Evaluating the Potential of Using Passive RFID Technology as a Real Time Location Tracking System to Assist an Individual with a Visual Impairment

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ABSTRACT

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This study evaluated the potential of using Passive Radiofrequency Identification [RFID] Technology as basis for a Real Time Location Tracking System [RTLTS] to assist an individual with a visual impairment participating in physical activities, such as basketball. While RTLTSs exist based upon other technologies, Passive RFID Technology had yet to be examined for its potential in such an application. In this study, a system was designed and modified, for Passive RFID Technology, in order to enhance the performance of the RTLTS. More specifically, the first iteration of the software code employed the use of multiple RFID antennas to cooperatively designate unique zones, which allowed for the identification of a user's general position. A series of tests were then conducted to assess the system's accuracy. In addition, it was determined whether or not factors, such as the addition of multiple tags identifying an object, change in the attenuation level and height level of the antenna, or the position of the tag, had a significant effect on the accuracy of the system. This study showed that the system's greatest accuracy was obtained when six distinct Passive RFID tags were used to identify the object and when the antenna had a direct line of sight to the tags. Results also showed that these read accuracy rates were indeed comparable to other technologies. Therefore, there exists optimism in using Passive RFID technology as a basis for a RTLTS to assist an individual with a visual impairment.

Keywords: Visual Impairment, Blindness, Passive, RFID, Real Time Location Tracking System

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CHAPTER 1: INTRODUCTION AND BACKGROUND

The purpose of the study was to evaluate the potential of using Passive Radiofrequency Identification [RFID] Technology as a basis for a Real Time Location Tracking System [RTLTS] to assist an individual with a visual impairment. Other technologies, such as Global Positioning System [GPS], Infrared, and Ultra Wide Band, have been widely considered for the application of RTLTS. Therefore, background research was first conducted on these different technologies to gain an understanding of not only how each was able to function in such a capacity, but to analyze the advantages and disadvantages of each. While there has yet to be an ideal technology for the use of RTLTS to assist an individual with a visual impairment, it should be noted that RFID has been often overlooked as a potential candidate for such an application. However, in this specific chapter, investigative research was conducted to not only gain familiarity with the components and current application of the RFID technology but also to learn how such a technology could potentially be used within a RTLTS.

While this chapter was focused extensively upon the potential of using RFID for an RTLTS, emphasis was also placed upon the importance of such a study. It should be recognized that nearly 150 million individuals, throughout the world, have been classified to have a form of visual impairment. Therefore, this chapter also investigated the basic ocular anatomy and physiology of an individual, the causes of the most prevalent visual impairments, as well as the limitations that hinder physical activity for individuals with a visual impairment.

Section 1: Basic Ocular Anatomy and Physiology

The eye is a complex anatomical structure that is referred to as one of the most sensitive and delicate organs within an individual's body. The human eye has the unique functional ability of refracting light sources and then producing a focused image that can stimulate neural responses within the human brain [1]. Therefore, such an anatomical component is of importance as it enables an individual with the ability to see all visual images. While this specific organ is quite small in physical size, the human eye still has an array of important regions, which include the following: the cornea, sclera, aqueous humor, vitreous humor, iris, lens, and the retina [See Figure 1]. It needs to be understood that each component of this anatomy has a prominent role in the human eye's complex function.

Figure 1: Ocular Anatomy [1]

Cornea

The cornea is a transparent, dome-shaped structure that could be found within the anterior region of the human eye. As the outermost component of the eye, the primary purpose of the cornea is to serve as a protective shield to protect the rest of the organ. For instance, the cornea may prevent the entrance of any germs, dust, or any other harm matter into the ocular [1]. However, the cornea also acts as the human eye's outermost lens. In essence, the cornea is a structure that is held responsible for controlling the amount of light source entering the human eye, and then refracting the light source onto the lens region of the eye [2].

Nonetheless, in order to accomplish the function of being able to refract light onto the lens, it is of great importance that the cornea has a transparent shade of color. Therefore, unlike other tissues within the human body, the cornea is a component that does not receive proper nourishment from blood vessels. Even if the cornea were to receive a small amount of blood vessels as a source of nourishment, the presence of these vessels would have a profound effect on the structure's ability to refract light source onto the lens and could ultimately distort the visual image seen by an individual. Thus, the cornea is a structure that is supplied with oxygen and nutrients through the tear-fluids from the tears films and the aqueous humor [2].

Sclera

The sclera, which is the white region on the exterior of the human eye, possesses tough and rugged surface properties to sufficiently protect and provide the shape for the organ [1]. More specifically, this component of the eye is the outer surface layer that is protecting the more sensitive components of the inner region of the eye. Also, the sclera functions as a component that ensures that light sources do not go anywhere except through the transparent cornea. Thus, unlike the cornea, the sclera does not have to be transparent. With this, nutrients and oxygen could indeed be provided through blood vessels. These blood vessels are able to provide the proper nourishment as they are minimally located on the episclera, which is a thin membrane layer located right on top of the sclera [2].

Aqueous and Vitreous Humor

Within the human eye, there are two regions referred to as humors, or liquids, which are primarily responsible for occupying the spaces between different structures of the ocular [2]. The Aqueous Humor is said to fill, with liquid, the front region of the human eye as it occupies the region behind the cornea and in front of the lens. In regards to this specific humor, the fluid is produced at the back of the ciliary body and then is secreted into the aqueous chamber through the ciliary processes [1]. This function is of importance as the Aqueous Humor carries oxygen and other nutrients, to the cornea and the lens, to provide those structures with the proper nutrients, and keep the structure's transparent color shade. In contrast, the Vitreous Humor is a liquid

region that is located behind the lens that is filled with a gelatinous substance that places force upon the sclera to obtain the proper spherical shape of the human eye.

Iris and Pupil

The iris is the region of the human eye that many may refer to as the “eye color.” The reason for the different “eye color” is that the iris is composed of pigmented fibrovascular tissues, also referred to as stroma [1]. The stroma is not merely responsible for differentiating the colors of the eye of each individual, but it plays a prominent role in connecting constricting muscles and dilator muscle [sphincter and dilator papillae] in order to control the size of the pupil [1]. With bright lights, the iris sphincter muscles will have a tendency to contract the pupil to reduce the amount of light coming in. In contrast, darkness will cause for the iris to have a tendency to open the pupil using the dilator muscles to allow more light to come in. This function is important as the contraction and expansion of the pupil ensures that appropriate amount of light source is able to reach the retina [2].

Lens

Once the light source is able to get through the iris and the pupil, it will then be able to reach the lens of the human eye, which maintains a transparent color shade. Therefore, similar to the cornea, the lens is unable to receive the proper nutrients from blood vessels, but rather receives nourishment from the Aqueous Humor. In regards to the function of the lens, it is of importance to understand that the structure of lens is

attached to a mass of zonule fibers, which are then connected to the posterior region of the ciliary epithelium. This structural arrangement plays a significant role in the function of the lens as it enables the lens to change its flexible structural shape [1]. The adjustment of the shape of the lens will then allow for the image to be more in focus. For instance, to focus on a near object, the posterior region of the ciliary epithelium would contract which would result in the zonule fibers to loosen up. The result of such an action will allow for the lens to change its' shape in order to contract in diameter and also thicken to create an increase in acuity. Therefore, the lens plays a prominent role in the vision process of the human eye.

Retina

The retina is a component that is a light-sensitive layer located in the posterior region of the human eye. Uniquely, this component of the ocular possesses specialized cells, referred to as photoreceptors, which allows for the retina to detect the intensity and frequency of the light entering the eye [1]. The two primary forms of photoreceptors, within the retina, are the rods and the cones. In regards to the rods, these photoreceptors are able to detect the intensity of light, and thus are more sensitive to changes between light and dark, as well as shape change. In contrast, cones have the tendency to detect frequency of light and have a prominent role in an individual being able to see differences in color change and the fine detail of a visual image. Nonetheless, even though the rods and cones have vastly different functions,

both photoreceptors have the ability to send nerve impulses to the brain by sending the signals through the optic nerve, which is a network of nerve cells.

Section 2: Process of Image Formation

In being able to process the formation of a visual image onto the retina, each component of the human eye must be able to function properly. In order to comprehend the pathway of how a visual image is formed onto the retina, it is of ease to analyze the diagram provided in Figure 2.

Figure 2: Pathway of Image Formation [2]

The pathway of the image formation begins at the moment in which scattered light sources are able to reach a specified object [indicated by the red arrow pointed in the upward direction]. Once the light source comes into contact with the object, it would have the tendency to leave the surface of the object and is directed into vastly different directions. Ultimately, the human eye will be able to collect a small proportion of the

light source, which was previously reflected by the object, and then begin a process of trying to focus the visual image onto the retina.

Upon the arrival of the light source onto the human eye, it would first come into contact with the curved region of the cornea. Due to the significant difference between the refractive index between air and the liquid of the aqueous humor, the cornea has a prominent role in being able to allow for limiting the amount of light source entering the human eye, as well as also refracting approximately 80% of the light source onto the lens [2].

While the cornea is primarily responsible for the refraction of the light source, the lens is a component of the human eye that has a prominent role in the formation of a focused and sharp image. In order to accomplish such a task, the lens has the ability to undergo a process referred to as accommodation, which allows for the lens to change its structure, shape, and also adjust the focal length to provide sharp and focused images at close and distant ranges [2]. With the process of accommodation, the human eye will be able to focus upon an object at close distance if the lens is able to become thicker in shape. The thickness of the lens may only increase if the ciliary muscles are able to contract, while the zonule fibers are relaxing. In contrast, the human eye will be able to focus upon an object at a distant range if the lens is quite thinner, which results from the ciliary muscles relaxing and the zonule fibers contracting.

