced by the employee interface software that includes instructions and visual feedback elements. The touch screen is connected to the second USB port and emulates a USB mouse. It transforms physical taps into mouse click events. This allows employs to interact with the software's graphical user interface to indicate their intent to check in or out items. Alternatively, the touch screen monitor could be replaced by a traditional monitor and USB mouse.

Finally, each item in the storeroom is outfitted with one of the UHF EPC Gen 2 tags. Each tag is adhered to a piece of rubber foam insulation that is slightly larger than the tag. In the foam, a punch is created in a section of the excess that is not covered by the tag. Through the punched hole, a plastic tie fastens the foam and tag to the item. The location and details of fastening tags to specific items is left for further research for Raytheon Company due to the uniqueness of each item.

Software Platform

With the hardware design completed and physical connections determined, the second step of the design focused on the selection of the software platform. The factors impacting the selection process included the distribution licenses (open

source software being preferred), availability of corporate and community support, and the level of support for multiple hardware architectures and operating systems. The employee interface is the first software component and is responsible for interacting with the UHF RFID reader, the near-field RFID reader, the touch-screen monitor, and a database back end. To simplify the process of multiple operating system support, the employee interface software was developed in Java following the Java 6 Standard Edition specification. Sun Microsystem's runtime environment was selected to ensure Raytheon Company could obtain corporate support for the Java platform if necessary^[9]. Sun Microsystem's free and open-source MySQL relational database management system was selected as an entry level storage solution, also ensuring access to corporate support options and cross-platform capabilities^[10]. The open-source PHP scripting language coupled with the Apache HTTP Server were selected to generate the manager web site's reporting and analysis tools as a dynamic web site^[11, 12]. Corporate support for PHP is available through Zend Technologies^[13]. The Apache HTTP Server was selected because of its global dominance and active community despite corporate support from the Apache Foundation not being available.

Three object models were created in the MySQL database that represented a unique tagged item, a generic equipment type, and a tag read event (see Figure 5). The "tags" table is used to represent the unique tagged items. Each record consists of the programmed RFID tag number, Raytheon Company's assigned serial

number, a reference to a generic equipment type, and an item specific description. The description is intended to be used as a note field in the manager web site. The “equipment” table is used to store information about generic equipment types. This allows for the reuse of common information among like items. Each record consists of a title, which is expected to contain the manufacturer name and model number of the item, a detailed description, and a picture. The “events” table represents a time log of item movements. The “type” column represents an integer encoded enumeration value that identifies the event as an item moving through the portal, an item being checked in by an employee, or an item being checked out by an employee (see Table III). The “extra” column contains the employee badge data for events representing items being checked in or out by an employee. For events representing an item moving through the portal the “extra” column value will be NULL.

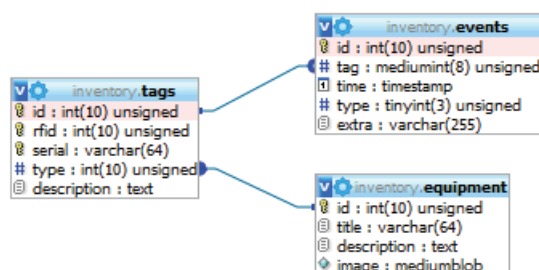


Figure 5. MySQL database object models and relations.

Table III. TYPE ENUMERATION VALUES USED IN THE “EVENTS” DATABASE TABLE.

Integer Value	Name	Description
1	READ	Represents an item passing through the portal.
2	CHECKOUT	Represents an employee checking out an item.
3	CHECKIN	Represents an employee checking in an item.

Employee Interface

Next, the employee interface software algorithms were defined. Two primary tasks were identified for this component: log a READ event to the database anytime a tag enters the portal and associate an employee’s badge data along with a specific action (CHECKOUT or CHECKIN) to specific tags. To perform these tasks simultaneously, a multi-threaded architecture was employed. Three threads run simultaneously and are referred to as the foreground, Alien reader, and user-interface (UI) threads. The foreground thread is started by the Java virtual machine and is responsible for the primary application logic (see Figure 6). The foreground thread starts the Alien reader and UI background threads. The Alien reader thread communicates with the UHF reader and the database interface. It also exposes a function that allows an external thread to receive a list of tags currently in the antenna field. The UI thread communicates with the operating system capturing input from the human interface devices and the rendering of the graphical user interface on the graphics adapter.

