Using Radio Frequency Identification and Virtual Reality to Map and Track Assets

by

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Thesis in partial fulfillment of the requirements for the degree Bachelor of Science in Business Administration in Information Systems

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May 8th, 2011

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Introduction

Radio Frequency Identification (RFID) technology has shown widespread applicability in asset mapping and tracking in predefined areas (such as inside a warehouse or store), allowing for increased accuracy in the tracking of tagged items (Hardgrave, 2008). Coupled with the lowering costs of an RFID system implementation these benefits have caused a recent spike in the adoption of RFID systems across several industries (Delen, 2007). Currently, the primary method for tracking and cataloging RFID tagged assets is text based. A standard text report is generated in which the data for each tag is coupled to the reader which scanned it, thereby denoting its time-stamped location in a facility. While effective for certain applications, a textual presentation of xyz location data greatly reduces the ability for physical interactivity with tagged assets in predefined real-space. That is to say, a text document with xyz coordinates tied to referent positions on a shop floor is an ineffective method for a mobile user to locate RFID tagged assets actively, given that the text document does not respond dynamically, and does not display the data in a transparent and accessible visual form. Therefore it is the goal of this thesis to design a proof of concept for a system which allows for RFID xyz positional data to be displayed within a virtual 3D environment. By allowing a user to locate tagged assets actively through a model created using game engine software, which links xyz coordinates of the asset in real space to the xyz coordinates of a 3D model of the space, we greatly improve the visual presentation and usefulness of RFID data, as well as fill in the missing pieces of the RFID map.

An Introduction to Technologies Used

What is Radio Frequency Identification?

Radio Frequency Identification (RFID) is a form of auto-identification technology that uses radio frequencies to transmit data from a tag to a reader for the purposes of identifying and tracking assets. RFID belongs to a family of devices that also includes devices such as the all-familiar barcode and QR code. These technologies, such as barcodes, have seen great success in inventory management systems since the mid-1970's, with RFID standing as the newest evolution of the technology (Hardgrave 2008). While RFID tags first arose in the 1940's in military applications (Hardgrave, 2006), the technology as a whole suffers from fragmentation due to differences in production and various broadcasting allowances. Currently a variety of competing standards exist with regulating bodies such as the Federal Communications Commission, EPCGlobal and DASH7 Alliance attempting to establish a common set of standards and regulations, so far without much success.

Despite the variability in hardware, at the core most RFID systems follow the same principles. An RFID system is comprised of four main parts: a tag which is attached to the object to be tracked, an RFID reader, one or more antennae attached to the reader, and a computer. For an RFID tag to be successfully read it must be within range of a complete RFID system. At the software level RFID data is usually scrubbed (meaning the removal of superfluous or corrupt data), and then stored within a database so that it may be further analyzed.

RFID tags consist of an antenna and a chip that are contained within a variety of materials such as plastic cases or stickers and tend to be around the size of a price tag. The chip stores a limited amount of numerical information which gives it a unique identity, and which is then transmitted either passively or actively. Passive tags are activated and subsequently read by the radio waves that an RFID antenna puts out. The RF energy charges the tag allowing it to send back its information to the reader, which is then interpreted by a computer. Active tags contain a battery alongside the tag's antenna and chip, allowing the tag to broadcast its data actively, without requiring a charge from the RF reader. RFID readers and their antennae vary in broadcast frequencies as determined by local and international standards as well as how they propagate their respective waves. Frequencies include low, high, ultra high and microwave, with a higher frequency generally achieving a longer read range.

Overall RFID provides numerous advantages over formerly used auto-identification solutions in terms of efficiency, accuracy and versatility. The primary advantages being: (1) RFID is not hindered by line of sight; (2) A single reader can read several hundred RFID tags per second; (3) RFID tags can store more data than previous auto-identification solutions; (4) the data on RFID tags can be manipulated; (5) RFID tags using Electronic Product Codes (EPC) and serialized global trade identification numbers (SGTIN) allow for specific item level tracking (Delen, 2007).