After the light source travels through the cornea and the lens, it continues its path through the vitreous humor before finally reaching the retina. With the functions of both the cornea and the lens, an image is transmitted to the retina. However, the

image that is produced, within the retina, is an inverted image of the real object. Thus, the pathway for the formation of a visual image does not conclude at this point in time. Instead, the same light source is able to activate the two primary photoreceptors, which are the rods and cones. These photoreceptors then send nerve impulses to the brain by sending the signals through the optic nerve, which is a network of nerve cells. To this day, very little is known about what happens to the optic signal once it begins its voyage down the optic nerve. But, it has been determined that the optic nerve of each eye sends the image that it sees to the opposite hemisphere of the brain. This would then result in the proper orientation of the object and is the final visual image of the object.

Section 3: Classifications of Low Vision

The World Health Organization [WHO] has approximated that nearly 150 million individuals have been identified as visually impaired throughout the world [3]. However, this number will continue to rise steadily over the next few decades. The reason is not only due to individuals aging, but also due to the notion that many individuals continue to be unaware of the different classifications of visual impairment. Only through educational health programs and annual visits to an optometrist will an individual be able to come to realize if they could potentially possess a form of visual impairment [3].

With the human eyes being a vital component of an individual's anatomy, health physicians often recommend that each individual take the opportunity to visit an optometrist, on a yearly basis, to receive an eye examination. In such an examination, multiple tests are performed to assess the functionality of the human eye. The most common form of eye assessment is the eye chart [seen in Figure 3], which is primarily used to measure the visual system's ability to perceive detail.

Figure 3: Eye Chart [4]

In this specific eye test, the physician places an individual 20 feet from the location of the eye-chart. The individual is then asked to recite the various alphabetic letters that are present. Such a test allows an optometrist to evaluate a person's visual acuity. For instance, for an ideal situation, a patient would possess 20/20 vision, which is measured by an individual being able to read letters of a certain size at a distance of 20 feet. For those who do possess normal vision, the optometrist will determine the vision line in which the patient is able to read without any problems. For example, if an

optometrist diagnoses an individual with 20/40 vision, the visual acuity represent the idea the patient can just read letters, at 20 feet, that someone, with normal vision, could distinguish at a distance of 40 feet from the chart.

The use of an eye chart as a medical tool for eye examinations is of vast importance since an optometrist can evaluate a patient's visual acuity and potentially diagnose one of the following classifications of Low Vision and Blindness, which established by WHO, a doctor or an optometrist may diagnose any individual with the following conditions:

- **Normal Vision:** Vision Acuity of 20/20 [3]. (Seen in Figure 4)
- **Low vision:** Vision acuity between 20/70 and 20/400 with the best possible correction of 20 degrees or less [3]. (Seen in Figure 5)
- **Blindness:** Vision acuity worse than 20/400 and the best possible correction of 10 degrees or less [3].
- **Legal Blindness:** Defined as vision worse than 20/200 or a visual field of 20 degrees or less [3]. (Seen in Figure 6)

Figure 4: Normal Vision

Figure 5: Low Vision

Figure 6: Legal Blindness

Aside from the use of an eye chart to assess visual acuity, an optometrist may implement other assessments to evaluate other forms of visual impairment. For instance, in regards to determining if an individual possesses color blindness, a physician would require a patient to take the Ishihara Color Blindness Test [seen in Figure 7].

Figure 7: Ishihara Color Blindness Test [5]

This specific test consists of an array of colored images with each image containing hundreds of dots appearing in randomized color and size [5]. However, within this image of patterned dots, there exists a numerical figure that will be visible to those individuals with normal color vision, and difficult to observe for those individuals who have a red-green color deficiency. Similar to determining color blindness, there exists

other evaluative tests have been implemented to assess the following visual impairment classifications:

- **Travel vision:** Ability to see at 5-10 feet what the normal eye can see at 200 feet [3].
- **Light perception:** Individual can distinguish a strong light 3 feet from the eye but cannot detect hand movement at same distance [3].
- **Color Blindness:** The inability to perceive differences between some of the colors that others can distinguish [3].
- **Total blindness:** Cannot see a strong light [3].

Section 4: Causes of Low Vision

Even though the World Health Organization has said that nearly 150 million individuals have been identified to have visual impairment, it is important to note that not all individuals have the same Visual Impairment classification. With the array of different forms of visual impairment, it is not surprising that there is a wide range of different causes. According to WHO, the most prevalent causes of visual impairment include the following: Cataracts, Glaucoma, Diabetic Retinopathy, and Childhood Blindness [3].

Cataracts

According to WHO, cataracts continues to be one of the most prevalent causes of visual impairment throughout the world [3]. With cataracts, it has been noted the visual quality of an individual will gradually begin to degrade due to a significant change in the

clarity of the lens component of human eye. Since the lens is primarily composed of water and protein, it is the responsibility of these specific proteins to provide the proper nutrients to keep the clarity of the lens. However, as an individual continues to age, the structures of the lens will begin to diminish. As an individual grows older, proteins will have a tendency to change their alignment and begin to form clumps within the lens [6]. In many instances, cataracts will begin quite small, and the cloudiness will only affect a minimal region of the lens. As one ages, the cataracts will then continue to grow slowly, and cause for a significant reduction in the amount of light that reaches the retina. Therefore, with cataracts, an individual will experience consistent blurriness in their vision, and a significant reduction in their visual clarity [6].

Glaucoma

Glaucoma, which is another prominent cause for visual impairment, is an ocular disease in which the optic nerve is severely damaged. As stated previously, the cornea and the lens receive the proper nourishment from aqueous liquid instead of blood vessels. Therefore, the human eye has a process in which it is responsible for producing aqueous liquid that enters into the Aqueous Humor. However, to prevent the consistent build up of liquid within the Aqueous Humor, the eye has a complex drainage system that is able to filter out the liquid [7]. If an individual is diagnosed with glaucoma, the optometrist will recognize there is a failure within the drainage system of the eye. Therefore, with not enough liquid being filtered out by the drainage system, the intraocular pressure in the eye will significantly increase. If the intraocular pressure

continues to be quite high, the pressure level will reach a critical stage and will cause significant damage to the optic nerve [7]. Once the optic nerve is damaged, an individual will experience permanent loss of their vision.

Diabetic Retinopathy

Any individual, who is diagnosed with Type I or Type II Diabetes, is susceptible to having some form of visual impairment in their lifetime [8]. The primary reason for this is that diabetes has a prominent effect upon the circulatory system of an individual's retina and thus can lead to one having Diabetic Retinopathy. In the early stages of Diabetic Retinopathy, an individual will begin to have arteries, within the eye, that become weakened and start leaking blood vessels upon the retina [8]. And, without the proper medical treatment, the arteries will only continue to get weaker and will eventually leak enough blood vessels into the Vitreous Humor. With this leakage, blood spots will be projected onto the retina as the light source leaves from the lens. It is these blood spots that will cause vision to get significantly blurry and cause a reduction in visual clarity.

Age-Related Macular Degeneration

Another leading cause for visual impairment is referred to as Age-Related Macular Degeneration [ARMD]. As an individual continues to grow with age, ARMD becomes more prevalent as the arteries, within the ocular, begin to harden. This presents a significant dilemma as the hardening of the artery prevents the macula, which is the

light sensitive tissue of the retina, from receiving proper nourishment. Without the proper oxygen and nutrients, the macula would be unable to function in the proper manner. Therefore, ARMD is responsible for the reduction of the clarity of seeing an image as it causes for the gradual decrease in the sharpness and fine detail of an individual's vision [9].

Section 5: Adapted Physical Activity for Individuals with Visual Impairment

John F. Kennedy, the 35th President of the United States of America, once said, "Mankind's greatest strength is our ability to acknowledge our differences, but our greatest weakness exists in failing to embrace these differences" [10]. In the world we live in today, it is quite apparent that we are all each quite unique and diverse in different capacities. There are some disabilities and differences that are visually distinguishable between each person, such as one's physical appearance and behavior pattern. But, it is also of vast importance to understand that there are several differences that are far less noticeable, such as an individual's ability to learn, their creative traits, and even their communication skills. Nonetheless, as President Kennedy said, our society is aware of these many differences, but it is still our reactions and perceptions towards these differences that becomes the primary reason for why we continuously fail to embrace the many disabilities that are present.

Many individuals continue to be unaware of the idea that our society has grown accustomed to forming social and physical barriers, in regards to individuals with a disability, through our actions and personal beliefs [11]. Our society's perception and

attitude towards others have been classified as a significant factor that has had a profound effect upon preventing the inclusion of individuals, with a disability, in many physical activities. The basis for such a notion is that mankind has a tendency to perceive an individual, with differing abilities, in a negative manner and incapable of participating in any form of physical activities or making the proper decisions. Since attitudes and perception are critical in determining an individual's willingness to participate in an activity, the effects of attitudinal barriers, on an individual with different social and physical abilities, have often deterred their participation in any level of physical activity involvement [11].

The effects of attitudinal barriers remain quite prevalent and continues to be a considerable factor for many to overcome. As this group remains unwilling to be involved in physical activities due to fear of humiliation, our society will continue to overlook the desire of individuals, with disabilities, to have active participation in athletic recreation [12]. Thus, with no high demand for equipment specifically for adaptive physical activities, manufacturing companies usually have no desire to design and supply any type of a modified apparatus.

The lack of modified equipment for adaptive physical activity is another prominent barrier experienced by those individuals diagnosed with a disability [12]. Many athletic recreational activities require the use of some form of equipment, whether it is a ball to shoot with in the sport of basketball, or even a bat to swing with in the sport of baseball. However, for an individual who had a visual impairment, it would be quite difficult, without the proper assistance, for one to not only navigate themselves towards the

basketball hoop, but also to locate the basketball within the court. Therefore, equipment selection can have a profound effect upon increasing or decreasing the active participation of individuals with diverse abilities.

It is of essence to promote positive attitudes and perceptions, as well as being able to provide modified equipments, to promote inclusive physical activity within our society. It is through the process of changing perceptions and promoting positive attitudes that can significantly influence the level of physical activity involvement of people with differences in ability. By providing equipment options that have been modified to suit groups with a specific disability, the individuals will be able to feel acceptance into our society, and will continue to have the desire to perform different recreational activities.