Alien provides a high-level, royalty-free, closed-source Java API to communicate

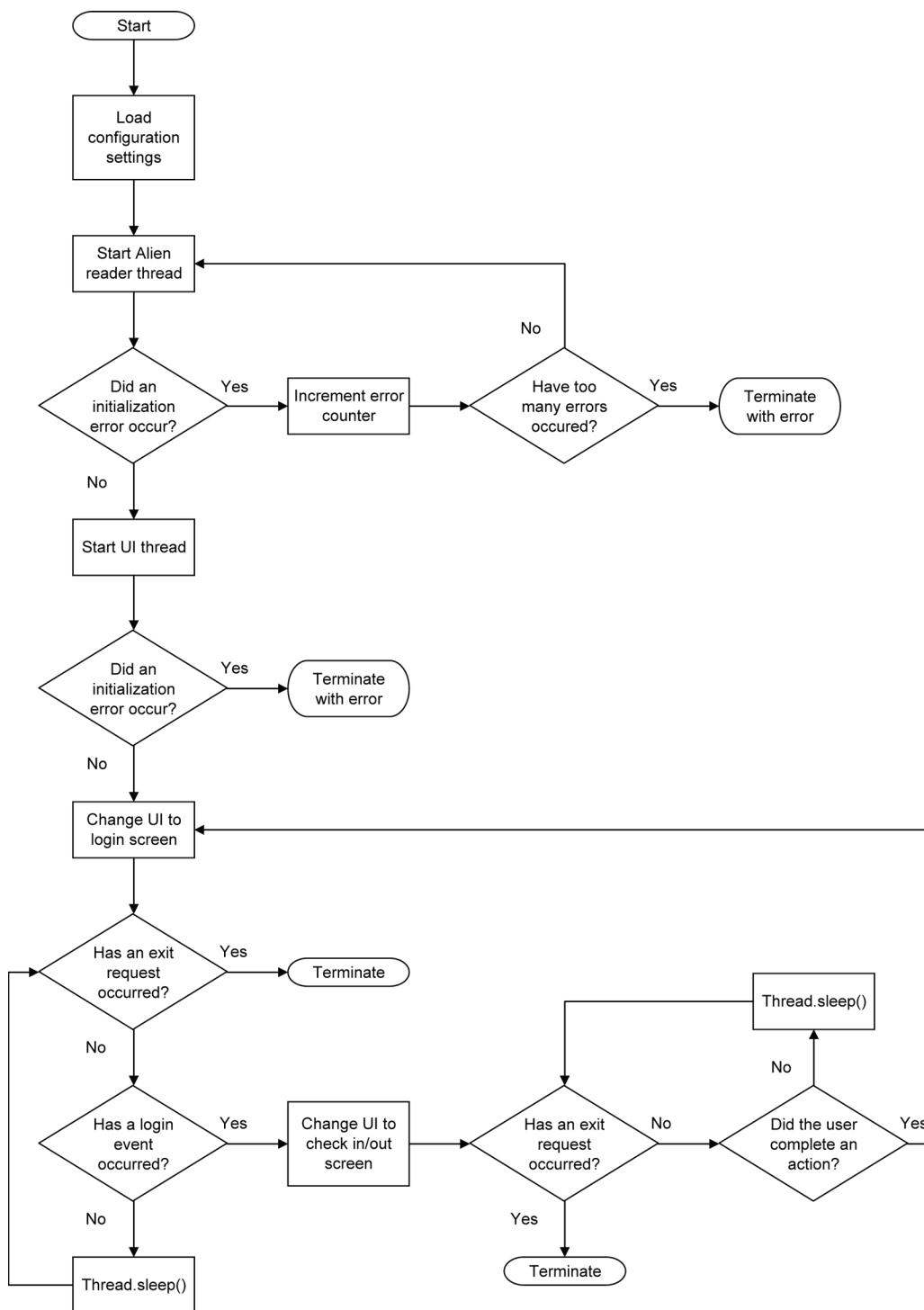


Figure 6: Flowchart of foreground thread logic.

with the UHF reader. The Alien thread is a managed component of this API and allows for event-driven programming. Communications with the UHF reader over TCP/IP sockets and translation of stream data to Java objects is handled internally by the API. The foreground thread provides relevant configuration settings obtained from an external XML file and launches the Alien thread. Launching the thread opens the TCP/IP socket to the UHF reader and performs an authentication request. Due to start up delays, the reader connection does not always open on the first try. If a connection or authentication failure occurs, an exception is thrown and the Alien thread terminates. The foreground thread catches any thrown exceptions, increments a counter, and launches a new Alien thread. If the connection or authentication attempts fail after a configured number of retries, the program terminates displaying a graphical interface error dialog. If the connection and authentication requests are successful, the Alien thread sends operational commands to the UHF reader in response to changes in the displayed UI screen. While on the login UI screen (waiting for badge data from the near-field reader), the UHF reader is configured to operate in autonomous mode. Autonomous mode causes the UHF reader to continuously notify the Alien thread of tag read events. While on the check in and out UI screen, the UHF reader is configured to operate in a manual, polled mode. In this mode, the field is scanned for tags only by request of the UI thread. Whenever a tag read event is received, in either autonomous or manual modes, the unique tag number and the time stamp of the read are logged to

the database.

The user interface was developed using the Swing Widget Toolkit. The UI thread is a managed component of the toolkit and also allows for event-driven programming. Communications with the human interface devices and graphics adapter are handled internally. The login screen is presented in full-screen, exclusive mode (see Figure 7). Full-screen exclusive mode hides graphical components of the operating system (such as the Start bar on Microsoft Windows) and gives the interface a kiosk feel. Running in this mode prevents employees from attempting to perform any action other than check in or out items on the PC workstation.



Figure 7. Login screen before an employee badge has been read.

