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Adding Virtual RFID to Second Life

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By

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ABSTRACT

Second Life (SL) is a popular online 3D multi-player virtual world where the limits of creating objects and scripting interactions among objects and avatars are based on the player's imagination and scripting skill. Real life, by comparison, is often limited by current technology more than creativity. This thesis investigates a new way to merge reality and virtual reality, in particular, by modeling one emerging real world technology, radio frequency identification (RFID), in the SL virtual world. We investigate how RFID can be deployed and tested in a virtual world, a modeled healthcare facility, as a step before the much more expensive step of deploying it in a real world setting. RFID is just one of many emerging technologies that can be simulated in SL – others include GPS, smart devices, massive use of sensors, using natural language to talk to devices, and many more. The potential impact of testing these technologies in a simulated world before deploying in the real world could lower costs and accelerate the pace of technology change.

This thesis is approved for recommendation to the Honors College.

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1. INTRODUCTION

1.1 Problem

Radio Frequency Identification (RFID) is a rapidly maturing item identification technology. RFID promises to optimize supply chains and inventory asset management systems by providing continuous visibility for item location, type, and ownership. RFID can help organizations optimize their supply chains, locate lost goods, reduce shrinkage and theft, and reducing overstocking and under stocking of goods.

In the last several years, the US government and Wal-Mart have invested heavily in RFID. The EPCglobal standards organization has set standards for tags formats, the reader-tag air interface, and an application program interface for tag readers. While the technology for tags and readers is still expensive, RFID is already cost effective for tagging cattle, pets, people, expensive portable equipment, and individual retail items, even down to the level of apparel, though not yet down to the level of cans of soup. At the same time, companion technologies are still relatively immature, including RFID security.

While RFID technology itself has obvious value, the question is often asked – what is the return on investment (ROI) for RFID. Some compelling answers are beginning to make this business case. But there is no straightforward way to determine the cost of an RFID deployment beforehand and to predict the value it will add. Developing technology for assessing when one RFID configuration adds value and comparing configurations and their costs and benefits would help industry determine RFID tradeoffs and assess when and how to deploy the technology. The present approach is to deploy an RFID system in the field. This is very expensive, often ties the solution to a collection of RFID hardware and software vendors, and does not permit much experimenting with alternative configurations.

Just as software developers use prototyping frameworks to rapidly test and assess ideas, there needs to be a way for RFID solutions to ascertain what effects on real-life situations various RFID architectures will exhibit. Thus, an alternative approach would be to simulate an RFID deployment in a virtual world.

Second Life is a 3D multiplayer gaming environment. At present, Second Life is mainly viewed as a social networking virtual world, a kind of 3D MySpace providing a meeting place for people who wander through a virtual landscape. The framework itself, however, allows for a variety of real-world applications that are only recently being developed.

Would it be possible to use Second Life as a kind of simulation environment where we can create virtual RFID and then test it in different configurations before deploying it real field studies? This could provide a low cost way to try-before-you-buy for different RFID configurations, reducing the risk of expensive deployments, increasing the likelihood that an RFID solution would add value to an adopting organization.

1.2 Thesis Statement

The use of the Second Life engine (a virtual world) to simulate RFID operations viably mimics real-world RFID technology in a way that can allow users the ability to rapidly develop and test related RFID deployments with the knowledge that they will behave in a fairly realistic manner.

1.3 Approach

The approach taken to test this thesis involved three main steps:

- Virtual RFID tags and readers were modeled in Second Life by building tag and reader objects and attaching scripts to them. When an object containing a virtual tag passed within range of a reader, the reader recorded the unique tag value.
- A remote database for recording tags was deployed on a server outside of Second Life.
- A means of transmitting the SL tag reads to the remote server was developed. Since the link between SL and the remote database was two way, queries to the database could be transmitted and displayed in SL.

After developing the basic ability to model virtual RFID readers and tags and connect them to a database, further work has continued through integration with TagCentric RFID Middleware, the addition of security and access level management, and finally deployment in a fully-functioning virtual hospital replete with virtual RFID readers that can track the virtual hospital's inventory, assets and personnel.

1.4 Organization of This Thesis

Chapter 2 provides background on RFID technology and on the Second Life simulation environment. Chapter 3, 4, and 5 describe the architecture, implementation and results of this study. Chapter 6 summarizes our results, describes the contributions of this thesis, and suggests directions for future work.

2. BACKGROUND

2.1 Key Concepts – RFID and Second Life

This thesis combines ideas from two key emerging technologies – radio frequency identification (RFID) and 3D multi-player virtual world gaming (in particular, Second Life).

2.1.1 Key Concept #1 – RFID

Like barcodes, RFID is an automatic identification technology. RFID tags can be placed on physical things to identify them [1, 2]. Unlike barcodes, reading RFID tags does not require line of sight; the reading distance can vary from inches to ten or so feet (for passive tags) and to hundreds of yards (for active tags); many tags can be read almost simultaneously; and the tags uniquely identify every tagged entity as an individual (e.g., this bottle of coke is distinguishable from that one).

An RFID system is a combination of relatively cheap RFID tags attached to or embedded in objects, and RFID readers used to scan an area for any tags within range. Though over fifty years old, RFID technology is undergoing rapid standardization and deployment into industrial, retail, and medical supply chains.

RFID tags are normally composed of two parts. One is an integrated circuit that handles information storage and RF signal modulation. The other is a simple antenna used to transmit and receive signals from RFID readers. A newer, integrated form of “chipless RFID” tags has been developed with no integrated circuit at all, allowing direct application of tags onto inventory as well as being a less expensive technology [3].