RFID tags do, however, suffer from certain issues. RF energy, depending on the frequency, can be refracted or completely blocked by materials such as metal and liquid. The refractions and lack of penetration can cause a variety of errors: RFID tags may not be read, or they may be read several times, or may return inaccurate location coordinates, including positions outside the scanned area. This causes issues primarily when the tags are adhered to metallic or liquid filled goods. Furthermore tags surrounded by these materials (i.e. a pallet of soup cans) are often not read at all. RFID tags can also experience interference from external RF devices such as wireless local area networks (WLAN) (Kamaladevi, 2010). RFID systems vary on their read ranges as determined by the combination of the tag and reader. Read ranges vary between less than a meter to up to ten meters. In regards to positional accuracy, RFID tags have been shown to suffer from a margin of error of one to two meters determined by tag type, frequency, reader and reader layout patterns (Reza, 2009). In order to track an RFID tag throughout an entire environment, one must employ the use of multiple readers and RFID systems thus increasing operation costs. Furthermore, RFID tags have some difficulty mapping real time movement due to lags that exist between hardware points in an RFID system. RFID tags are also more expensive than traditional barcodes and must be added to current production processes in order to either attach them to the surface of the object or imbed them within it. RFID tag prices, however, have been steadily declining and adoption rates have begun to increase.

In most RFID systems the data is typically output as text, displaying information such as the tag's location, item specific electronic product code, data and time of the scan and the identifying label of the reader which scanned it. An RFID tag contains enough memory to hold between 96 to 256 bits of information. This allocated memory, much like a license plate on a car, stores a unique identification number, which allows it and the tagged object's details to be stored in a database (Hardgrave, 2006). It is up to the computer (and corresponding database) to retain, match and secure the information to which the unique identification number corresponds.

Location	EPC	Date/Time	Reader
Distribution 1	0023800.341813.5000024	10-31-10 12:35	Inbound
Distribution 1	0023800.341813.5000024	11-1-10 02:35	Conveyer
Distribution 1	0023800.341813.5000024	11-1-10 04:52	Outbound
Store 12	0023800.341813.5000024	11-4-10 08:03	Inbound
Store 12	0023800.341813.5000024	11-4-10 12:20	Sales Floor
Store 12	0023800.341813.5000024	11-8-10 09:30	Box Crusher

Table 1 - Example of Typical RFID Data

Adapted from (Hardgrave, 2008)

Although useful, data presented in this manner isn't convivial to visualizing the actual position of an object in space, a theme which will be addressed throughout this thesis. Furthermore, RFID data often needs to be scrubbed as over-reads (reads outside of the intended scanning area), misreads and superfluous information are sometimes present amongst accurate reads. This scrubbing is handled through various software applications that are part of the RFID system. The amount of data created is also of issue. A warehouse moving thousands of RFID tags through even a few readers will generate a massive quantity of information which may then be effectively mined for business intelligence, but at the same time may create storage and backup issues.

RFID tags have been shown to increase inventory accuracy in certain department stores by 17% as well as eliminate various forms of out of stocks through the specific item level visibility an RFID system provides (Delen, 2007). They may also help reduce shipping and receiving costs by allowing for a reduction in processing errors as well as a reduction of inventory risk, by contributing to lower levels of shrinkage and obsolescence. Through RFID's item level tracking, specific goods can be better monitored for their use or non-use, as well as identifying which particular goods frequently subject to theft (Waller, 2011). In response to the evidence of the benefits that an RFID system can provide, companies such as Wal-Mart and have begun to mandate the use of RFID to many of their top suppliers (Procter and Gamble/Gillette, Kraft). Additionally the Department of Defense, Target, Albertson's and Best Buy have also established certain RFID usage mandates (Delen, 2007).

The use of RFID in business will likely expand in the coming decade, although standards and implementation procedures may remain variable. However, RFID is also finding its way into other contexts where there is a need to identify and track resources--even living ones. Imbedding RFID chips in animals and humans is already occurring and brings with it ethical dilemmas revolving around privacy and consent issues (Foster, 2008). RFID is also a leading candidate technology in regards to its applicability in Smartdust systems. Smartdust is a system, existing primarily in theory, which is comprised of many tiny sensors, such as RFID tags, that can communicate with each other wirelessly in order to provide a wide range of information such as temperature, location, vibration, chemical presence, etc. Smardust systems have had suggested applications ranging from agricultural diagnostics (Aquino-Santos, 2011) to being embedded into textiles in order to create smart fabrics (Farrer, 2010).