The login screen displays a company logo. The logo can be customized using a setting in the XML configuration file. While the login screen is displayed, keyboard events are captured and buffered. When the correct near-field RFID reader data

sequence is received, the instruction label changes to indicate to the employee that their login request has been received (see Figure 8). The employee badge data is parsed and the foreground thread notified that a user has logged in. The foreground thread triggers the Alien thread to reconfigure the reader mode as previously discussed.

The logo for Cal Poly, featuring the words "CAL POLY" in a green, serif font. The text is underlined with a thick black horizontal bar.

Please wait as your items are being scanned.

Figure 8. Login screen after an employee badge has been read.

The foreground thread closes the login window and opens the check in and out window again in full-screen, exclusive mode (see Figure 9). A single polling of the antenna fields is performed and the list of tags sent to the check in and out window. The list of tags is used to populate a list widget. Each row in the list widget includes a thumbnail view of the generic item's picture, the generic item's title, and the specific item's serial number. A selected row in the list is highlighted green and the text is made bold (to help employees that may be color blind). A deselected row has

a white background with text carrying normal weight. The ability to deselect items is useful in the case that a tag on a nearby shelf is accidentally read. Employees are provided instructions on how to use the check in and out window. The employee may select one of four buttons along the bottom of the screen. The first allows them to re-scan the field for additional items. The next two buttons allow the employee to indicate their intent to check in or out the selected items. The last button allows the employee to cancel the transaction. Upon completion or cancelation of the transaction, the foreground thread closes the check in and out window and re-opens the login window.

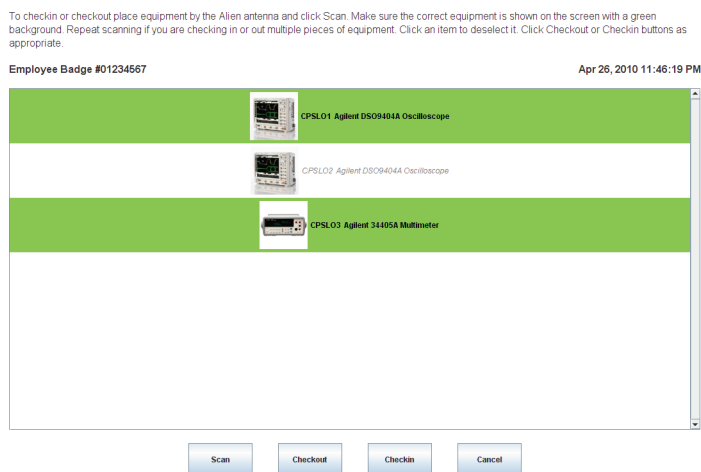


Figure 9. Check in and out screen showing selected and deselected items.

Because the employee software runs in full-screen exclusive mode, no window controls are presented (such as minimize and close buttons). To stop the UHF reader and terminate the employee interface, a manager must first connect a keyboard

to the PC workstation. While the login screen is active, the manager may type Ctrl+X. When the login screen receives this special key combination it signals to the foreground thread that an exit request has been received. This special keyboard combination cannot be generated by the near-field RFID reader, so an additional keyboard must be connected to send this command.

Manager Web Site

The final component is a reporting and analysis tool for management use. This component is presented as a dynamic web site. If the optional second networking adapter is included in the PC workstation, management may access this web site from remote workstations connected to the corporate intranet. Without the optional second networking adapter, management will have to shutdown the employee interface and launch a web browser on the PC workstation to access the web site. The web site is written in PHP and served by an Apache HTTP server on the PC workstation. The web site provides a home page acting as a table of contents (see Figure 10), a search page (see Figure 11), and three listing pages for the three database models (see Figures 12, 13, and 14). The listing pages provide paginated tables allowing table data to be viewed in manageable chunks. Each listing page provides two subpages that provide additional functionality related to the specific model. A site map is provided in Figure 15.

The screenshot shows the home page of the RFID Inventory Management web site. The page has a blue header with the title "RFID Inventory" and the subtitle "Cal Poly RFID Inventory Control Panel". The header also includes the text "PolyGAIT | Cal Poly". Below the header is a green navigation bar with the following menu items: Home, Event Log, Tags, Equipment, and Search. The main content area is divided into two columns. The left column contains four sections: Home, Event Log, Tags, and Equipment. Each section has a heading and a brief description of the page's functionality. The right column contains a "Quick Search" section with a search input field and a "Search" button. The footer of the page is blue and contains the text "© 2008 Cal Poly PolyGAIT Laboratory | Design by: styleshout | Valid XHTML | CSS".

RFID Inventory

Cal Poly RFID Inventory Control Panel

PolyGAIT | Cal Poly

[Home](#) [Event Log](#) [Tags](#) [Equipment](#) [Search](#)

Home

The **Cal Poly RFID Inventory** system monitors and logs all equipment activities. The **Cal Poly RFID Inventory Control Panel** provides administrative staff an easy-to-use web interface with the ability to view and search the event log and manage RFID tag and equipment listings. The control panel also allows for easy statistic gathering and graphing.

Event Log

The **Event Log** page allows administrators to view the complete list of RFID actions. Events include equipment check-ins, equipment check-outs, and door reads. The event log is searchable, sortable and filterable.

Tags

The **Tags** page allows administrators to view, modify, and create new RFID tags. The page also allows detailed usage graph generation for each tag. Tags are associated with specific equipment types (see Equipment Management).