RFID tags are divided into three varieties based upon power use. *Passive* tags do not contain an internal power supply. Instead, they rely on current induced across the antenna by reader fields. This current provides enough power to activate the CMOS and power a response to the reader. The range of passive tags extends to a few meters. *Active* tags utilize an internal power supply. Benefits of the internal power supply include accuracy and the ability to transmit at higher power, to be read at greater distances (up to hundreds of meters), and enabling active tags to survive in environments where passive tags fail, such as areas with high humidity or lots of organisms (which block RF signals). Drawbacks of active tags are that they are more expensive to manufacture and they require a battery (though battery life of an active tag can be as much as ten years). *Semi-passive* tags are a third type, and combine the strong points of both active and passive tags. They contain an internal power source similar to active tags, but it is only used to power the integrated circuit. Signal response broadcasting is handled in the passive-tag manner. The benefit to semi-passive tags is increased sensitivity (up to 100x more in some cases), which is utilized to increase range and reliability. [3]

RFID readers convert radio wave information from RFID tags into digital data useable by other devices and computers. An RFID reader is composed of antennas to sense signals, a receiver/transmitter to send and receive pulses of information from tags, and a control unit that processes all the received information. Integrated anti-collision algorithms function to distinguish between multiple simultaneous signals and ensure each tag is processed once and only once per scan cycle.

One or more RFID readers, objects marked with RFID tags, and associated middleware and database software together form an asset management system for keeping track of inventory items, equipment, and people. In the past three or so years, RFID is beginning to be widely deployed especially in the retail industry where it was initially used to track pallets and containers on pallet but is now beginning to be used to track items including apparel. RFID is used in newly issued US passports and may eventually begin to be used by consumers to track their own personal items. Within ten years, RFID could be omni-present in our daily lives.

2.1.2 Key Concept #2 – Second Life

The other key concept is Second Life (SL) [4, 5], a free Internet multi-player 3D virtual world. SL was inspired by the concept of a metaverse (from Neal Stephenson's novel *Snow Crash*), a user-defined world in which people can communicate, interact, work and play, a candidate for a next generation World Wide Web. SL has been featured on TV shows (*The Office, CSI New York*). Players (termed residents, about 13M world-wide) download a free browser-like client that allows them to see a portion of a large and growing 3D world that is stored on remote servers at Linden Labs, the developers of SL. Players control corresponding avatars (graphical representations of a user). Players can communicate (with chat and voice), can teleport to new locations and wander freely in open areas, can optionally use SL currency to purchase virtual land, and can build buildings, make objects, and script interactions (using a programming language with a syntax similar to C).

Initially, SL was used as a social networking utility – a place where people could meet, talk, and explore. Recently, however, commercial and government applications have begun to explode. For instance, the Maldives became the first country to create a SL embassy, allowing avatars to chat with a simulated ambassador about everything from visas to trade and tourism, and other countries are following suit [5]. Another area of SL/real world merging comes in the form of education. Universities from Vassar to Harvard have begun using Second Life as a means of creating a virtual classroom complete with voice communication.[6] Over one hundred islands have thus far been sold for academic purposes, with the University of Arkansas joining in November 2007.

On a technical level, Second Life has several features which make it a prime candidate for research, particularly for this project. Linden Labs designed Second Life from the ground up with the intention of allowing players a simple means of creating a limitless number of in-world, sharable objects. Objects can be scripted with behaviors that govern how they interact with the built in SL physics engine, each other, and avatars. Thus, a player can create anything from a simple sphere that bounces along the ground to expensive homes, sports cars, and pilotable fighter jets. The collection of user-created content already present throughout the virtual world is astounding and growing at a rapid pace.

SL's proprietary, event-driven scripting language, called Linden Scripting Language (LSL), allows for a robust array of object-control scripts to be applied to nearly any object a user creates. LSL is also capable of communicating with remote servers in several ways, allowing users the ability to create and manage data as well as interact with Second Life remotely and automatically. This was an important requirement in the present project.

Though most of Second Life's world exists in a broad, connected public world, Linden Labs also allows groups to purchase and utilize private "islands" for education purposes. University of Arkansas now rents and operates one of these islands as a basis for project development.[7] SL access control enables the project to simultaneously use Second Life's capabilities while remaining accessible only to Arkansas students during initial development.