Modifications for Basketball for Individuals with Visual Impairment

In regards to basketball, an individual, with a visual impairment, often is unable to participate in such an athletic activity due to the inability to recognize their precise location on the basketball court, as well as the inability of finding the movement of a basketball. Therefore, several sporting goods companies have entered the sales market by providing basketballs that can provide some aide. More specifically, these basketballs have a sound component, such as a beeping device or bells, implemented into the center of the basketball [12].

While the sound component within the basketball is aimed to assist in tracking the location of the basketball, problems will still continue to arise from this specific modified

equipment. One common complaint regarding such an apparatus is that the use of bells or a beeping sound, within a basketball, does not necessarily provide enough guidance as the sound tends to fade away as the ball goes further away from the user. Also, once the ball stops its movement, the user will be unable to hear any noise associated with the ball, and thus will have difficulty in locating the ball. In addition, the modifications of the basketball still have not resolved the issue of providing aid, to the individual, of finding their precise location on the court and where they would need to shoot the basketball to make a basket.

In order to resolve the dilemma of tracking the location of the basketball and the user within the basketball court, a new system should be implemented. Therefore, the purpose of this specific study was to propose, design, test, and implement a location tracking network that enables an individual with visual impairment to determine their precise position on a basketball court. Once a system was defined and designed, it was believed that this system would not only be used to locate an individual, but also would have the capability to translate the position coordinates into either an auditory or tactile feedback to the user.

Section 6: Technologies Available for Basis of Real Time Location Tracking System

The primary purpose of a technology, such as a positioning system, was to have the ability to provide the location of a specific object in a specific environmental setting, whether it was in an outdoor setting, or even inside a house or a facility. In many cases, it would be considered ideal to have a location tracking system that is able to provide the position of an object in a real time manner. Therefore, a real time location tracking system [RTLTS] would have the ability to continuously track the location of the object as it moves through the environmental setting. However, the basis for a RTLTS could be composed of various technologies, which are stated below.

Global Positioning System

One of the most recognized real time location tracking systems is the global positioning system [GPS], as it is often designed as a handheld reader that is able to assist in the navigation of airplanes and even automobiles. In order to provide real time location tracking, GPS consists of several satellites that are positioned, in a fixed manner relative to the ground, to orbit around the Earth and are required to continuously transmit specific signals [13]. A GPS receiver then has the ability to accept these signals from the different satellites, and evaluates the time interval it takes for the signal to travel from a satellite to the receiver. This time interval is of great importance as it is then used in a mathematical algorithm to calculate the latitude and longitude of the object being tracked [13]. Such coordinates are then able to provide the precise location of the object.

While GPS is indeed used for the navigation of airplanes and automobiles, it is important to recognize that GPS signals are indeed quite weak. Therefore, it is often recommended to be only used in areas with an unobstructed pathway between the GPS receiver and the sky. With this in mind, such a technology would not be feasible for an indoor environmental setting as the walls and ceilings of the building will pose as an obstruction between the pathway of the satellite and the receiver. Ultimately, such an obstruction will cause for a significant impairment in the signal reception leading to either inaccurate tracking of the ability, or the inability to even locate such an object.

Infrared [IR Technology]

It has been suggested that Infrared [IR] Technology should be considered as the primary component of a RTLTS. With such an approach, the object to be tracked would possess its own emitter, identified by a unique code, which would periodically emit an IR signal [14]. Such a signal would then be detected by the several IR receivers that would be located within a pre-determined environmental setting, and would then be processed by a software code that will be able to determine an approximate location of the object being tracked.

The use of infrared technology, however, has several limitations. While there is optimism to use IR, such a technology is often used for determining the position of an object based primary upon the presence of the object. With this notion, IR technology would not be practical for real time tracking. In addition, another limitation is that the signals of IR do not have the ability to penetrate through dense material components,

such as walls of building, and thus could often cause the system to “lose” sight of the object. In a similar manner, the system may “lose” track of the object if the orientation of the IR tag is not in the same line of sight as the corresponding receivers of the system. Therefore, the limitations and costly expenses, of such technology, could limit the potential such technology.

Ultra Wideband

Another potential technology for an RTLTS would be Ultra Wideband [UWB]. As with infrared technology, the use of UWB would entail for the environmental setting to have several UWB antennas located throughout. And, for the desired object to be tracked, it would need to possess a receiver upon it. The system would then function through the antennas being able to propagate radio signals, which have distinct wide bandwidths, to the receiver [15]. Once the signals have been obtained by the receiver, it would then be analyzed by a mathematical algorithm that considers the time of arrival of the signal rather than the signal strength. Such an algorithm is then said to have good location accuracy and will only to continue to be improved with the implementation of more antennas.

While it is believed to have good accuracy, there still remain some doubts in regards to the use of UWB for a RTLTS. The primary reason is that the radiofrequency bandwidths of the UWB have yet to be standardized, and the Federal Communications Commission [FCC] has yet approve it for public use worldwide [15]. In addition, the components of the UWB technology remain quite expensive to purchase.

Section 7: Radio Frequency Identification Systems [RFID]

Even though Radio Frequency Identification [RFID] systems have been known to be in existence since at least the beginning of World War II, the prevalence of this specific technological was not truly recognized until the past two decades [16]. With the recent technological advancements in recent years, researchers and developers have been able to recognize that RFID systems can implement the use of radio frequency waves to transmit and receive information regarding an object. The process of how a generic RFID system is used is illustrated in Figure 8.

Figure 8: RFID System Pathway [16]

As illustrated in Figure 8, an RFID system usually implements the use of an RFID reader, RFID Active or Passive tag, as well as an RFID antenna. The tag, which consists of a microchip attached to a radio antenna mounted on a substrate, is then placed upon any desired object, in which user wants it to be identified. Once the RFID system becomes operational, radio transmission are sent by the RFID reader to the RFID

antenna to obtain a request for information regarding the object with the tag [16]. The tag then sends a response back to the antenna, with information regarding the tag, and finally back to the reader. Once the reader obtains the information regarding the tag, a user may then establish a computer program that requests the reader to send the information into the host computer, where it can be further analyzed by the program.

Section 8: Passive RFID vs. Active RFID

Radiofrequency Identification technology is not merely based upon the implementation of a universal system for all applications. But instead, different RFID systems, such as Passive RFID and Active RFID, are employed with different systemic characteristics to optimize the performance of the technology within a specific application [16]. More specifically, Passive RFID and Active RFID systems can be distinguished through characteristics such as the radio frequency band used within the system, the power source of the RFID tag, and the communication process that exists between the tag and the reader.

The most prominent distinction between the Passive RFID and Active RFID system is based upon the power source associated with the system's respective RFID tag. In regards to the Passive RFID system, the tag does not have the capability of establishing a communication pathway between itself and the reader since the tag does not possess its own power source, such as a battery. Instead, the Passive RFID tag relies upon the radiofrequency energy transferred from the reader to the tag to generate the power necessary for the communication pathway [16]. In contrast, an Active RFID system

possesses a tag component that uses an internal power source, such as a battery, to continuously power the tag to have the ability to initiate communication, with the reader, by sending its own signal [16].

Therefore, as each RFID system is powered through different means, it is seen that the communication pathway, between the reader and the respective tag, is unlike one another. In regards to the Passive RFID system, the communication pathway begins with the reader sending a specific radiofrequency signal to the desired tag. Once the signal has been received by the antenna component of the passive tag, the signal is then sent to the integrated circuit. This signal is then able to provide a power source to the respective tag, and then can finally send an informative response to the reader. With an Active RFID system, there exists an active transponder that functions similarly to that of a Passive RFID system since the tag is only activated when it is able to receive a signal from the reader [16]. However, an Active RFID system can have the tag initiate a communication pathway since each tag possesses a power source that enables it to do so. Such a feat is accomplished since a tag is able to emit a signal at pre-determined intervals that is read by the reader to initiate the communication pathway.

Several other characteristics of the Passive RFID system and Active RFID system are also prominently different due to the implementation of different power sources of each respective RFID system. A summary of the differences can be seen in Table 1:

Table 1: System Characteristic of Passive RFID versus Active RFID System [16]

	RFID System Type	
System Characteristic	Passive RFID System	Active RFID System
Power Source of System	No power source within RFID tag. Power source is received from radiofrequency signal sent from reader.	Power source is within the RFID tag, through the form of a battery.
Communication Pathway	Communication Pathway initiated by reader and sent to the antenna of desired tag. Signal then travels to integrated circuit before the tag then sends a response back to reader.	<u>Active Transponder</u> Communication Pathway initiated by reader. <u>Beacon</u> Communication Pathway is initiated by tag sending signals to reader at pre-determined time intervals.
Size of RFID Tag	Typical Size of Passive RFID Tag 5 millimeters by 5 millimeters [0.196 inch by 0.196 inch]	Typical Size of Active RFID Tag 84 millimeters by 9 millimeters [3.307 inches by 2.1259 inches]
Read Range	Approximately 3 meters [9.83 feet]	Approximately up to 1 kilometers [3,280 feet]
RFID Tag Costs	Between \$0.10 and \$10.00	Between \$10.00 and \$100.00

As seen in the Table 1, the primary difference between Active and Passive RFID tags is associated with the power source. Since Active RFID tags are operated through a battery source and allow for greater read range in comparison to Passive RFID tags, this technology has been recognized as the most common type of RFID technology to be used in location tracking systems [17].

The functionality of Active RFID technology begins with corresponding tags possessing a unique electronic code that differentiates it from another tag. Active RFID reads are then placed upon an environmental setting and are emitting radiofrequency signals that are scanning for the presence of these tags. Once information is obtained

from these scans, data is then transmitted from the antenna into an Active RFID reader that processes and stores the information that has been acquired. Location can then be determined based upon the presence of the object within the environmental setting. In order to have a visual display of the location, a software code could be created and used on a desktop. While Active RFID technology should indeed be considered for RTLTS, the cost of implementing such a system is quite expensive [18].