Equipment

The **Equipment** page allows administrators to view, modify, and create new equipment types. Equipment types allow for easy classification, identification and grouping of different RFID tags.

Quick Search

Figure 10. Management web site home page screenshot.

The screenshot shows the 'RFID Inventory' management website. The header is blue with the title 'RFID Inventory' and 'Cal Poly RFID Inventory Control Panel'. A green navigation bar contains links for 'Home', 'Event Log', 'Tags', 'Equipment', and 'Search'. The main content area is divided into two sections: a large 'Search' form and a smaller 'Quick Search' form. The 'Search' form includes input fields for 'Tag Number' and 'Tag Serial', and a 'Search' button. The 'Quick Search' form has a single input field and a 'Search' button. The footer is blue and contains copyright information: '© 2008 Cal Poly PolyGAIT Laboratory | Design by: styleshout | Valid XHTML | CSS'.

RFID Inventory
Cal Poly RFID Inventory Control Panel

PolyGAIT | Cal Poly

Home | Event Log | Tags | Equipment | Search

Search

Use the form below to search for a tag by number or serial.

Tag Number:

Tag Serial:

Search

Quick Search

Search

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Figure 11. Management web site search page screenshot.

RFID Inventory
Cal Poly RFID Inventory Control Panel

PolyGAIT | Cal Poly

Home | **Event Log** | Tags | Equipment | Search

Event Log (All Events)

The following table provides access to view registered events. There were 7 total events found.

Previous Page • Next Page Export to CSV

Time	Type	Tag	Serial	Employee
2010-04-27 04:16:41	Check-In	3d7	CPSLO3	01234567
2010-04-27 04:16:32	Read	3d7	CPSLO3	
2010-04-27 04:16:24	Check-Out	3d7	CPSLO3	01234567
2010-04-27 04:16:11	Check-Out	3cb	CPSLO1	01234567
2010-04-27 04:16:01	Read	3cc	CPSLO2	
2010-04-27 04:15:58	Read	3cb	CPSLO1	
2010-04-27 04:15:52	Read	3cb	CPSLO1	

Previous Page • Next Page Export to CSV

Quick Search

Actions

- View All Events
- View Read Events
- View Check-Out Events
- View Check-In Events
- View 30-Day Activity Graph

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Figure 12. Management web site “events” table listing page screenshot.

RFID Inventory
Cal Poly RFID Inventory Control Panel

PolyGAIT | Cal Poly

Home | Event Log | **Tags** | Equipment | Search

Tag Management

The following table provides access to view and modify RFID tags. Use the link on the left to add or customize the table view.

Tag Number	Serial	Last Action	Details
3cb	CPSLO1	2010-04-27 04:16:11	Check-Out Details
3cc	CPSLO2	<i>None</i>	Details
3d7	CPSLO3	2010-04-27 04:16:41	Check-Out Details

Quick Search

Actions

- [Add New Tag](#)

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Figure 13. Management web site “tags” table listing page screenshot.

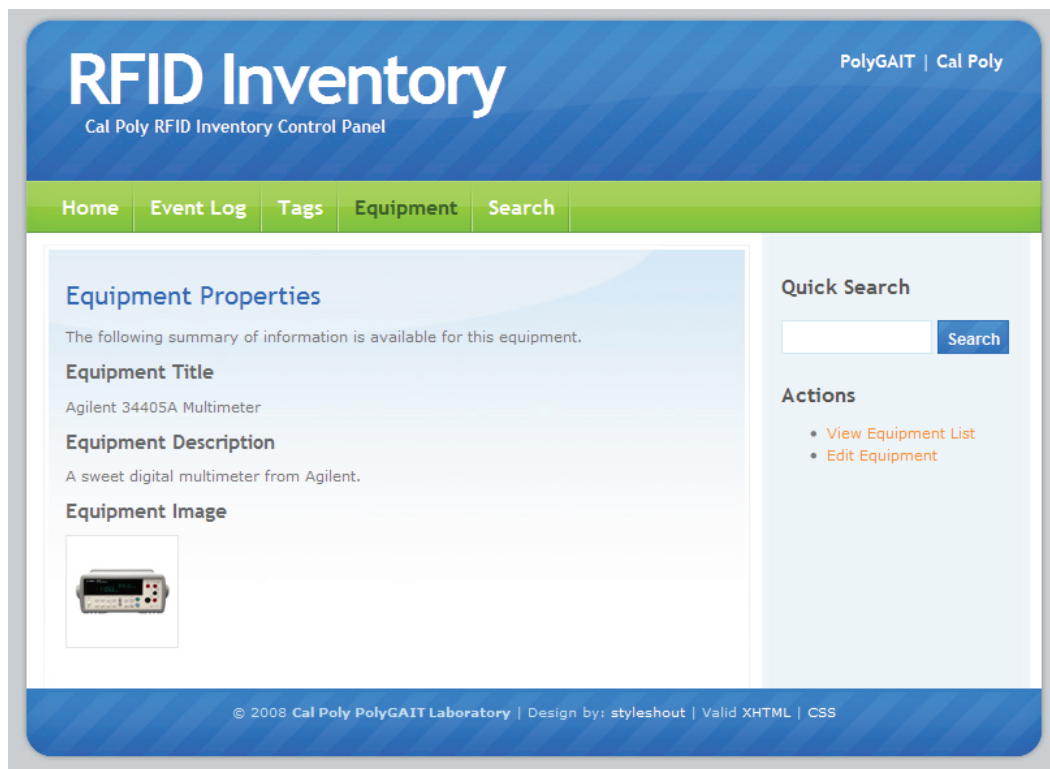


Figure 14. Management web site “equipment” table listing page screenshot.