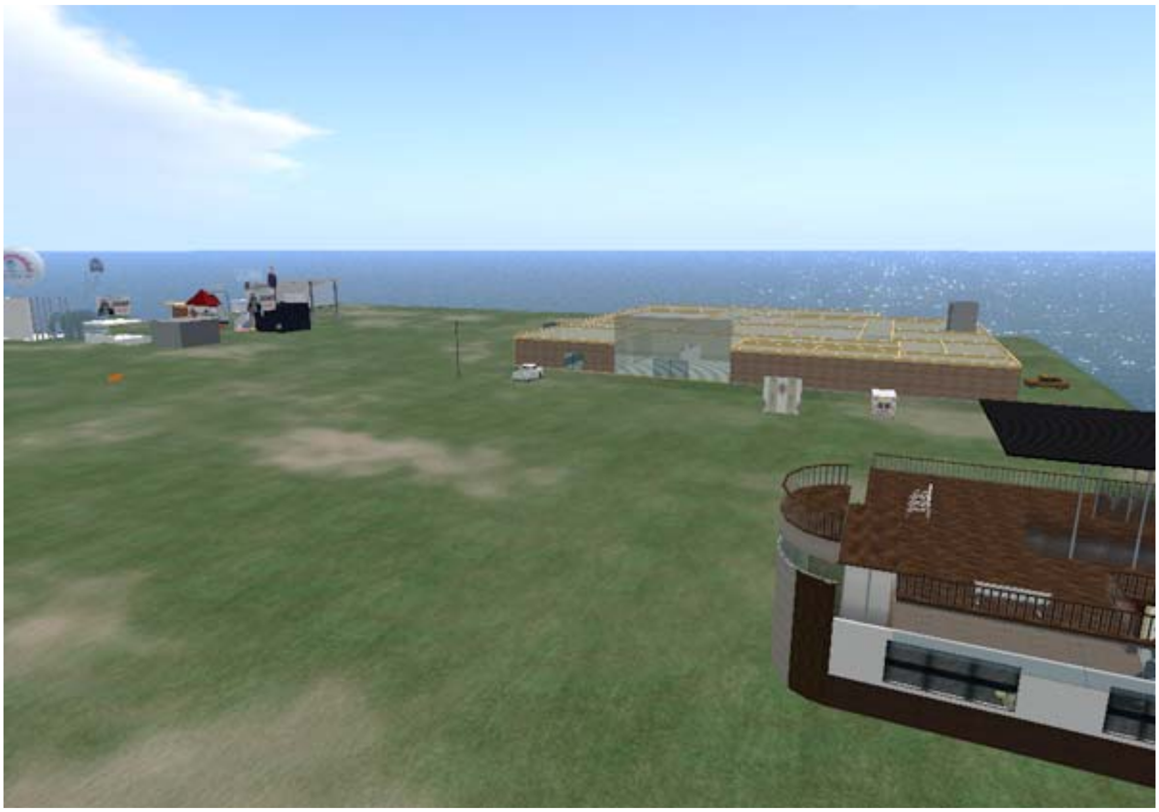

Figure 1: University of Arkansas Second Life Island

2.2 Related Work

Second Life is not the first 3D simulation environment. Well before Second Life was launched in 2003, the US and Europe used 3D multi-person simulations to model and to train. The US military used a 3D simulator for tank crew training for almost 30 years and uses a 3D game, America's Army, for training and recruiting. The popular

Sims games, developed by Electronics Arts, have been popular daily-life simulations for over eight years.

Since its launch in 2003, Second Life, in addition to its primary use as a social networking site, has been used as a educational and research platform and is only recently beginning to be used as a modeling platform.

Second Life is being used as an experimental platform for educational purposes. Harvard University has offered credited classes in Second Life for the last two years. The class's instructor, Rebecca Nelson, stated that virtual worlds were key to evolving and improving education and that they were a "giant leap forward in their ability to enable communication, class participation, and certain types of simulated activities."[6] Many other universities have begun building toward offering classes purely through Second Life as well. At the University of Arkansas, with the acquisition of an island, one course has already based its research around the medium (Artificial Intelligence, CSCE Department, Spring 2008) and another is planning to instruct some class sessions in-world (Virtual Worlds and Healthcare Logistics, CSCE Department, Summer 2008) while involving high school students in the EAST program [8, 9, 10].

As Second Life expands, so too does the virtual economy inside. This Linden dollars-based economy can be linked to real-world funds. In 2007, Linden Labs recognized this opportunity and began a "Second Life Market Data Project." Since then, SL demographic data has been collected and made available in a series of reports [11]. At $200USD ($25,000 Linden Dollars), these reports are geared toward businesses and research teams looking for extensive market data rather than curious individuals. The reports are extensive. Each quarter, an analysis of Real Life Brands as well as an analysis of SL's Entertainment market, Buildings and Real Estate, and even Women's Clothing trends is published and made available. In contrast to Linden Labs' lack of personal data in studies, Market Truths is able to base data on real life gender, age, and any other identifying factors they wish. To date, Market Truths' customers have included American Apparel, various hotels, General Motors, and Toyota as well as various smaller business ventures [12].

In addition, Linden Labs itself publishes a series of Service Metrics and Usage Statistics that are freely available on the Second Life Grid network [13]. Key metrics are compounded and released on a monthly basis in both Excel and the new, open source Google Documents formats. These measure the SL economy itself, but business researchers are working on expanding into other sectors.

Risks inherent in business of all types have proven to exist in the virtual economy, however. On January 23, 2008, Linden Labs shut down its in-game banks, all of which were directly funded with actual money paid in by Second Life's Citizens as they purchased Linden Dollars. The Wall Street Journal reported the story: "In the real world, banks are reeling from the subprime-mortgage mess. In the online game Second Life, a shutdown of the make-believe banking system is causing real-life havoc for thousands of people." [14]. Linden Labs attributed the act to being a measure to stem "complaints that some of the virtual banks had reneged on promises to pay high returns on customer deposits." These banks were run just as everything else in Second Life: by citizens themselves. They operated around Linden Dollars, allowing avatars to purchase dollars and then deposit these dollars into the bank via virtual ATMs. Unfortunately, this also means that neither Linden Labs nor anyone else had oversight over these banks. As a result, the players who ran the banks attempted to entice deposits by offering interest rates they could not meet. Most of the banks used the investments to buy land or even to gamble, resulting in loss of investors' money. Linden Labs could not continue to back this, so the plug was pulled. Thus, from here on, only chartered banks will be allowed to operate in Second Life.

In a recent article about Second Life's potential use in simulation, Computer World's Senior Editor, Ian Lamont, noted the following strengths [15]:

- The ability to simulate real-life objects in three dimensions.
- Letting users build 3D models based on 'blue-sky' concepts, ranging from "sandbox" experiments to giant building or product sims that let companies test their ideas without having to make major real-world investments in land, equipment, and human resources.
- Structured activities in 3-D spaces, such as orientations and tours of museum sims
- A shared, real-time space that can host widely distributed groups of people. Interpersonal communication that incorporates body language and visual clues.
- A safe space that protects the privacy and real-world identities of users while letting them project real or ideal identities.