Passive RFID technology, on the other hand, has yet to be considered for the use of RTLTS. The reason is that it is believed that Passive RFID tags do not possess their own power source, and thus are assumed to have a limited read range. However, it is important to recognize that Passive RFID technology functions in the same manner as that of the Active RFID technology. In addition, the costs of the components of Passive RFID technology are far more cost effective [16]. Therefore, research should be conducted upon evaluating the performance of Passive RFID technology as a basis for a real time location tracking system.

Section 9: Product Specifications and Features of Passive RFID Tags

Within the PolyGait Laboratory, which is operated by Industrial and Manufacturing Engineering [IME] Department, the Passive RFID components were limited due to funding. More specifically, the only Passive RFID Antennas available were the Poynting Antenna [A-Patch 0025], while the only Passive RFID Readers available were the Sirit Reader [*INfinity* 510 UHF Reader]. However, there exists a vast array of Passive RFID tags available throughout the PolyGait Laboratory. Below are descriptions of the Passive RFID tags that are available.

Avery Dennison-224 [20]

Figure 9: Avery Dennison – 224 Tag Inlay
[20]

- **Product Specifications:**

- **Antenna Size:** 3.471 x 0.3208 inc
- **Operating Frequency:** Global (860 – 960 MHz)
- **Integrated Circuit [IC] – Manufacturer & IC Name:** NXP G2XL or NXP G2XM
- **Memory:** 240 bits EPC or 240 bits EPC + 512 bits User Memory
- **Operating Temperature:** -40°F to 185°F [-40°C to 85°C]

The Avery Dennison (AD)-224 is an Ultra High Frequency [UHF] Passive Inlay has been advertised, by its manufacturer, as potentially the “future of Passive RFID tags.” Many are optimistic about the potential of AD-224 since this specific inlay supposedly has the capability of being used for different purposes. For instance, studies have shown the successful performances of the AD-224 in activities such as aviation baggage tracking, asset and retail tracking, and even routing tracking. The success of the performance of the AD-224 is attributed to the feature characteristics of the inlay. More specifically, one important feature of the tag is that it has the capability of being used through global UHF frequencies, which spans the range of 860 to 960 MHz. Another unique feature is associated with the idea that these inlay tags have a unique 32 bit serial number that is already factory programmed, which enables the ease of being able to identify a specific tag. Another prominent feature that makes this tag quite likeable is that it has extra user memory which enables for more applications to be

used. Ultimately, these various features and advantages of the AD-224 make such a UHF inlay tag quite attractive to the consumer.

Avery Dennison [AD]-230 [20]

Figure 10: Avery Dennison – 230 Tag Inlay [20]

- **Product Specifications**

- **Operating Frequency:** Optimized for 860 – 928 MHz
- **Integrated Circuit [IC] – Manufacturer & IC Name:** Impinj Monza 3
- **Memory:** 96 bits EPC
- **Operating Temperature:** -40°F to 185°F [-40°C to 85°C]

Another Passive UHF inlay designed by Avery Dennison is referred to as the Avery Dennison [AD]-230. While the AD-230 is a Passive UHF inlay, there are some unique designed characteristics that are able to differentiate this specific model from the AD-224. Some key features include this specific UHF inlay having a shortened inlay length that is able to fit 3 inch label width applications. First and foremost, the shortened inlay length would be desirable as it would allow for different orientation and location placement of the tag. With a shorter inlay length, the orientation and location placement of the tag will not significantly affect the read rate of this specific Passive tag. Another significant feature of this inlay tag is that it has a strong read range, and thus means there will indeed be greater read rates which would insure increasing system reliability.

Sirit's RSI 616 [21]

Figure 11: Sirit RSI 616 Tag Inlay [21]

- **Product Specifications:**
 - **Antenna Size:** 3.62 x 2.625 in.
 - **Operating Frequency:**
 - 902 - 928 MHz Americas, 4 W EIRP
 - 869.4 - 869.56 MHz Europe, 0.5 W ERP
 - **Integrated Circuit [IC] – Manufacturer & IC Name:** Monza 3
 - **Memory:** 96 bits EPC
 - **Operating Temperature:** -40°F to 185°F [-40°C to 85°C]

Similar to Avery Dennison, Sirit is another prominent company that provides their own product series of Passive RFID tags. However, unlike the UHF inlay tags seen in the Avery Dennison product series, Sirit provides a far more complex integrated circuit within the design of most of their UHF inlay tags. In regards to the Sirit RSI-616, the complex integrated circuit was designed to have an omni-directional surface independent antenna. This specific characteristic of the inlay has prompted the RSI-616 to be one of the most prominent UHF inlay tags marketed by Sirit since it possesses the capability of being able to be used for a broad variety of applications. More specifically, one would be interested in this specific inlay because it would be beneficial for application-use which require orientation insensitivity, longer read ranges, or on items that are close in proximity to metals. But, while the broad variety of applications may intrigue consumers, it is important to note a significant limitation of this specific UHF inlay. It is that the operating frequency for the RSI-616 is not for global frequencies, but

rather only covers those frequencies in the United States and several countries throughout Europe.

Sirit's RSI 655 [21]

Figure 12: Sirit RSI 655 Tag Inlay [21]

- **Product Specifications:**
 - **Antenna Size:** 0.659 x 0.512 in
 - **Operating Frequency:**
 - 902 - 928 MHz Americas, 4 W EIRP
 - 869.4 - 869.56 MHz Europe, 0.5 W ERP
 - 865.6 - 867.6 MHz Europe, 2 W ERP
 - **Integrated Circuit [IC] – Manufacturer & IC Name:** NXP UCODE G2XL
 - **Memory:** 96 bits EPC [scalable]
 - **Operating Temperature:** -40°F to 185°F [-40°C to 85°C]

The Sirit RSI-655 is another Passive UHF inlay tag, but differs from others as it uses a hexagon-shaped integrated circuit. With a small near-field antenna designed within this UHF inlay, one may choose to select this specific design as it could potentially be able to obtain strong read ranges. With strong read ranges, there will indeed be greater read rates, which would allow for the consumer to have an increase in system reliability. This is of great importance for a consumer who would like to have a tag that would be used for high-value asset tracking and applications where a small form factor tag is required. However, once again, it is seen that this specific UHF inlay tag does span the

global frequencies, but rather is limited to frequencies within the United States and several countries in Europe.

Section 10: Application of Passive RFID Systems

Passive RFID systems are now highly regarded as a successful technological advancement that is able to transmit the identification of a tag, on an object, through wireless communication. With the growing success of such a system, the application of this specific technology has grown tremendously, as it has been implemented to provide inventory for items in a warehouse, inventory of livestock for farmers, and even providing the government with a system that is able to obtain a numerical count of vehicles passing an automobile toll booth [22].

Automobile Toll Booth with RFID System

In recent years, the United States and several other countries have implemented the use of an RFID system in a tollbooth as seen in Figure 13.

Figure 13: Automobile Toll Booth with RFID System [22]

The goal of such a system is to provide a more efficient and accurate method of receiving monetary toll funds, as well as reducing traffic delays. With this implementation, an inexpensive RFID tag, with a corresponding account number, is placed upon the windshield of the automobile. Once the automobile passes through the automobile toll booth, an RFID antenna, which is mounted on the toll booth, would read the RFID tag associated with the automobile. Once the tag has been read, the information is transmitted by the antenna to a computer program that verifies that the tag ID number corresponds to an active toll account, a debit is then placed onto the automobile driver's account, and the car is allowed to pass [22].

RFID System Used to Track Livestock

In the United States, farmers have begun considering the use of an RFID system to track livestock, such as their cattle. This can be seen in Figure 14.

Figure 14: RFID Used to Track Livestock [22]

The reason for this is that several RFID tags have shown to be functional in a rural setting, as these tags are able to be read through dirt and damage caused by an animal [22]. In addition, the implementation of an RFID system allows for a company, or farmers, to track individual animals for their inventory.

Potential of RFID in Real Time Location Tracking Systems

When implementing the use of RFID systems in various applications, many engineers deploy the usage of RFID portals. Traditionally, an RFID portal is a system, consisted of an antenna and a reader, which is created to have an interrogation zone that allows for RFID tags to be promptly passed through to be read. As with the application of the RFID systems in the inventory of livestock and in automobile toll booths, the implementation of stationary portals has been commonly accepted. With this specific RFID portal, an antenna and a reader are mounted onto a desired object that is required to remain stationary. Therefore, the reader and antenna must wait for the tag to pass through the designated area of interrogation to read the information about an RFID tag.

Even with the significant advancements with RFID technology, there has yet to be an ideal system that is able to provide a precise real time location of an object using an RFID system. Many may come to such a conclusion since it has been well-documented that RFID is not specifically designed to engineer a system that provides a precise real time location of an object [23].

Nonetheless, recent studies have still been conducted to evaluate the potential of Passive RFID technology, for such an application, and these studies have shown that there remains optimism. It is important to understand that such hope is based upon gaining a further understanding of the installation and implementation process of the RFID system. More specifically, to have a real time location system, the system must have the capability of automatically and continuously tracking and reporting the

location of a tagged object. In order to accomplish such a feat, one must take into consideration several concepts of the system:

- **The ability and capability of the different types of RFID Passive and RFID Active tags.**

The tag, which will be placed upon an item, will have a unique identification code that will be read by the readers and antennas of the system. However, as stated in the previous section, there exists an array of differences between the tag characteristics of RFID Passive and RFID Active tags [24]. Therefore, one must first conduct a series of tests to evaluate the benefits and limitations of each tag type before making any decision on which tag will be better suited for real time location tracking of an object.

- **The placement of readers and antennas within the environment setting.**

The placement of the readers and antennas is of great importance to properly place these components in a location that will be able to read the information from the tag. If the tag is not located within the interrogation zone of the antennas and readers, no information will be obtained regarding the specific RFID tag [24]. Thus, the lack of information obtained from the tag will prevent one from identifying the real time location of the object.

- ***The mathematical algorithms that will be implemented within the computational monitoring system.***

In order to find the precise real time location of an object, a computational monitoring system must be implemented. The purpose of such a component is to allow for the user to send protocol commands that will be able to provide the antennas and readers with a guidance of what tag information should be gathered. The tag information will then be transmitted from the readers to the computational monitoring system. Once information has been received by the computational monitoring system, mathematical algorithms can be used in being able to provide an analysis of the precise real time location of the object.