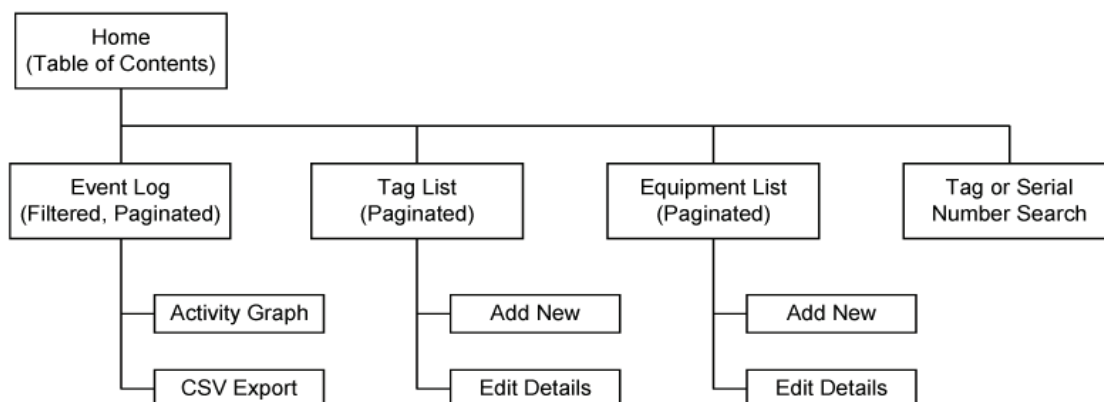


Figure 15. Site map of management web site.

The first “events” table subpage provides an interactive 30-day activity chart

rendered using an Adobe Flash Player movie^[14]. The second “events” table subpage exports the event log data to a CSV file enabling spreadsheet analysis using tools like Microsoft’s Office Excel and OpenOffice.org’s Calc. The two subpages for the “tags” and “equipment” tables enable adding new and editing existing records using HTML forms.

Apache’s built-in authentication and authorization modules can be used to limit access to the interface. A minimum of two modules must be employed to enable these restrictions. The first provides the authentication source or the list of user names and passwords. A basic approach may be utilized where the user names and passwords are stored in hashed form in a text file and accessed using the “mod_authn_file” module. This isn’t the most secure solution as the user names and passwords will be stored on the computer that the employees will be interfacing with. An option would be to query a local LDAP directory or Microsoft Active Directory for authentication using the “mod_authnz_ldap” module. Additional solutions exist for connecting to different databases, and Raytheon Company is encouraged to research the different options listed on the Apache web site that will best suit their corporate environment. The second module that must be enabled configures how to authenticate the user. The “mod_auth_basic” module causes a requester’s web browser to display a pop-up dialog prompting for a user name and password. While this authentication mechanism is easy to use, it includes a potential security risk as the user name and password are transmitted unencrypted. To resolve

this issue, the “mod_auth_basic” module should only be employed when the Apache server is also configured to deliver content over a Secure Sockets Layer (SSL). This ensures that all communications (not just the authentication step) are encrypted between the requester’s browser and the PC workstation. With the authentication source and the authentication mechanism defined, Raytheon Company’s management may add their user names to a list to enable access to the web site. By default, any user name not included in the list is denied access.

VII. Test Plans

The database will first be populated with test data. Ideally, at least three equipment types and at least three tags per each equipment type will be created. During development of the employee interface, a simple UHF reader emulator will be constructed to send tag read events at a preconfigured interval such as five to ten seconds. With a steady flow of periodic read events, the interface usability may be tested as construction progresses. Emulating the near-field reader and login events can be performed by typing on a keyboard when the login screen is displayed. The initial employee interface testing will be performed by repeatedly completing the check in and out process emulating the readers. Once the operations of the foreground and user interface background threads are stable, testing will progress to include actual reads received from the UHF and near-field readers.

Testing the management web site will be performed in two stages. The first stage includes utilizing automated tools such as the World Wide Web Consortium's (W3C) validators and link checker^[15, 16, 17]. The pages will automatically be crawled and checked for valid XHTML 1.0 Strict syntax, valid CSS 2.1 syntax, and no broken links. Passing these validations ensures the web site will render as expected in the most-common web browsers. In addition, the web site will undergo an automatic Americans with Disabilities Act (ADA) accessibility check using WAVE, a free evaluation tool provided by the web site WebAIM^[18]. WAVE can quickly identify programming errors that lead to accessibility problems in addition to providing

a checklist that must be manually reviewed for proper accessibility compliance.