Researchers are beginning to use SL to model the real world – especially the architecture of buildings. NBC News reported on a New Media Consortium case study about Santa Clara University using Second Life to model its upcoming new library [16]. It stated that the University's intent was much the same as our own, to use the virtual model as a "faithful replica" that could be "used by students and faculty at Santa Clara University to explore innovative ideas for the interior spaces."

Similarly, Dresden's *Gemaldegalerie Alte Meister* museum was modeled in SL, with every room and every piece of art reproduced to scale, available online 24/7 from anywhere on the Internet. It became the first international museum to produce a full, scaled clone of itself, allowing guests to chat, view art and associated information, and even participate in education workshops regarding the art. Other museums across Europe and the United States are hurrying to respond [17].

Using Second Life to model RFID, smart devices, and business processes appears to be a new use, pioneered by our project at the University of Arkansas. At University of Arkansas, faculty and students from computer science, art, business, and healthcare are participating in projects that involve virtual RFID and/or modeling logistics in healthcare facilities [8, 9, 10]

3. ARCHITECTURE

The approach taken to complete this project began with the creation of a simple, basic RFID tag reader and a “tagged” object. The reader was capable of detecting the tagged object within a certain range and displaying a line of information about each detected object to nearby users. With this completed, the project next needed a way of storing the data encountered by the reader objects. To handle this rather important aspect of the project, it was determined that a third-party server was going to become necessary rather quickly. Thus, a server was established to handle everything from discussion forums to web hosting, database integration into the project, and a PHP/Java control framework. This allowed Second Life reader objects to pass data through XML-RPC or simple HTTP requests into a PHP form located on the new server. From here, the data is capable of being placed in a database or manipulated in any way a researcher wishes, either with Java or PHP languages. Both XML-RPC and HTTP allow for two-way communication between the Second Life client and the third party server, effectively creating an information highway leading to a separate machine capable of performing nearly any data manipulation not available with Linden Scripting Language (LSL) natively.

With the major data analysis and storage problems handled, work has continued through the improvement of RFID objects, integration into TagCentric Middleware Framework, security and access level management, and ultimately a fully-functioning hospital replete with a large variety of user-contributed RFID objects that serve a multitude of smaller functions.

3.1 High Level Design

A high level design of the system is shown in Figure 1. A virtual RFID reader in SL senses an event – the presence of a tagged object – and reads the tag value. It then communicates this tag read to a remote server and in particular to a remote database on that server.

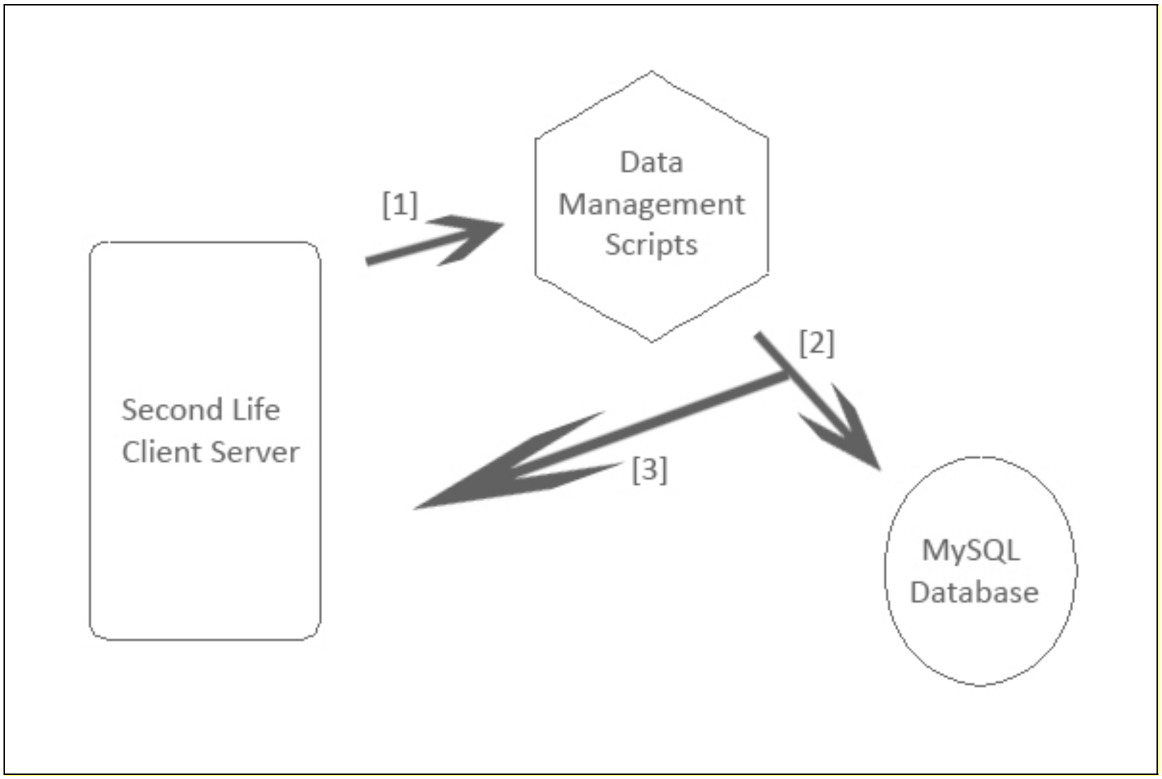

Figure 2: High Level Architecture

[1] Data from SL to Scripting Server. [2] Parsed data sent to MySQL Database. [3] Parsed data returned to SL Server.