In regards to how RFID applies to this thesis, we used two phased-array RFID antennas to read a number ultra-high frequency tags in order to determine their xyz location data within the coordinate system of a mock store. The tag specific positional data was then sent to a computer and stored in a database. This data was then fed to an installation of the game engine Unity, allowing for an accurate and visually accessible representation of the tagged object's positions and movement.

What is Virtual Reality Technology?

Virtual Reality (VR) refers to a computer-generated environment which models the experiences and sensations of real or imaginary locations for the user.

The development of computer based VR technology began in the late 1960's with Ivan Sutherland's *Sword of Damocles*. The *Sword of Damocles* was a head mounted display that presented primitive wireframe rooms to users and allowed for perspective shifts via head tracking according to the direction of a user's gaze. In the 1970's and 80's VR began to find widespread use in flight simulators and training devices for both US Air Force and NASA pilots through the Visually Coupled Airborne Systems Simulator (VCASS) and VIrtual Visual Environment Display (VIVED) (Mazuryk 1996). In the late 1980's and early 90's VR technology became commercially available for the first time with devices such as the DataGlove and Eyephone Head Mounted Display. This commercial availability began VR's assimilation into various video game applications. The 90's also saw the development of Cave Automatic Virtual Environment (CAVE) which used stereoscopic images on the walls of rooms instead of head mounted displays to recreate environments (Mazuryk 1996).

VR technology can be subdivided into various levels of user immersion. Desktop or Window on World (WoW) systems are the simplest form of VR simulation, making use of a monitor to display a monoscopic image of the world. Fish Tank systems make use of head tracking and motion sensing in order to create a more immersive experience but still rely on monoscopic monitor displays. Immersive systems are designed to immerse the user fully through the use of either a head mounted display or fully interactive room such as CAVE. (Mazuryk 1996). For this thesis we will be primarily focusing on Desktop VR as generated by video game engines. Since the 1990's Desktop VR technology has grown to find numerous applications in areas such as medical and therapeutic assistance, educational enrichment, as well as architectural and historical visualizations.

Recently physical therapy specialists at Rutgers University were able to develop a VR simulation using a VR system and components from a Nintendo Wii to create simulations that assisted stroke patients in regaining certain motor skills. Patients were presented with a variety of VR games that automatically adapted to each individual's motor skills. After a six week period all of the patients had either increased on gained previously absent motor abilities (Burdea, 2011). VR simulations have also been shown to assist in the treatment of a variety of anxiety disorders including phobias (such as flying and driving) social anxiety disorder, and post-traumatic stress disorder. Researchers at Hong Kong's Polytechnic University have tested a VR simulation constructed with video game engine software (3DVia Virtools) that would increase first-time patient's familiarity with a hospital's psychiatric ward in order to decrease preconceived notions and anxieties regarding the ward (Lau, 2010).

Desktop VR applications may also allow for the refinement of distance learning in e-classrooms. A study based around interactive video chat has shown that VR enriched classrooms may provide a more immersive and interactive setting amongst students and educators, allowing for higher quality interactive dialogue (Falloon, 2011). Researchers at Melbourne Australia's Monash University are in the process of developing an online game dubbed Art Educational Multiplayer Interactive Space (ARTEMIS) in hopes of reinvigorating history and theory in art and design education in order to assist undergraduate art students. Students, in lieu of traditional lectures, are encouraged to play an interactive online multiplayer game in which they are able to interact with the avatars of famous artists and their subjects as well as other students. The students are then quizzed over the in-game material they have learned with passing grades allowing them to progress the game (and thus progress in the course). Students using ARTEMIS showed an increase in sustained attention as well as a desire to participate in the game's online community. Students appreciated the interactivity that ARTEMIS provided over traditional coursework and found it easy to relate to (Janet, 2009). Furthermore several universities have begun to view game based VR as a viable educational tool and have setup curricula based around these so called serious or persuasive games. Examples of such curricula include the Massachusetts Institute of Technology's Games-to-Teach, the University of Illinois at Chicago's Visualization Lab. Additionally events such as the Serious Games Conference are held to discuss the applicability of VR in education (Kinkley, 2009).