Section 11: Mathematical Algorithms to Compute Real Time Location of Object

As stated previously, RFID technology is not designed to have the application of being able to provide precise, real time location of an object. Nonetheless, different mathematical algorithms, within a computational monitoring system, have been implemented into an RFID system to evaluate and analyze the technology's performance in being able to provide data regarding an object's precise location. In recent studies, the mathematical algorithms are often based upon the theory of trilateration and triangulation.

- **Trilateration**

Trilateration is a mathematical approach (i.e. Received Signal Strength [RSS], Time of Flight [TOF], Time Difference of Arrival [TDOA], and Phase Difference of

Arrival [PDOA]) that can be used to measure the relative location of one point in comparison to another point by evaluating the separation distance using the range information of an RFID tag estimated by different RFID readers.

- **Triangulation**

Triangulation is a mathematical algorithm that takes into account the location of a point by simply measuring the angle from that desired point to a pre-determined second point.

Time of Arrival

A potential approach that has been considered is an RFID system that is designed to evaluate the time interval that is required for the readers to obtain information regarding a specified RFID tag. Recent studies have documented that the two renowned methods that take this specific approach are referred to as Time of Arrival [TOA] and Time Difference of Arrival [TDOA].

If one were to implement the use of TOA in a RTLTS, the system software would entail a mathematical algorithm that evaluates two vastly different characteristics of the system. The first characteristic that would be assessed would be the time interval of the read rate, which is the time that would be required for the tag information to be read and processed by one reader [23]. The algorithm would then repeat this process for each of the readers present within the system and will record this information into a database. Another important characteristic measured in the TOA approach would be the evaluation of the speed of the signal that travels from the tag to the reader. Again,

this characteristic will be measured for each reader and will have the data recorded onto the database. Next, the algorithm will consider these two characteristics and provide an approximate location of the tracked object. However, it is said that the method requires highly accurate time synchronization from all of the tags and readers to be able to provide a precise, real time location of an object.

Therefore, due to the vast importance of being able to synchronize the time-aspect of all the components of the system, recent studies have suggested the use of Time Difference of Arrival [TDOA]. Again, this method emphasizes the approach of being able to obtain the time interval that it takes for a reader to read and process the tag information of the object being tracked. However, unlike the method in TOA, the synchronization of all components of the system is no longer of great importance. The reason for this significant difference, between the TOA and the TDOA, is that the mathematical algorithm, of the TDOA approach, does not look at the read rates of each pathway as separate entities. Instead, an approximate location of the tracked object will be measured through analyzing the speed of the signal, and calculating the difference between the read rate intervals between the tracked object and each of the separate readers [23].

In order to validate the use of TDOA within a real time location system, simulations and prototypical systems were evaluated in a study conducted by A. Bhatia and his peers [23]. In this specific study, a simulation of the performance of the TDOA approach was performed with the computational software, MATLAB. In this simulation, the primary objective was to see the average error distance that was recorded for the

tracked object. Therefore, an indoor room setting, with the dimensions of 250m by 250 m, was created with readers located at 25m apart from one another in this simulation. An assumption, that each reader had the capability of being able to read tags within a distance of 50m, was made. As the simulation was ran for several hundred experimental tests, it was seen that the average error distance was approximately 5m. The error distance continued to increase if the room setting area was increased. However, an increase in the number of readers was shown to significantly decrease the error in distance [23].

A prototypical system was evaluated in the study analyzed by Bhatia and his peers [23]. In order to compare results from the simulation models, the researchers also used the same parameters. Results had shown relatively similar data as the average error distance was slightly higher at a distance of 6m for the same dimensional settings. Nonetheless, the simulation and prototypical models have verified the potential of the TDOA approach in a real time location system as it does not rely upon synchronization of all components, and can indeed provide reasonable accuracy in detecting the location of an object being tracked [23].

Spatial-Domain Phase Difference of Arrival

Another potential mathematical algorithm in determining the location of a tagged object is the use of Spatial Domain Phase Difference of Arrival [SD-PDOA], which is referred to as Angle of Arrival [AOA]. By incorporating such an approach, an estimated distance, of the tagged object, could be determined based upon measuring the phase

signal of the desired tag [25]. More specifically, the system would implement the use of a pre-determined number of antennas that will be placed at fixed locations. The location of the tagged object will then be determined by the phase signal difference between the different antennas. Through this process, a corresponding angle and path difference can be correlated with the phase signal difference. Thus, such a method could potentially provide for a mathematical approach in being able to find the location of a tagged object.

The limitations, associated with the SD-PDOA, have played a prominent role in preventing such an approach from being used in a real time location system. The primary limitation is that the accuracy is based upon the precise angle measurements that are obtained [25]. If a minimal error in the angle measurement is obtained, the mathematical algorithm may provide a significant error in the estimated location of the tagged object. Another limitation is that the SD-PDOA has shown to be quite ineffective within an indoor environment, as the environment may possess material that could cause inaccurate angle measurements due to reflection of the phase signals. With this limitation, it seems as though the most optimal environment, for the SD-PDOA, would be one in which the line of sight, from the tag to the antennas, is not obstructed by any object. Therefore, one may conclude that such an approach is not suitable for an indoor environment.

Landmarc Approach

In a study conducted by Lionel M. Ni and his fellow colleagues, the researchers proposed the Landmarc Approach, which took into consideration the use of trilateration [18]. In order to accomplish such a feat, Ni established an RFID system with the primary components consisting of four RFID readers and the use of Active Ultra-High Frequency [UHF] tags. In this specific study, Ni chose to utilize RFID readers that are designed to have pre-assigned power levels [1-8] that represents the correlation associated with the received signal strength [RSS] that is needed for the reader to obtain information regarding a desired tag on an object. In essence, the power levels of the four RFID readers can be used as a characteristic that provides a broad definition of different regional zones in a room setting. Thus, with this unique feature, the desired tag can be identified into a specific zone as a mathematical algorithm is able to take into consideration the power levels, in each of the four readers, which cover the distance of each region. However, the Landmarc approach was not solely based upon using the power levels of the readers.

Instead, another important component implemented into the Landmarc Approach was the use of Active UHF tags not only on the object, but was used in the room setting with the intention of being used as fixed reference points [18]. With this specific approach, the readers were able to continue to use the method of measuring power levels to approximate the location and distance of the object tag. However, the method of measuring the Euclidean distance, which is the distance between the signal strength from the tag of the object and each reference tag, was taken into consideration. Such a

measurement was obtained with the following equation in Figure 15, where E denotes the distance, S denotes the signal strength from the tag of the object, and Θ denotes the RSS from the reference tags.

$$E = \sqrt{\sum_{i=1}^n (\theta_i - S_i)^2}$$

Figure 15: Equation for Measuring Euclidean Distance [18]

The results, from the study conducted with the Landmarc approach, have illustrated several important characteristics and concepts regarding the implementation of such a method in an RFID system. First, there does exist different possibilities of being able to improve the precision of locating an object, as it is not solely based upon adding more RFID readers. Similar to the approach of using Active UHF tags as reference points, these different possibilities would not only yield more accurate and reliable results regarding the precise location of the object, but a cost-saving opportunity to establish an RFID system.

Even with the significant advantages associated with the Landmarc system, it remains difficult to overlook the problems associated with such an approach. While the approach is able to provide quite accurate information regarding the position of an object, the time to obtain an analysis of the location was considerably quite long. This specific study has shown that it exceeds over a minute for the RFID readers to scan the different power levels and estimated the signal strength of all Active UHF tags within the room setting. Another prominent dilemma was that the placement of the reference tags and the readers were of vast importance since the regional zones were based upon

the location of these components. Therefore, the problem remained to be the issue that the regional zones would continue to be altered and in different orientations if the RFID readers were positioned diversely. Nonetheless, it was of vast importance to consider the proposal of the Landmarc approach as it established the basis for the potential of using RFID technology to obtain a precise, real time location system.

Section 12: Purpose of Study

An individual, diagnosed with a visual impairment, often must experience the many social and physical barriers when trying to participate in a recreation activity. While it will remain quite difficult in changing our society's perception on individuals with a disability, it should be noted that our society has an opportunity to assist in overcoming any physical barrier that is presented. While it is evident that an individual, with a visual impairment, may experience difficulty in performing certain aspects in the sport of basketball, it should be known that assistance can be provided through the modification of the equipment, such as the implantation of sound components inside the basketball. However, there has yet to be an assistive device that is able to provide assistance in navigating a person towards not only the basketball hoop, but to locate the individual within the court.

Therefore, the purpose of this study was to suggest the implementation of a real time location tracking system to assist an individual, with a visual impairment, to recognize their precise location on the basketball court. While there exist real time location tracking systems available on the market, it was desirable to have one that was

cost effective. Due to the relatively low cost of the Passive RFID tags [between \$0.10 and \$0.50] and the corresponding Antenna and Reader, it was decided that the Passive System would be the proper choice for the RFID Technology even though such technology was not specifically designed for real time location tracking. The reason for such optimism was associated with the notion that RFID technology has been used in a vast array of applications, and has been recognized as quite reliable in tracking objects as it passes an RFID portal, as seen in Figure 16.

Figure 16: RFID Portal Reader [16]

With this specific study, it was hypothesized that Passive RFID technology would be able to be used as the basis for a real time location tracking system. It was believed that such a system would then be able to recognize the accurate location of an individual within a pre-determined environmental setting. Therefore, to accomplish such a feat, a software code was written to not only establish a communication pathway between all

of the components of the system, but to function in a manner that requests the system to provide a visual database of the object being tracked. With this, the first iteration of this design was employed with the use of multiple Radio Frequency Identification [RFID] antennas to cooperatively designate unique interrogation zones, which allowed for the identification of a general position of a user. However, future iterations will involve either a reference tag scheme or a phase shift determination for identifying relative position more precisely and with fewer readers.