3.2 Server Architecture

The database server currently resides in a research lab on the University of Arkansas campus. It is configured with Ubuntu Linux 7.10 for usability and advanced security. The server hosts a basic Apache web server with communication forums, progress blog, and bug tracking features. The Apache server is also the method of receiving HTTP requests from Second Life clients. This is accomplished through a series of PHP scripts which LSL is capable of fluidly interacting with, both sending and receiving. These scripts achieve an array of functionality, especially with database manipulation. Sun's Java is also available to be utilized in any way a researcher needs, the Open-Source TagCentric RFID middleware solution is deployed for ease of Second Life/Real World integration, and MySQL handles all of the data storage. Communication is handled through a simple HTTP system with the option of XML-RPC for exceptionally long strings of data.

3.3 Second Life Architecture

Use of Second Life's engine architecture is freely available [5]. Registering with Linden Labs is simple, as is the Second Life proprietary client used to interact with the virtual world. The project utilizes a privately-owned island for all research. This allows researchers to create, build, experiment, and store progress without fear of outside interference or unnecessary lag. The island is now sub-divided into partitions for organization, including an area for permanent deployment of completed pieces, an area for free building and testing that is cleared on a regular basis, and several areas for other campus projects. The free area allows anyone with access to the island to construct and script with absolutely no limits beyond those mandated by Linden Labs' engine restrictions. Thus, anything that is feasible within Second Life is available for the project's use from the beginning. Once pieces have been constructed and tested within the free area, they can be moved across the island to the permanent deployment area, where no auto-return function is active. The permanent deployment area already contains an entire model hospital, a two-story virtual home, and well over two thousand “prim” objects related to the project.

Figure 3: Virtualized Hospital Implemented Within Second Life

The Second Life aspect of the project was planned from the beginning to be extremely modular and easy to adapt. Each script has been designed first as a generic function and later given additional specifications to adapt it to each situation as necessary. This has virtually eliminated the need to “re-invent the wheel”, as there are a multitude of scripts at various levels of complexity that can be quickly adapted to fit specific needs. Scripting areas include base RFID functionality, communication, security, database management, AI/automated control, path-finding/waypoint derivation, audio streaming, and object interaction. Second Life’s simple drag-and-drop method of applying scripts to objects makes the process of implementing a new object type as easy as building the model, finding a script from the collection that applies, dragging it onto the object, then editing the resulting script to achieve desired functionality.

For example, to add a door to the hospital that reads RFID badges held by avatars, determines whether the avatar should be granted access to the room or not, records the date and time as well as the name of the accessing individual, then opens the door (or not), one would simply model the door, drag the appropriate security script and a communication script into the door's scripting collection, then watch as the door springs to life. Similarly, to add an entire integrated RFID reader, it is a quick process of acquiring one of the pre-constructed RFID reader models, dragging a reader script onto it, then adjusting one integer value within the script to place the reader into the desired subnet of readers. Giving the reader the further ability to export the data it collects into the remote database is, once again, dragging a single script onto the model.

3.4 Communication Architecture

As mentioned, communication between Second Life and the proprietary server is handled in two ways: HTTP request and XML-RPC. The majority of the project currently uses HTTP requests as a means of transmitting data. Linden Labs' HTTP interface setup is rather simple and intuitive as well as handled through the same LSL scripting as object control. Ergo, script interaction is fluid and even allows for one script that simultaneously controls the object and interacts with the external server at the same time. In addition, the HTTP interface does not incur the same 3 second speed penalty as XML-RPC, though it is engine-limited to a maximum concurrent number of requests from a single object. The project is yet to hit that cap even once, thus why HTTP is the favored means of communication.

XML-RPC communication boasts a much higher total data throughput ability. However, unlike HTTP communication, the XML-RPC request MUST be initiated from the remote server. LSL is incapable of initiating transactions through XML-RPC in any manner. Once the communication link has been established, though, two way communication becomes possible. Another pitfall of XML-based communication is that the maximum number of queued requests is limited to one at a time. Further requests instead overwrite previous ones as they are received. To exacerbate the situation more, these are also subject to a mandatory 3 second delay as they reach Second Life's XML front-end server. The ramifications of this should be obvious and can only be dealt with by carefully constructing possible XML requests from the server so that there is no chance of accidentally overwriting one necessary request with a second. As XML communication not only houses these flaws, but is inherently more complicated to construct than HTTP, until the project requires the sending of large-scale amounts of data, there is no reason to use it on a daily basis.

4. IMPLEMENTATION

4.1 RFID Simulation in Second Life

The RFID system that the project established within Second Life models a real RFID system. Second Life inherently assigns each object a Universally Unique Identifier (UUID) string, which functions similarly to information contained within an RFID tag. The RFID system currently uses these as pseudo-tags for database organization, though eventually a system will be implemented to customize the tag information further and allow for more robust manipulation of tag groups.

The virtual tag reader is scripted to continuously poll for objects entering a specific distance range. Every time an object does so, an event is triggered within the reader which checks to see if the object contains an RFID tag. If a tag is present, the reader shifts to another event handler which processes the data and exports it to the remote server for analysis/storage. Although readers in real life work somewhat differently, namely objects without tags are never even noticed by the reader at all, the way Second Life's event handling is structured led to our current implementation. Even though the readers do not function in the same way technically, the end results have the same effect.