VR and 3D modeling tools are now widely used as tools to recreate, analyze and visualize archaeological sites and buildings as well as the objects that populate those environments, such as pottery, tools, sculptures and other artifacts. Researchers at Polytechnic University of Valencia, Spain have managed to use augmented reality (a form of virtual reality in which a computer generated image is overlaid upon a user's natural field of view) in conjunction with various 3D modeling programs such as Cinema 4D to recreate the Cathedral of Valencia. An archive was created of the cathedral's past architectural features, as well as its sculpture and paintings. Drawing on this archive researchers were able to create a system which allowed the user to accurately superimpose those virtual images onto the extant walls and ceilings of the cathedral, thus creating a new and historically insightful real-time experience (Portales, 2009). Even members of the team assisting in this thesis, Dr. David Fredrick, associate professor of Classical Studies, and Kennan Cole, research assistant for the Center for Advanced Spatial Technologies, have used 3D modeling software (Cinema 4D and Unity) to create historical models of the buildings and homes in ancient Pompeii. Their ongoing project, known as the Digital Pompeii Project (DPP), seeks to develop environments in which visualization and navigation of the ancient city is possible. Enabling users to move physically both between and inside of buildings using a virtual medium allows for more historically accurate and insightful observations in regards to Roman architecture, art and sculpture, and how these forces shaped daily life in Pompeii. Recently DPP focused on the importance of a statue of Priapus and its relative location inside the House of the Vettii. By combining existing theories of its placement with that of the architectural effects made visible through a 3D model of the house, they were better able to make historical and cultural inquiries of the role it played for the inhabitants (Cole, 2010).

What is Unity?

Unity is a game development and authoring tool developed by Unity Technologies which allows the user to generate interactive 3D content which can be used in a variety of visualizations. While primarily designed for videogame development, Unity is also commonly used for architectural visualization and real time 3D-animation. Unity runs on both Windows and Mac OS X operating systems and unlike many other game engines, has the ability produce games that run on Windows, Mac, Wii, Playstation, Xbox, iPad, iPhone, Android and internet browsers using the Unity web player.

While still a new face on the game development software scene, Unity has won such awards as the Wall Street Journal's 2010 Technology Innovation Award in the software category (Totty, 2010) as well as Gamasutra's "Top 5 Game Companies of 2009" (Nutt, 2009). Despite its growth Unity's developers remain in close contact with its users through direct forum postings and their annual world conference, Unite, which our team was able to visit in Montreal in November, 2010. Unity comes in two versions, the free basic version and the paid pro version. Considering the availability of Unity's free basic version (which is still rather robust) in comparison to expensive competitors' software, it is easy to see why Unity rapidly rose in popularity amongst both new and academic / non-commercial developers.

Unity makes use of an integrated development environment which provides such tools as hierarchical asset view formats, visual editing, detailed property inspectors, terrain creation and live game previews. Unity natively supports integration with a variety of 3D modeling programs such as 3ds Max, Maya, Blender and Cinema 4D and allows for automatic importation and updating of assets loaded into a project. Unity's graphics engine can make use of Direct3D, OpenGL, OpenGL ES and other proprietary APIs. Unity also supports a variety of texture mapping and image effects, such as normal mapping, reflection and transparency, still and flowing water, and ambient occlusion. Unity also makes use of Beast Lightmapping, Umbra occlusion culling and Nvidia's PhysX physics engine.

As previously mentioned, Unity supports multi-platform publishing, including several mobile platforms which have allowed it to earn a name for itself in the realm of mobile development. However, Unity's robust and highly popular web-player is perhaps its strongest publishing asset and was a main decision factor in choosing to use Unity for this thesis. Unity's web player natively supports a wide range of hardware devices and drivers in both DirectX and OpenGL, allowing us to focus more time on creating an environment rather than running browser compatibility tests. Unity's web player is also free for the user to download and has a relatively small footprint, while at the same time being able to generate extremely high quality in-browser graphics. Currently Unity's web player has had over 35 million installations, and continues to grow in popularity (Unity Technologies, 2010). The ability to publish directly to a web player allows anyone with an internet connection instant access to our RFID lab environment, and reinforces the proposal for a truly mobile RFID tracking device.