With the automated tool checks complete, the second stage will include a rigorous, manual usability and security testing. The usability test will involve performing each of the triggerable actions in the interface (such as clicking on each link) and manually verifying appropriate responses are generated. In addition, the forms will be tested to ensure content is properly saved to and retrieved from the database. After manually testing the functionality, a security test will be performed. All the forms will be tested for SQL injection vulnerabilities, all URL's will be tested for request variable vulnerabilities, and invalid URL's will be tested for vulnerabilities. To aid in this security testing process, the Xdebug extension for PHP will be used^[19]. This utility allows for detailed profiling of each request including detailed logs of variable states and memory usage. If any issue is found at any point during the testing process, the issue will be researched, identified, and repaired. After repairing any found issues, the testing process will start over using the automated utilities until no remaining issues can be found.

The last phase to the test cycle will include a complete system demonstration put to use by volunteers. During the demonstration, students will be given brief instructions on how to use the system, but left to play with checking in and out items. Reviewing the logs will prove useful to verify that the system operates correctly and that the system can operate for an extended period of time. It is also expected that students from outside the project will be able to give valuable

feedback concerning the level of detail and relative accuracy of the interface's instructions.

VIII. Development and Construction

The system was constructed using the Eclipse Integrated Development Environment^[20]. The Java Development Tool (JDT) and PHP Development Tool (PDT) plug-ins were utilized to develop the employee and manager interfaces^[21, 22]. In addition to constructing the individual interfaces, a Nullsoft Scriptable Install System (NSIS) installer was created to automate the installation process of the employee interface, manager interface, and all required dependency applications and configuration settings^[23]. In addition, an Apache Ant build script was developed to automate the process of compiling the individual components followed by the NSIS installer^[24]. A working prototype of the system was configured in the PolyGAIT laboratory with the reader and antenna again mounted above the entryway. The hardware was connected and TCP/IP configurations applied as depicted by Figure 2.

With the working prototype in place, a User Guide was produced that provided background information about the system architecture, detailed instructions on how to setup the hardware and software, and general operating procedures for starting and managing the software. The User Guide assumed that the PC workstation would be running a Microsoft Windows operating system and that installation of the software would be performed using the automated NSIS installer. The User Guide's intended audience includes the information technology personnel.

IX. Test Results

During development a continual process of manual testing was performed. This approach was tedious but proved useful in uncovering several issues. Once programming was completed and the prototype installed in the PolyGAIT laboratory, ten students volunteered to participate in test trials. Approximately 15 items were tagged and registered in the database. Students were given the opportunity to choose to check out and in equipment in any sequence they desired. Each student utilized the system for at least 30 minutes. In addition, the PC workstation was left turned on for several days straight to confirm that prolonged operation could be reliably expected.

The prototype worked as expected with the exception of one common complaint. Over half the students that tested the system found that the employee interface was slow to transition between the login screen and the check in and out screen. Further testing revealed this was due to unpredictable delays associated with transitioning the reader between the autonomous and manual, polled modes. These delays appeared random in length and uncontrollable by external software. A solution to this issue would include a rewrite of the software to only support tag reads from the autonomous mode instead of the manual, polled mode.

An interesting observation from the compilation of the trial data showed that all items were properly read when passing through the portal. Although students typically performed the check out and in procedure, a few cases were caught where

the students carried an item through the portal without issuing a check in or out action. During the trial, the worst case read scenario either did not occur or did not negatively impact the system's operation.

X. Conclusion

At the conclusion of this project, a working prototype of a passive RFID asset tracking system was shown to work with good reliability. This paper and a CD including the user guide and binary and source formats of the software were given to PolyGAIT to be delivered to Raytheon Company. Although it was experimentally shown that passive tags do not provide the same level of reliability as active tags, one could reasonably expect a passive RFID asset tracking system to provide more accurate results than a paper-based process for a significantly reduced price over an active RFID solution.

Testing the software was the most difficult aspect of constructing the system. Researching better testing methods led to the discovery of many different useful applications and best practices. The first best improvement that could have been implemented would have been to write and maintain unit tests. Unit testing provides an automated way of ensuring that code works according to predefined rules ensuring. This ensures that expectations about the code's operation are met throughout the development cycle. The second improvement would include the incorporation of an automated graphical user interface testing tools. These tools are capable of driving a computer system sending mouse click and keyboard events and verifying the output adheres to a predefined process. Lastly, the use of a more feature rich RFID emulator could have been employed. An open-source tool called RifiDi runs as an Eclipse plug-in and fully emulates the ALR-9800 reader^[25]. In the

future, use of these tools would be employed to help minimize the manual effort required in testing the software.

In addition, several issues were uncovered throughout the software development cycle concerning the continual mode change of the Alien reader between the autonomous and manual, polled modes. Although the issues were addressed, user feedback during the test trials showed that it continued to prove problematic by causing long delays after a user logged into the system. Unfortunately, the system architecture design prevented changing the program to operate with the reader continuously in autonomous mode without a complete rewrite. In the future, a different software architecture will be employed in which the mode of the reader would continuously remain in autonomous mode.