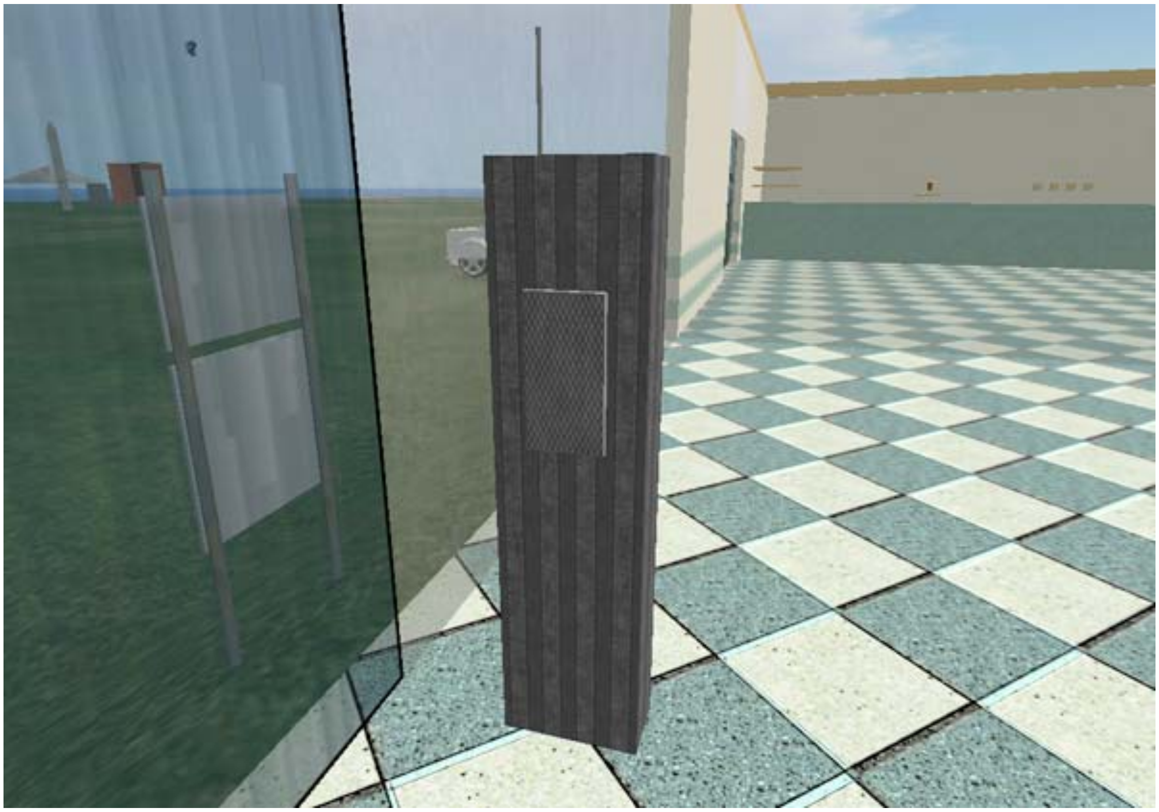

Figure 4: Simulated RFID Tag Reader Inside the Hospital

Virtual RFID objects exist currently as objects which have been flagged as "containing" an RFID tag. There are also simulated RFID tags which can be worn by avatars and applied to complex objects which operate in the same manner as objects that have been RFID-flagged. Both RFID tags and RFID-flagging are done through a simple RFID script which identifies whatever it has been applied to as an RFID-enabled object with tag number equal to the object's UUID. If the script is applied to a complex object, the object will from then on act identically to an asset in the real world that contains an RFID tag. That is, the object will respond to any RFID reader fields it enters. Similarly, if the script is applied to a small, wearable object, the script will convert the object to a virtual tag. This tag can then be attached to avatars, giving them the same RFID capabilities as objects with the embedded script.

4.2 Server Implementation

The project's remote server implementation is handled by a variety of PHP scripts hosted through the Apache web configuration. As data streams in, it is redirected to a specific PHP script based on which SL LSL script was used to send the information. Once the data is directed to the proper PHP script, the server analyzes it and adds or deletes rows from the database to coincide with the new information. For example, if an avatar wearing an RFID tag attempts to enter a room that is RFID secured, the door's RFID reader will gather the identification data from the avatar's RFID tag, compile it, then send it to the server through HTTP.

Once the data reaches the server, it is redirected to a PHP script that handles security access. This script first reads the data, then queries the proper database for a matching security clearance. If the avatar's tag identification is present as being an allowed access tag, the server then responds to SL through the LSL script and grants access while simultaneously recording the admittance in a security-access database. The script then opens the door, admits the RFID-tagged avatar, then closes the door and re-arms the script. If instead the RFID-equipped avatar is missing from the security access database, the server responds to the LSL script with a negative. The LSL script then relays this information to the door, which refuses to open.

All of this activity happens nearly instantly, so an avatar that walks up to a door will know long before reaching it whether the door is going to slide open or not. All other implementations across the island are similarly high-speed due to the use of HTTP request communication rather than XML-RPC.

4.3 Second Life Object Implementation

Creating a series of interconnected, RFID-enabled “smart” objects quickly became the focus for the project. Because the demonstration implementation was set to be a hospital from early on in the project, most effort was directed toward creating “improved” versions of common hospital objects that would act as various examples of ways RFID technology would positively affect the health industry. RFID-enabling avatars, equipment, and supplies was one kind of improvement. Another was smart devices.

An issue we faced was, we could model a device as it is today or model a future, smarter version or even a version that defies laws of our world’s physics (invisible devices that teleport instantaneously). Most of the time, we chose to investigate the middle ground – devices that model a future, smarter world where all objects can communicate with each other but where they still follow the laws of physics of our current world. That is not to say that there are no flying carpets, magic potions and mysterious doorways in the hospital – imagination is still an important ingredient in our work.