Objective

As noted in the introduction, the objective of this thesis is to create a system that would allow a user to grasp visually the location of RFID tagged assets by combining RFID scanning technology with Unity. The interface will use a three-dimensional representation of the space where the asset is housed. This solution will allow for an enhanced user view of physical space through the ability to "see" the asset represented in virtual space, thus allowing assets to be tracked more rapidly because of the visual rather than textual display of their location.

Current Visualization Standards

As previously discussed, RFID data is commonly displayed textually in tables with very crude to non-existent visual representation of the tag's physical location inside of an environment. This is partially due to the fact that most RFID tagged assets are being read for their location as it pertains to a very specific area such as a loading dock or box crusher and general proximities are easily discerned. However, as RFID read ranges increase, the scanning of entire environments (such as warehouses) are becoming possible, increasing the desire to able to immediately grasp the physical location of an object. Furthermore most RFID systems are not currently enabled to read z location data, such as an object's height or elevation, and are therefore confined to representations on a 2D plane. Even with z location tracking enabled on RFID systems, it is not a solution in and of itself as we witnessed at the University of Arkansas' RFID test lab. The lab's system was designed so that while the tags' locations were being tracked they were simultaneously displayed upon a simple xyz graph shown below.

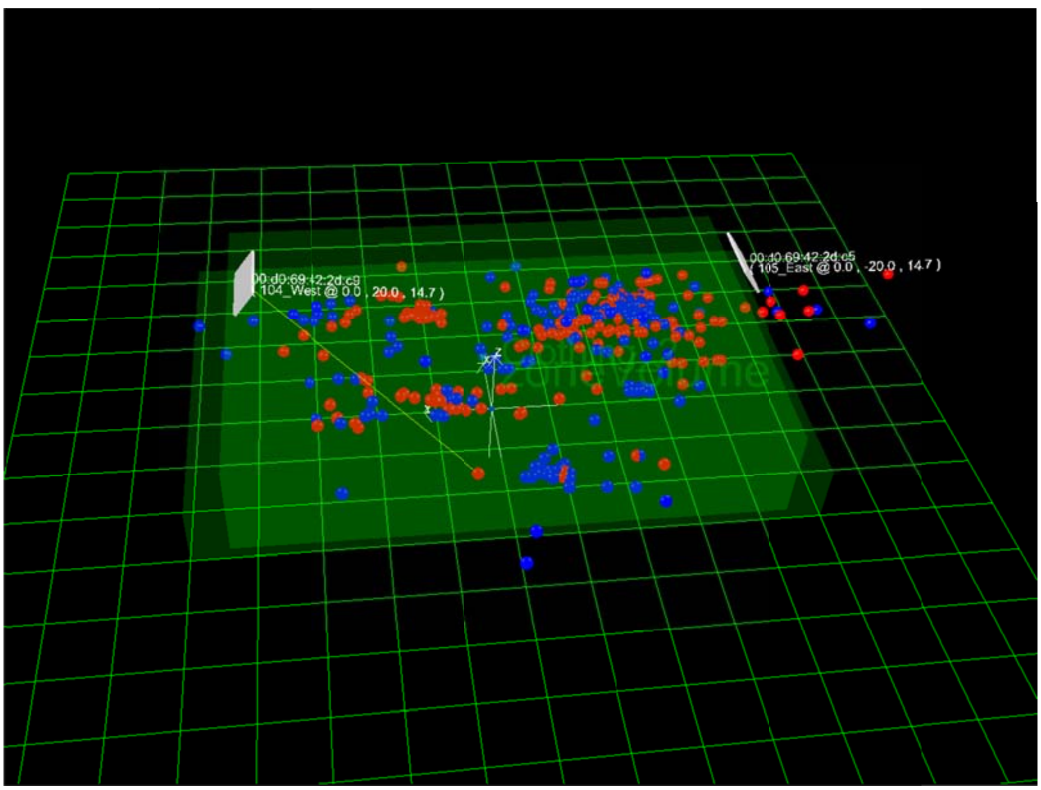

Figure 1 - Current 3D Representation of RFID Positional Data at the University of Arkansas RFID Lab