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A. Costs

A PC workstation, monitor, and mouse were available in the PolyGAIT laboratory and utilized for the test pilot. These items did not need to be purchased. The funding for this project was managed by the Cal Poly Grants Development Office. The total cost billed to Raytheon Company for hardware was \$10,000. The following list includes the estimated individual hardware costs:

- Alien ALR-9800 Enterprise Reader: \$1500 Total
- Alien ALL-9354 "M" UHF Tags: \$0.44 Each / Quantity 2000 / \$880.00 Total
- Alien ALR-9611-CR Antennas: \$150 Each / Quantity: 2 / \$300 Total
- RFIDEas pcProx Proximity Reader: \$200 Total

B. Source Code

The source code, documentation, and dependencies are included on a CD provided with the submission of this report. The following README text has been included for reference:

```
RFID Inventory - A Passive RFID Asset Tracking System
(c) 2008-2010 Kyle James Dodson, kdodson@calpoly.edu
-----
```

About

```
-----
This project represents two software packages linked by a common
database. The first interface connects to an Alien ALR-9800 reader
and logs read, check out, and check in events. The latter two events
are submitted by users that login using an HID badge. The second
interface is a dynamic web site served by an Apache HTTP Server
installation that provides access to a reporting tool.
```

Environment

```
-----
This folder represents an Eclipse IDE workspace. All code may be
viewed using a simple notepad, but automated build tools have been
integrated with Eclipse simplifying many processes. If you choose to
use Eclipse be sure that the JDT and PDT plug-ins are installed.
```

Documentation

```
-----
For developer documentation refer to the source code. All source
files are thoroughly documented. For end-user documentation, refer to
the compiled PDF file in the /docs folder.
```

Folders

```
-----
The following descriptions should help get you going.
```

```
/build - Contains an Apache Ant build file and an Eclipse run profile
        to launch the Ant build file. View build.xml for the available
        targets. Note that this build file expects to be run from
        Eclipse.
/cd - Contains InfraRecorder project file to burn the contents of
     this Eclipse workspace to a CD.
```

/docs - Contains the sources and a PDF of the User Manual.
/java - Contains the sources of the employee interface (the graphical user interface that interacts with the Alien ALR-9800 reader).
/nsis - Contains the NSIS installer sources. This can only be used on Microsoft Windows platforms.
/php - Contains the sources of the manager web site (the reporting and analysis tool).
/util - Contains the contents of the Alien developer CD (three zip files) which provide the reader dependency library and documentation. The pcProxConfig.exe installs the RFIDeas pxProx reader drivers for Microsoft Windows platforms.

License

All source code written by me is marked with an appropriate copyright. The source code is licensed to allow anyone affiliated with Cal Poly and granted permission by the EE department (or myself, of course) to utilize it for free. Maybe one day I can get it released under an open source license. It is incredibly important to note that I do not provide any warranty or guarantee that this software will work or is fit for use for a particular purpose. Use it at your own risk. Also please note that other packages are included with this distribution and are subject to the following licensing terms:

- Alien Library
This file is proprietary and closed source. It is provided by Alien Technology for use with Alien readers. Redistribution is allowed only for use with Alien readers.
- Apache HTTP Server 2.2.8
The Apache HTTP Server is released under the Apache License 2.0. You may view the complete license text and terms online at:
- <http://opensource.org/licenses/apache2.0.php>
You may access the Apache HTTP Server source code online at:
- <http://httpd.apache.org/download.cgi>
- Java 1.6.0 Update 5
This file is proprietary and closed source. It is provided by Sun Microsystems for use by a value-added application. Redistribution is allowed only when bundled with a value-added application.
- MySQL Server 5.0.51a
This file is released under the GNU GPL 2.0. You may view the complete license text and terms online at:
- <http://opensource.org/licenses/gpl-2.0.php>
You may access the MySQL Server source code online at:
- <http://www.mysql.com/downloads/mysql/>
- MySQL Connector/J Library
This file is released under the GNU GPL 2.0. You may view the complete license text and terms online at:
- <http://opensource.org/licenses/gpl-2.0.php>
You may access the MySQL Connector/J source code online at:

- <http://www.mysql.com/downloads/connector/j/>
- PHP 5.2.5
 - This file is released under the PHP License 3.0. You may view the complete license text and terms online at:
 - <http://opensource.org/licenses/php.php>
 - You may access the PHP source code online at:
 - <http://www.php.net/downloads.php>
- phpMyAdmin 2.11.5
 - This file is released under the GNU GPL 2.0. You may view the complete license text and terms online at:
 - <http://opensource.org/licenses/gpl-2.0.php>
 - You may access the phpMyAdmin source code online at:
 - http://www.phpmyadmin.net/home_page/downloads.php

C. Analysis of Senior Project Design

Project Title: Design of a Passive RFID System for Asset Tracking

Student's Name: Kyle James Dodson

Student's Signature:  _____

Advisor's Name: Dr. James Harris

Advisor's Signature: _____ **Date:** _____

Summary of Functional Requirements: First, this project produced an experiment and results to select the best performing passive RFID tag from the leading manufacturers' top products. Second, this project produced an experiment and results to determine the differences between passive and active RFID tag read rates when applied to an asset tracking system. Third, this project produced a passive RFID asset tracking system prototype. The prototype contains two interfaces, the first enables employees to check items in and out and the second enables managers to query item statuses.