5. RESULTS

5.1 RFID Results

At the beginning of our project, the main goal was to determine whether it would be feasible to create a method of rapidly developing, simulating, virtually prototyping, and finally analyzing the effectiveness of RFID-enabled systems inside Second Life's engine. The deployment of the SL virtual RFID tagging system demonstrates much of this goal.

As of now, the project boasts a basic hospital with various RFID systems residing within. The performance of the RFID systems is similar to real-world RFID setups. The virtual system is now capable of recognizing, parsing, and acting on RFID-tag scripts in a way similar to a real-world RFID system. When an RFID reader on the SL island detects a tag, the tag's information is sent to the remote server, which then places the information into the appropriate database. Multiple tags can be detected and handled simultaneously by both the RFID readers and the server-side scripting.

Since the project aimed to create first generic scripts, then narrow the range of each as needed, there are a variety of developed and functional modules that can potentially be re-used in other RFID simulation areas. Although most objects created relate to the health care industry, the underlying system can easily be transposed into other RFID application areas. Item level retail and tire management logistics scenario investigators are underway, complementing the health care application scenario.

5.2 Second Life Results

At the beginning of this project, it was unclear whether Second Life would be an appropriate tool to create RFID simulations that could be both useful and time-efficient. We have demonstrated that Second Life is suitable. RFID simulation and event-driven scripting seem made for one another in a way that a normal scripting language such as Perl could not straightforwardly achieve without considerable complicated code. Event-driven scripting is an integral part of the project's success.

A second observation is that Second Life made it feasible to quickly construct and assemble physical assets for the healthcare scenario inside the island. In one semester, untrained programmers learned Second Life, built a hospital, populated it with smart devices, and scripted the devices to follow business processes.

Not everything about SL object construction and scripting is ideal. Students had trouble constructing complex objects from simple parts – for instance, it was hard to change a tire on a truck without taking off other tires. And the three second delay that SL imposes on interactions with a remote server makes some kinds of modeling less than ideal. In addition, SL's integration of various in-world abilities that are impossible in the real world often led to accidental implementation of project assets that are unattainable in real RFID systems

6. CONCLUSIONS

6.1 Summary

Second Life virtualization and RFID simulation are complementary and synergistic. This project involved developing a way to model virtual RFID readers and tags in SL, developing a remote database on a server outside SL, and then connecting the two so that when virtual tags are read by virtual readers in SL, they are recorded in the remote database. We deployed our virtual RFID in a healthcare scenario but note that it could be similarly deployed in any RFID scenario. The project developed the beginnings of a powerful simulation environment for modeling RFID, sensors, smart devices, and how these can interoperate in business scenarios.

6.2 Contributions

This project contributes to both Second Life research efforts and RFID development as follows:

- Using SL, RFID technology and smart devices can now be effectively prototyped and tested without the need to wait for coming technology to catch up.
- Parties interested in how RFID integration would improve their business can now experience a hands-on demonstration to understand the benefits and business case for integration.
- Further SL simulation projects are beginning to establish a framework to ease the learning curve and speed development.

- Positive RFID education can be demonstrated in a comfortable environment, which may familiarize the public with RFID and improve how RFID is viewed in the public sector.
- Our research helps to open the door to using the Second Life platform as a simulation environment for next generation technologies like RFID.

6.3 Future Work

While this thesis provides the basic framework for RFID virtualization in a virtual world, there is much more work to be done to fully integrate the two technologies:

- Import and export operators could be developed to easily map an architectural drawing from other environments into SL or from SL to those other environments. Then it would be easier to map an architectural drawing for a house, hospital or city into SL or to export a plan for RFID deployment from SL to a real hospital.
- The connection from SL to databases on remote servers is forged (as described in this thesis). It would be interesting to further connect a middleware system like the UA TagCentric RFID Middleware system to SL virtual RFID readers in such a way that, without changing TagCentric, it could monitor a SL simulation of a healthcare facility. Then, the design could be exported to a real world healthcare facility, and TagCentric could continue to monitor that, again, without change. That parallelism between model world and real world could be exploited to test real world software against virtual world simulations.
- A Healthcare Toolkit could be constructed consisting of an inventory of SL models for supplies, smart devices, and business processes as found in a hospital.

Vendors could supply simulation models along with their products. A library of plug-in scripts could be developed for everything from pathfinding to communicating with bots using natural language. Using the toolkit, users could rapidly snap together models of their own healthcare facilities, smart devices and RFID systems before purchasing the hardware. Methods are needed for exporting designs and also for creating estimates for costs.

- Many real-world healthcare experiments have involved deploying active or passive RFID, and we are only beginning to model some of these in SL. Using the virtual world to model virtual RFID in other areas beyond healthcare presents many more opportunities to use virtual worlds to model RFID solutions as a low cost step before deployment.
- Similarly, the range of kinds of simulated sensors and smart devices could be extended from RFID to motion, temperature, and many other kinds of sensors. We need to experiment with standard ways that smart devices can communicate with each other, e.g., with agent communication languages and policy management languages. We also need to experiment with ways that people and smart devices can communicate, for instance using menu-based natural language. It also makes sense to work on soft controllers, which are universal remotes (like Star Trek communicators) that discover the API of an object, download it, and then can control that object (since having remote controls for each object clearly does not scale).
- Real-world spaces could be instrumented with sensors that tied directly into SL mirror worlds. Then, one could use SL as a viewport into a real room.

Collaboratories are remote control models that can be used to control real instruments at remote laboratories, allowing collaboration by parties not able to travel to a site. One example would be if astronomers control an expensive telescope from the comfort of their home laptop. Another would be if doctors could examine a rural, remote, isolated elderly patient – a virtual home visit.

- An access control method is needed for allowing specific parties access to the demonstration area of the island while keeping the generic population out.
- Video tutorials and presentations need to be created both as marketing and as a way to show potential clients the benefits of the new simulation technology.