In addition, tests were conducted to analyze whether or not factors such as directionality of tag, attenuation and height levels of the antenna, and the implementation of multiple tags to track an object had a significant impact upon the read accuracy of the technology of Passive RFID as a real time location tracking system. And, after the conduction of this study, the hope was to recommend the use of Passive RFID technology, for the RTLTS, along with a form of tactical stimulation in order to assist an individual, with a visual impairment, with a directional guidance of where the basketball hoop was located.

CHAPTER II: DESIGN DEVELOPMENT AND FEASIBILITY TEST

In order to gain a sense of familiarity with how each component of the Passive RFID Technology functions as a unified system, a series of preliminary tests were conducted. A Passive RFID Antenna Placeholder and Cubic Testing Structure were first designed and manufactured. Next, a software code was designed with the sole purpose of tracking the zones in which a Passive RFID tag was located within. A series of tests were then conducted to analyze and evaluate the performance of the RFID technology as a RTLTS. The tests consisted of evaluating the presence of the vast array of Passive RFID tags that were present within the testing environment, the number of times each Passive RFID tag was read by the system, as well as the range of how far each Passive RFID antenna was able to read a designated tag.

Section 1: Designing and Manufacturing Passive RFID Antenna Placeholder Stand for Feasibility Test

In order to evaluate and analyze the performance of RFID technology within a RTLTS, a placeholder stand for the RFID antenna was first designed and manufactured. With this, the materials that were needed were the following:

- Total of 20 feet of 1" PVC pipe needed
 - o 2 – 2 foot section of 1" PVC Pipe
 - o 6 – 1 foot section of 1" PVC Pipe
 - o 2 – 5 foot section of 1" PVC Pipe
- 6 – 1" PVC Elbows
- 2 – 1" PVC T-Joints
- 2 – 1-1/4" PVC T-Joints
- 8" x 8" plywood
- 4 screws [for plywood]
- 2-wingnuts

- PVC clamp

Since 1" PVC pipes were generally sold with the stock size of ten feet, it was of necessity to measure and cut the original length of the PVC pipe into the desired dimensions. Therefore, for a two foot section of 1" PVC pipe, a distance of two feet was first measured with a measuring tape. Once a measurement was made to determine the distance, a marker was then used to designate the desired cut length. Next, to obtain the desired portion size of the PVC pipe, a PVC cutter was then used to cut the PVC pipe at the designated mark. The same process was used to obtain a total of two sections of 1" PVC Pipe with the length of two feet, six sections of 1" PVC Pipe with the length of one-foot, and two sections of 1" PVC Pipe with the length of five feet.

In order to construct the base of the placeholder stand, I first took one section of the 1 foot PVC Pipes and placed one PVC elbow at each end. Next, at the end of each of the PVC elbows, I then needed to connect an additional section of one-foot PVC Pipe. Once attached, I then connect one PVC T-Joint [1"] to the end of the one-foot PVC Pipe. In addition, it was important to note that the single, vertical component of the T-joint had to be directed in the upward direction. Next, I connected the PVC Pipe with the corresponding length of two feet to the each end of the PVC T-Joints. Afterwards, PVC elbows were connected to each end of the two-foot long PVC Pipes. Finally, I completed the base of the placeholder stand by connecting the two PVC elbows with another one-foot PVC pipe. Once the base of the placeholder stand had been completed, I placed a PVC pipe the length of five feet to each of the 1" PVC T-joint attachments.

In regards to the PVC T-Joint with the diameter of one and a quarter inch, I identified the center point of the horizontal region of this specific component. Next, I used a quarter inch drill bit to create a corresponding hole. Next, one wingnut was fitted into the hole. The same procedure was repeated for the other corresponding T-Joint. Once this step had been completed, I then connected the two T-joints with another one-foot PVC Pipe. In order to attach the antenna to this specific component, I first measured the corresponding distances between the threaded holes on the antenna onto the 8" by 8" plywood. Once the corresponding marks were made onto the plywood, I used the quarter inch drill bit to create a corresponding through hole. Next, I attached the plywood onto the Sirit Antenna by screwing in the four screws into the four through holes that have been created. Next, I placed the one-foot PVC pipe in the middle of the plywood, with the two T-joints extended beyond the plywood. Next, I used the two PVC clamps and placed each approximately two inches from the edge of the plywood. Once the position had been determined, I drilled in the screws to clamp the PVC Pipe. Once this component had been constructed, I allowed for one end of the PVC T-Joint to slide through the vertical five-foot PVC Pipe, and slipped the other end PVC T-Joint to the other vertical five-foot PVC Pipe. In order to position the Antenna component, I twisted each of the wingnuts to tighten the component to the vertical PVC Pipe.

Next, the top component of the stand had to be constructed. For this, I first took one of the one-foot PVC Pipes and placed one PVC elbow at each end. Next, at the end of each of the PVC elbows, I connected an additional one-foot PVC Pipe. Finally, I connect one end of the PVC elbow to the vertical, five-foot PVC pipe, and the PVC elbow

to the other vertical PVC Pipe to complete the structure. Below, Figure 17 shows a SolidWorks design of the Passive RFID Antenna Placeholder Stand, and Figure 18 shows an actual image of such a stand. For images of the construction of the RFID Antenna Placeholder Stand and additional Solidwork Designs for the structure, please refer to Appendix A.

Figure 17: SolidWorks Design of Passive RFID Antenna Placeholder Stand

Figure 18: Design of Passive RFID Antenna Placeholder Stand

Section 2: Conducting Feasibility Test

Once the Passive RFID Antenna Placeholder Stand had been constructed, a series of tests were conducted to evaluate the performance of the Passive RFID system in tracking corresponding Passive RFID Tags. Initial feasibility tests were first conducted with the pre-assigned program setting that was provided, on a compact disc [CD], by the manufacturer of the RFID reader, Sirit. Therefore, it was of necessity to install the program onto a pre-assigned laptop to conduct these tests.

Once the installation of the software program was completed, an Ethernet cord was used to establish a communication pathway between the laptop and the Sirit Reader [INfinity 510 UHF Reader]. Also, one had to establish a communication pathway

between the Sirit Reader and the Poynting Antenna [A-Patch 0025] by attaching one end of the BNC cable to the Antenna and the other end of the BNC cable to either Input 1, 2, 3, or 4 of the Sirit Reader. Even though the proper cords had been connected to establish a communication pathway, it was important to correspond the proper internet protocol [IP] address of the Sirit Reader, which was identified on the device itself, with the designated laptop that was to be used.

Upon completing the setup for the Passive RFID system, one started the program designed by Sirit by double-clicking the icon on the desktop of the laptop. Once the program has been opened, a window screen appeared, as seen in Figure 19.

Figure 19: Infinity 510 Home Screen

One then clicked on the button “Configure,” which allowed the program to direct the user to a designated website provided by Sirit. In order to properly run the Sirit reader, the user was required to login with the term “admin” for the username and “readeradmin” as the phrase for the password.

Next, under the “System Status” section of the designated website, the user selected the “View Tags” link. Once in the “Reading Operating Mode,” the user needed

Section 3: Test of the range of how far the Passive Antenna is able to read a Designated Tag

As the Sirit Program allowed for the user to change the attenuation level of the Poynting Antenna, I first decided to evaluate the read range of the Antenna at different attenuation levels to gain a sense of the read range of the Poynting Antenna. In order to accomplish such a task, we obtained an Avery Dennison-224 RFID Passive Tag. We then used a portable hand-held reader to identify and note the specific identification number of the RFID Passive Tag chosen for use. To begin testing for the read range, an individual held the corresponding Passive Tag not only in front of their body, but also at the same height level as the antenna. Testing began by having the individual hold the tag flush with the side of the antenna, which was at a corresponding angle of 0° in relation to the right side of the antenna. Once in the proper position, the number of times that specific tag was read by the Antenna over a five second time interval was recorded. Next, the individual took an inch step backward and once again recorded the number of times that specific tag was read. This step was repeated in the same line of path until the tag was no longer read by the antenna, which corresponded to the identification tag no longer being seen in the summary page of the software program. And, this distance was recorded. Once the tag was no longer read in that same line of path, the same individual was positioned at an angle of 20° in relation to the side of the antenna. The same procedures were repeated and distance at which the tag was no longer read was recorded. The same procedures until were continued until one obtained read ranges at 180° (other side of the antenna), at intervals of every 20° . The same steps were repeated for the different attenuation levels to be investigated.

Results from this test can be seen in Chapter IV, Section 2, while a visual representation of the protocols can be seen in Appendix C.

Section 4: Test of the presence of the vast array of Passive RFID tags within the testing environment

With a defined read range over a span 180° for the antenna, the user had a sense of where the antenna should be able to read various Passive RFID tags. Thus, to test this notion, I obtained multiple different Passive RFID tags and used the portable hand-held reader to obtain the specific tag identification of each. Next, all the different Passive RFID tags were placed anywhere with the read range measured for the Attenuation Levels of 0, 50, 100, 150, 200, 250, 300, and 350. Once the tags were placed, the software program, provided by Sirit, was used to obtain a summary of the number times each tag was read over a span of different time intervals. The procedure was repeated by simply moving the tags to different locations. By implementing such a test, the user was able to recognize the feasibility of not only reading one specific tag within the read range of the antenna, but whether or not multiple tags could be read simultaneously. Results from this test can be seen in Chapter IV, Section 3 and a visual representation of such a protocol can be seen in Appendix D.

Section 5: Test of the Number of Times a Passive RFID tag is read through different activities

After testing if a Passive RFID tag can be read through a stationary position within the read range, the next test was designed to establish the notion that the tags could be detected and read throughout the events of different activities. For the first activity, I once again obtained a Passive RFID tag and identified the identification number associated with the tag. Next, I allowed an individual to hold the tag and walk around a zone, within the pre-determined read range, for a time interval of 15 seconds to identify if the tag was still being read. In another activity, I asked for an individual to hold the tag and jog around a zone, and then noted the summary of how many times the tag was read. In another activity, a NERF ball was obtained and an incision was made to allow for a Passive RFID tag to be placed within this slot. Next, the NERF ball was thrown at different speeds to see if the ball was read by the antenna as it “passed” by. In order to see a visual representation of these activities, refer to Appendix E. Summarized results can be seen in seen in Chapter IV, Section 4.