Primary Constraints: The biggest issue with the software was met during the testing phases. Testing the software was a much bigger task than was originally anticipated. It provided the opportunity to research better practices and common tools utilized in the computer science industry to automate and ease the process. The biggest issues encountered with hardware pertained to the changing of reader modes (autonomous to manual). It was a learning experience in that this particular device does not perform speedily when continually switching between modes.

Future design considerations would take this into account and base the system of continual operation in autonomous mode.

Economics: This project was funded by a grant for research. The total cost of the grant for Raytheon Company was \$46,000. The Grants Development Office estimated the hardware costs at \$10,000. This estimate originally included the cost of a purchase of a PC workstation for the PolyGAIT laboratory, but an existing workstation was available so an additional one was not purchased. The final hardware cost for the readers was \$2,880. The total final cost of the hardware could be estimated by including an additional \$1,000 for a PC workstation with a touch-screen monitor. This would bring the total hardware cost to \$3,880. Still, this estimation is well below original estimations. The total estimated student development time was 108 hours. The actual development time required to complete this project was approximately 190 hours.

Manufacturing: This package could be produced into a final product and sold commercially. If marketed properly, a good initial year would see 100 installations. Compared to other RFID consultation services and integration business, \$10,000 is a fair price for an entry level asset tracking system. With final estimated hardware costs at \$3,880, a difference of \$6,120 remains. If it is assumed that minor bug fixes will be required in the software totalling an additional 50 hours of work and if a single person could perform the 100 installations in a year, a pre-tax, pre-benefits wage of approximately \$61,200 would be earned. Although a respectable wage,

a more aggressive business plan combined with expansion strategies would be required to turn this venture into a profitable business. For consumers, the cost to operate the device equates to the cost of powering the PC workstation and readers. Conservative estimates show the per month operational costs to be \$150 per month.

Environmental Impact: Although thousands of tags are purchased to implement this system, the tags are passive and have a lifespan that will outlive the equipment it identifies. The system should help to reduce negative impacts on the environment through the assistance it will provide in locating lost assets. Currently, without the system, when a \$100,000 oscilloscope is lost a new one is purchased to replace it. With this system in place, the hope would be to positively identify the last person who had the oscilloscope and better track their movements to narrow the search for the item. In the end, the hope is that this system will decrease the amount of products being consumed to replace those that are lost.

Manufacturability: Each environment the system is deployed to will typically need special considerations for antenna and PC workstation placement. This will present the biggest issue, and sometimes specialized mounting brackets may be required. However, all the other components are easily obtained as they are off-the-shelf and decreasing in cost as time moves forward.

Sustainability: This matches very closely to the response given in the environmental impact section. This system should operate reasonably for a very long period of time. The software made use of Alien's proprietary API software. Alien has

been committed to providing updates to the API to support new readers as they are released. This has the wonderful side effect of enabling the software to continue to work even after the current hardware has become obsolete and replaced with new hardware. As long as an Alien reader is selected and the EPC Gen 2 standards followed this system should provide Raytheon years of service. Over time, it can be expected that new readers and tags will be made available that will perform higher (with respect to read distance) and more efficiently (with less power required).

Ethical: Issues regarding ethics and RFID technologies have been under debate for a number of years. This particular system provides insight into a person's exact whereabouts and what they're taking from the storeroom. This isn't however any different from the information that they were required to originally submit via the paper form. In addition, Raytheon Company has been using wireless identification badges for some time. Looking at the major concerns of privacy raised against RFID technologies, it's hard to find a real issue with this particular system. That doesn't mean that some abuse couldn't be found for it, though. It is definitely the hope of the developer that this system will not be used to invade or impeded any person's privacy unknowingly or unwillingly. Looking from a different perspective, it's interesting to note that the system demands honesty and integrity from its end users. It provides no fool-proof controls to ensure the users don't leave the room without identifying themselves and their equipment. It's expected that they will willingly report this information for the benefit of other coworkers and the company.

Health and Safety: Although the system emits electromagnetic radiation, the levels are kept low to fit with FCC regulations. Although no known health issue is currently known, should one be discovered it would be the responsibility of the developer and system maintainer to recognize the risk, properly assess it, and take action to ensure it poses no threat to any individual.

Social and Political: Following with the previous discussion about privacy, there are many individuals that are openly against RFID technologies. No particular invasion seems to occur in this instance and hopefully systems like this will prove beneficial casting a positive light onto the technology. The ideal hope is that this system reduces Raytheon Company's operating costs. With a reduction in costs, employees may be given the opportunity to experience a better workplace or receive additional pay. Taking an extremely optimistic viewpoint, one could hope that, because Raytheon Company often contracts with the government, this reduction in operational costs would translate to lower costs on tax payer funded projects.

Development: The number of new techniques and best practices learned from this project are many. As has been previously discussed, better techniques for testing code were identified in addition to automated testing techniques. Other important topics included multi-threaded software architecture, TCP/IP networked communications, graphical user interface design, and relational database management systems. In addition, a new and deeper appreciation has been developed for radio frequency communications thanks to the level of detail provided

in Dr. Daniel Dobkin's book *The RF in RFID: Passive UHF RFID in Practice*.