REFERENCES

[1] Radio-Frequency Identification, Wikipedia, http://en.wikipedia.org/wiki/RFID, accessed January 2008.

[2] What is RFID?, http://www.aimglobal.org/technologies/RFID/what_is_rfid.asp, accessed January 2008

[3] EPCglobal Homepage, http://www.epcglobalinc.org, accessed January 2008

[4] "Second Life," Overview Article, Wikipedia: the Free Encyclopedia, http://en.wikipedia.org/wiki/Second_Life

[5] "Second Life Web Site," http://secondlife.com/

[6] "Harvard Class Invades Second Life," Joystiq, September 12, 2006, http://www.joystiq.com/2006/09/12/harvard-class-invades-second-life/

[7] T. Hapgood (ART), F. Limp (ANTH/GEOS), T. De Noble (ARCH), D. Fredrick (FLAN and HUMN), C. Thompson and A. Apon (CSCE), M. Limayem (ISYS), Proposal: Request $3000 for one year subscription to Second Life, Sent to Chancellor John White and Provost Bob Smith in October 2007, funded within days, and C Thompson purchased a SL island for UARK in November 2007.

[8] C. Thompson (ed), Healthcare Logistics in the Second Life Virtual World: Status Report on Student Projects from Artificial Intelligence Class in Spring 2008, Computer Science and Computer Engineering Dept., University of Arkansas, Fayetteville, AR, http://www.csce.uark.edu/~cwt/COURSES/2008-01--CSCE-4613-5043--AI/DOCS/SL/doc/SL-PROJECTS--STATUS-REPORT-on-04-15-08.doc

[9] C. Thompson, "Smart Devices and Soft Controllers," Architectural Perspective Column, *IEEE Internet Computing*, January-February 2005. http://www.csce.uark.edu/~cwt/DOCS/2005-01--PAPER--IEEE-Internet-Computing--Smart-Devices-and-Soft-Controllers.pdf

[10] A. Hendaoui, M. Limayem, C. Thompson, "3D Social Virtual Worlds: Research Issues and Challenges," Architectural Perspectives column, *IEEE Internet Computing*, Jan-Feb 2008. http://www.csce.uark.edu/~cwt/DOCS/2008-01--PAPER--IEEE-Internet-Computing--3D-Virtual-Worlds.pdf

[11] Demographic Reports related to Second Life, Market Truths Ltd. Group, http://sl.markettruths.com/reports/default.asp

[12] A Winning Business Plan for Second Life, http://business2-cnet.com.com/A+winning+business+plan+for+Second+Life/2100-1025_3-6160433.html

[13] Second Life Grid Network Metrics, Linden Labs, http://secondlifegrid.net/resources/service_metrics

[14] "Cheer Up, Ben: Your Economy Isn't As Bad As This One," The Wall Street Journal, January 23, 2008, http://online.wsj.com/public/article_print/SB120104351064608025

[15] Ian Lamont, "Second Life's Virtual Potential Is Real," Computer World, November 20, 2007, http://secondliferesearch.blogspot.com/2007/11/second-lifes-virtual-potential-is-real.html.

[16] Santa Clara Island, New Media Consortium, http://virtualworlds.nmc.org/portfolio/santa-clara/

[17] Dresden's *Gemaldegalerie Alte Meister* museum, Wired Magazine, August 13, 2007, http://www.wired.com/culture/art/multimedia/2007/08/gallery_dresden

APPENDIX – EXAMPLE RFID SCRIPTS

1. Door Security

```
integer channel = 2500;
string password="password";
integer handle;

default
{
    touch_start(integer total_number)
    {
        llWhisper(0,"Password?");
        handle = llListen(0, "", NULL_KEY, "");
    }

    listen(integer chan, string name, key id, string msg)
    {
        llListenRemove(handle);
        if(msg == "bacon")
        {
            llWhisper(0,"Correct!");
            state open;
            //contact door to open
        }
        else
        {
            llWhisper(0,"Incorrect!");
            state default;
        }

    }

}

state open
{
    state_entry()
    {
    llOwnerSay("Door Open");
    float i = 0.0;
    while(i < PI_BY_TWO/2)
    {
        llSetRot(llEuler2Rot(<0,i, 0>) * llGetRot());
```

```
        llSleep(.2);
        i+=(PI_BY_TWO/10);
    }
    llSleep(5);
    llOwnerSay("Door closing");
    i = 0;
    while(i < PI_BY_TWO/2)
    {
        llSetRot(llEuler2Rot(<0,-i, 0>) * llGetRot());
        llSleep(.2);
        i+=(PI_BY_TWO/10);
    }
    llOwnerSay("Door Closed, Rearming");
    state default;
    }
}
```

2. Security Log (To Flat File)

```
string last_visitor = "";
float time;

default
{
    state_entry()
    {
        llSetAlpha(10,ALL_SIDES);
        llVolumeDetect(TRUE);
    }

    collision_start(integer num)
    {
        integer i;
        llSay(0,"In Collision");
        time = llGetTime();
        for (i = 0; i < num; i++)
        {
            string name = llDetectedName(i);
            if (name != last_visitor || time > 60)
            {
                string url =
"http://kcsdman.homelinux.net:81/log.php?";
                url += "name=" + llEscapeURL(name);
```

```
                url += "&uuid=" +
llEscapeURL((string)llDetectedKey(i));
                url += "&obj=" +
llEscapeURL(llGetObjectName());

                llHTTPRequest(url ,[HTTP_METHOD,"GET"],"");
                last_visitor = name;
                llResetTime();
            }
        }
    }
}
```