Section 6: Construction of Cubic Testing Structure

For the next phase of testing the feasibility of the RFID system as a location tracking system, I wanted to establish a “sensing” surface, which was broken down into small squares of equivalent sizes, which was then able to aide in determining the position of a tagged object. Therefore, to define a sensing surface to test this method’s capability of providing real time location, a cubic testing structure of the size of 9 feet by 9 feet by 9 feet needed to be constructed.

Designing and Manufacturing Cubic Testing Structure

In order to design and manufacture the Cubic Testing Structure, the materials that were needed were the following:

- Total of 144 feet of 1" PVC pipe will be needed
 - o 16 – 6 inch sections of 1" PVC Pipe
 - o 16 – 4 foot sections 1" PVC Pipe
 - o 24 – 4.5 foot sections of 1" PVC Pipe
- 8 – 1" PVC Elbows
- 24 – 1" PVC T-Joints
- 12 - 1" PVC Connectors
- 8 – 8" Cable ties

Since 1" PVC pipes are generally sold with the stock size of ten feet, it was of necessity to measure and cut the original length of the PVC pipe into the desired dimensions. Therefore, for a desired 1" PVC pipe with the length of six inches, a distance of six inches was first measured with a measuring tape. Once a measurement was made to determine the distance, a marker was then used to designate the desired cut length. Next, to obtain the desired portion size of the PVC pipe, a PVC cutter was then used to cut the PVC pipe at the designated mark. The same process was used to obtain a total of 16 sections of 1" PVC Pipe with the length of six inches each, 16 sections of 1" PVC Pipe with the length of four feet each, and 24 sections of 1" PVC Pipe with the length of 4.5 feet each.

To construct this structure, it was highly recommended to begin with creating the lower base. First, I obtained one section of the 1" PVC elbows and attached one section of the six-inch section of PVC pipes to each end. Next, I connect one PVC T-Joint [1"] to the end of each of the six-inch PVC Pipes. Afterwards, a PVC Pipe with the length of 4.5 feet was connected onto the ends of each of the PVC T-Joints. To the ends of both PVC

Pipes, I connected another PVC T-Joint followed by a connection with another PVC Pipe of the length of 4.5 feet. To each ends of these PVC Pipes, I needed to connect another PVC T-joint followed by six-inch long PVC Pipe. I then completed the first half of the base by connecting a PVC elbow to the ends of each of the six-inch long PVC Pipe. In order to complete the second half of the base, I repeated the same procedures that were previously stated and a square-shaped base was established. Once the lower base has been constructed, I created the exact same base, by following the same protocol, to obtain the component for the top of the Cubic Testing Structure.

After the completion of both the lower base and the upper base, I then needed to obtain one of the 1" PVC Pipe of the length of 4.5 feet and attached it, perpendicularly, to one of the PVC T-Joints on the lower base. The same procedure was repeated for the eleven other PVC T-Joints on the lower base. Once completed, I then attached a 1" PVC Connector to each of the 1" PVC Pipes of the length 4.5 feet. Next, I connected the remaining 1" PVC Pipes of the length of 4.5 feet to each of the recently attached PVC Connectors. Finally, to complete the Cubic Testing Structure, I aligned the top base to each of the 1" PVC Pipes of the length of 4.5 feet and then secured the attachment.

Section 7: Evaluating Software Program Provided by Tyler Peabody

Instead of designing a software code with the pre-assigned settings established in the Sirit Program, Dr. Tali Freed suggested discussing my options of how to create a system with the capability of providing a real time location of a Passive RFID tag with Mr. Tyler Peabody. In the conversations, it was recommended to use a program, such as Microsoft Access, to accomplish such a feat. The primary reason for such a recommendation was associated with the notion that Mr. Peabody had previously written a software code, in Microsoft Access, with the sole purpose of tracking the zones in which a Passive RFID tag was located within. Thus, with the similarities between the two projects, Mr. Peabody was kind enough to provide us with his software code as a basic foundation for what my code would need to entail to be able to have a system that would provide for a real time location tracking of a designated Passive RFID tag.

While the software code, in Visual Basic, provided by Mr. Peabody indeed served as a basic foundation for my own software code, it was of importance to evaluate each line of his code to gain a familiarity with not only the programming language, but also the communication pathway that was established between the antennas, reader, and Microsoft Access. Therefore, to establish a systemic environment that could easily be divided into well-established zone regions to track a Passive RFID Tag, the Cubic Testing Structure was of great use in such an evaluation.

Section 8: Initial Evaluation of Mr. Tyler Peabody's Software Code

For the initial evaluation of Mr. Peabody's software code in Visual Basic, it was determined that the Cubic Testing Structure was to be used for the creation of a systematic environment. Since knowing the placement of the Poynting RFID Antennas would have a prominent effect upon the performance of a RTLTS, it was determined that the best placement of these antennas would be at the four corners of the Cubic Testing Structure. At an approximate height of 4.5 feet, I used two cable ties to attach the Poynting Antenna to the PVC Pipes at the corner of the Cubic Testing Structure. This procedure was repeated for the other three Poynting Antennas at each respective corner of the Cubic Testing Structure.

Upon completing the attachment of the four antennas to the Cubic Testing Structure, one needed to establish a communication between the Sirit Reader and each of the four Poynting Antennas. Therefore, for one of the four Poynting Antennas, a BNC cable was obtained and one end of the cable was attached to the Antenna, and the other end of the BNC cable into Input 1. Under a clockwise direction, the user moved from the first corner of the structure to the next corner of the Cubic Testing Structure. Once again, the BNC cable was attached to the corresponding Antenna and the other end placed into Input 2 of the Sirit Reader. The same protocol was followed for the third and fourth Poynting Antennas, while remembering to go in a clockwise direction and placing the other end of the BNC cable into the Input that corresponded to the numerical order previously established in this process. After ensuring that all antennas were connected to the Sirit reader, an Ethernet cord was used to establish a

communication pathway between the laptop and the Sirit Reader. Finally, the corresponding power-cord from an electrical outlet was connected to the Sirit Reader. Once the connection had been made, it was ensured that the proper internet protocol [IP] address of the Sirit Reader, which was identified on the device itself, was in correlation with the designated laptop that was to be used prior to any usage. If proper connections were made, the Sirit Reader displayed three lights that were illuminated in green. Otherwise, one of the three lights had to be illuminated in green, and the user had to ensure that all connections were properly made.

However, prior to being able to test the capability of the software program provided by Mr. Tyler Peabody, it was of essence to first gain an understanding of the programming language, in Visual Basic, that was utilized. In order to accomplish such a feat, it was recommended to go from line to line, within the code, and identify the primary commands of each line. Once the primary commands had been identified, research tools, such as Microsoft Access Help Tool and the Internet, were used to gain some insight regarding the basis and purpose behind each command, as the action that is takes place due to the command. Table 2 illustrates the commands that had an imminent role within the original software code:

Table 2: Commands within Microsoft Access 2007

<u>Command</u>	<u>Action</u>
Option Compare	A command used to instruct Visual Basic on how to make string comparisons
Option Explicit	A command that is used to force an explicit declaration of all variables
Private	Command that allows for the creation of a variable that can be read only in its own procedure, according to where the declaration took place within the code
Boolean	A data type that is able to contain two distinct values such as being true or false, yes or no, or on or off.
Dim	Command that allows for the creation of an array
As String	A data type that is representative of a series of characters.
Single	A data type that is representative of a single character.
Sub	A command that is able to define a procedure which can allow for the execution of a block of code
If, Then, and Else	All three are commands that are able to perform a code based on the results of a specified test
Call	A command that allows for a specific command to occur.
End	A command that will immediately stop the execution of a command
Ubound	A command that ensures the return of the upper dimension of an array
Lbound	A command that ensures the return of the lower dimension of an array
Locate_tags	A command that finds the desired tag

Understanding the commands of the software code, however, did not provide sufficient enough knowledge to fully comprehend how, such a software program, was able to provide information regarding the real time location of an object. Instead, an analysis had to be conducted on the sequential placement of each command within the software code, and how such a chronological order, of these commands, had a prominent affect upon the performance and functionality of the entire system. In essence, if one placed a specific command prior to another command within the code, there was a distinct possibility that the system would function in a different manner than that of which was desired. By recognizing this importance, focus was then placed upon creating a visual representation of the progression of steps, between all the different components of the entire Passive RFID System, which were of essence in being able to provide an analysis of the real time location of an object. Therefore, the initial schematic, seen in Figure 21, was simply based upon having a conceptual understanding of the sequential order of the commands used within the software code designed by Mr. Peabody.

Figure 21: Visual Schematic of How Tyler Peabody's Software Code Functions

While the schematic above represents the entire pathway, in which I believed the software code was able to detect the location of a Passive RFID Tag, it was of importance to note that the visual representation was still an educated estimation of the entire process based upon knowledge on the progression of commands within the code. Nonetheless, such a pathway was verified through the process of debugging each line of the software code. In order to begin this verification process, it was first ensured that each antenna was properly connected, with the BNC cords, to the Sirit Reader as

stated previously. Similarly, it was ensured that the Sirit Reader and the laptop had established a communication pathway through the attachment of the Ethernet cord.

Next, the user opened the designated file ('ZoneTracker.aacdb') with the program Microsoft Access 2007. Once the program had been opened, the "Database Tools" Tab was chosen and "Visual Basic" was selected. By doing such a procedural step, one recognized that a new "Microsoft Visual Basic" window then appeared and contained the entire software code in the text window. Before continuing, the user went back to the Microsoft Access and ensured that the visual representation of the location tracker of the object was present. An image of such a screen is seen in Figure 22.

Figure 22: Graphical Summary of the Location of Tracked Object in Microsoft Access 2007

If not, one would need to expand the "Unrelated Object" tab on the toolbar on the left column. Under this tab, double click the "Zone Tracker" option to see the desired visualization. In order to view the graphical summary of the location of the tracked object and the code simultaneously, have both the Microsoft Access window and

Microsoft Visual Basic window side by side on the computer screen. Once the desired view had been obtained, I began the debugging process by clicking the “Connect” button, followed by the “Start Tracking” button within the Microsoft Access window. While the tracking process was activated, one could place “debug” markers in the software code by identifying the line of code that was to be evaluated and a marker was placed on the left column by simply clicking the left button of the mouse.

Through an understanding of the purpose of each command and debugging the software code while it was running, such a process allowed for a confirmation of how the software code was able to track an RFID Passive Tag within the designed environment. Once the user selected the “Connect” button followed by the “Start Tracking” button, the software code first went through an initialization phase. In this initialization phase, the software code first determined whether or not there already existed a communication pathway. If not, the computer established and activated a communication pathway between the computer and the reader. Once this procedural step had been accomplished, the code sent a command to the Sirit Reader to process a signal to establish the communication pathway between the reader and the four antennas.

Following the establishment of these communication pathways, the software code entered the “read phase.” In this phase, a specific line of software code allowed for the user to modify the settings of the attenuation levels of each Poynting Antenna. Similarly, another line of the code identified the identification number of the desired RFID Passive Tag that would be tracked. Once the code surpassed these specific

command lines, the next command was associated with requiring the Sirit Reader to allow for all four antennas to be in the continuous process of reading the desired tag.

While the antennas were continuously tracking the desired tag, the software code also had an “evaluation phase.” In such a phase, there was a command line, within the code, that provided correspondence between the identification number of the tag and a designated image. This image had great importance as it could then be displayed, within the Microsoft Access window, which would provide nine different zones in which the tag could potentially be in. However, to approximate the location of the tag, the software code had a command in which the reader analyzed which antennas were able to recognize the desired tag. More specifically, below were the scenarios in which the antennas may read the tag, and the corresponding regional zones can be seen in Figure 23:

- Zone 1: Read by Antenna 1 only
- Zone 2: Read by Antenna 1 and 2 only
- Zone 3: Read by Antenna 3 only
- Zone 4: Read by Antenna 1 and 3 only
- Zone 5: Read by Antenna 1, 2, 3 and 4
- Zone 6: Read by Antenna 2 and 4 only
- Zone 7: Read by Antenna 3 only
- Zone 8: Read by Antenna 3 and 4 only
- Zone 9: Read by Antenna 4 only.

Figure 23: Regional Zones of Environmental Setting

Once the reader was able to determine which antennas were able to read the desired RFID Passive Tag, the reader sent the analysis to the computer to interpret the results. The interpretation was seen through the visual display within the Microsoft Access window. With an image associated with the tag, the image was then placed within the corresponding zone that was previously determined by the reader. Such a process continued to be repeated until the user selected “Stop Tracking” to turn off the activation of the reader to signal the end of the experimental testing run.

Section 9: Evaluating Performance of Tracking RFID Passive Tag with Software Code by Tyler Peabody

With an understanding of the sequential order of the commands, within the software code, and how it was able to function in unison, an evaluative test was conducted on its performance on tracking a RFID Passive Tag. In this specific test, an approach similar to that of the Landmarc study was implemented as the user assigned each Poynting Antenna with a pre-determined attenuation value that represented the correlation associated with the received signal strength [RSS] that was needed for the reader to obtain information regarding a desired tag on an object. In essence, the attenuation levels of the four RFID readers were used as a characteristic that provided a broad definition of different regional zones in a room or environmental setting. Thus, with this unique feature, the desired tag was identified into a specific zone by determining which antennas, simultaneously, were able to promptly read the desired tag within the environmental setting.

To establish the regional zones within the environmental setting, the user decided upon using a specific attenuation level for all four Poynting Antennas. Once this attenuation level had been determined, the regional zones were created by first determining the read range of each of the antennas. In order to accomplish such a feat, an Avery Dennison [AD]-224 RFID Passive tag was obtained and a portable hand-held reader was used to identify the identification number of that specific tag. Next, the software code in Visual Basic was accessed and the identification number was placed into the command that identified the tag that was supposed to be tracked. Afterwards, an attenuation level was proposed to be used for the performance test. User then accessed the software code within Visual Basic, and the command line, in which the attenuation levels of each Poynting Antenna could be modified, was identified. The attenuation was then set for Antenna 1 [antenna connected to input 1] to the desired attenuation level of 100 and the other three antennas to the maximum attenuation level value of 350. Testing then began with the individual holding the tag flesh with the side of the antenna, which was at a corresponding angle of 0^0 in relation to the side of the antenna. Once in the proper position, the number of times that specific tag was read by the Antenna over a five second time interval was recorded. Next, the individual took a one-inch step backwards and once again the number of times that specific tag was read was recorded. This step was repeated in the same line of path until the tag was no longer reader by the antenna, which corresponded to the identification tag no longer being seen in the summary page of the software program. And, this distance was recorded. The same procedural step at an angle of 90^0 , with respect to the other end of

the antenna, was repeated and the corresponding distance was measured. Since each antenna could potentially have different read ranges due to an array of reasons, it was highly recommended to repeat steps to determine the specific read range of each Poynting Antenna within the environmental setting.

Once the read ranges had been determined for the four Poynting Antennas at an attenuation level of 100, regional zones were then established within the environmental setting. In order to construct such a zone, the process began with Antenna 1 and a measuring tape was used to identify the maximum read range of the antenna [from the direction of Antenna 1 to Antenna 2]. To indicate the max distance, a tape was placed on the ground at that specific distance and was considered as length $[L_1]$. Next, once again the measuring tape was used to identify the maximum read range of Antenna 2 [from the direction of Antenna 2 to Antenna 1. This distance was indicated with another piece of tape and this distance was referred to as length $[L_2]$. To determine the zone between Antenna 1 and Antenna 2, the guidance of the placements of the tape was used. With this, it was determined that Zone 1 would only be the region that corresponded to $[L_1]$, while Zone 2 corresponded to the overlap of the lengths $[L_1 - L_2]$, and Zone 3 was the length that only was L_2 . Figure 24 represents how the zones were conducted with this protocol. Next, these procedural steps were repeated for each side of the Testing Cubic Structure [i.e. for the side of Antenna 1 and Antenna 3, Antenna 2 and Antenna 4, and also Antenna 3 and Antenna 4]. By doing this, nine distinct zones were established as the “regional zones” of the environmental setting.

Figure 24: Creation of Zone 1 and Zone 2 for the Environmental Setting of System

Following the establishment of the regional zones, an analysis was conducted on the performance of tracking the location of an object. The user accessed the software code through Visual Basic and modified all four Poynting Antennas to each have the identical attenuation level. The attenuation level chosen corresponded to the desired size of the regional zone for the systemic environment. Next, it was ensured that the proper identification tag number had been classified within the command that sought the tag being tracked. Once these settings had been established, the individual stood within Zone 1 and held the RFID Passive Tag at chest level facing the front direction. Once settled within that position, the user selected “Start Tracking” to begin the communication pathway of the entire system. For a time period of 5 seconds, it was recorded whether or not the software code [through the visual representation seen in

Microsoft Access] was able to recognize that the RFID Passive Tag was indeed within Zone 1. Accuracy was defined to be the ability of the software code to properly depict, in the Microsoft Access Interface, the regional zone in which the tag was within. After the first time interval, the individual then moved into Zone 2 holding the tag in the exact same position and direction and once again the accuracy of the detection process was recorded. The same procedures for each of the nine zones were repeated. Once completed, the user selected “Stop Tracking” to deactivate the communication pathway.

While a RFID Passive tag could be located within the read range of the antenna, the antenna component did not always read the tag. Potential reasons included the directionality of the tag, as well as the possibility that the signals from the antenna had to go through the human body. Therefore, these reasons were believed to have a prominent effect upon the tracking the desired RFID Passive tag, thus testing protocol also considered the directionality of the tag being located. Therefore, as performed with the front direction, the same procedural steps were conducted for the backward (Direction 2), left (Direction 3), right (Direction 4), 45° (Direction 5) and 135° (Direction 6) directions. For visual clarification of these directionalities, one may reference Section 6 in Appendix.

Aside from the directionality of the tag, another factor that was presumed to have a prominent effect on the performance of the system was the height level of the antenna in comparison to the height of the RFID Passive Tag being tracked. Thus, to manipulate different height scenarios, all four antennas, within the Testing Cubic Structure, were

moved to a distance of one-foot higher than where the user had a tendency to hold the Passive RFID tag. At this specific height, the performance of the software code was then evaluated for all nine regional zones with all six corresponding directions that were previously tested. In a similar capacity, all four antennas should then be placed at a distance of one-foot lower than where the user has a tendency to hold the Passive RFID tag. By manipulating a change in the height of the antenna, the user was able to evaluate whether or not straight line of sight between antenna and the tag allowed for maximum accuracy in reading the tag. A visual example of the three heights can be seen in Appendix G.

While using the Testing Cubic Structure was able to provide a good testing environment, it was important to note that there existed a limitation. It was associated with the notion that the testing environment were neither able to expand nor shrink since the antennas were in a fixed position, and thus the attenuation level remained at a value of 100. However, it remained pertinent that the attenuation level values must be evaluated to investigate the performance of the system. Thus, it was highly recommended that the same procedural steps were conducted with the four RFID Antenna Placeholder Stands. More specifically, under each attenuation level, an environmental setting was created as done previously, and then the performance of the system was tested under different scenarios, such as with the six different directionalities and different height levels. To reference a more in-depth description of the procedures, please reference Appendix H. Results from these tests could be seen in Chapter IV, Section 5.

CHAPTER III: MODIFICATIONS TO COMPUTER SOFTWARE PROGRAM

The goal of this study was to be able to establish a RFID system that was able to provide real time location tracking of a pre-determined object. The software code, designed by Mr. Tyler Peabody, provided a substantial basis in accomplishing such a feat. However, there existed several persistent problems, which ultimately prevented the software code from being ideal for this specific purpose and goal. The most prominent problem consisted of the inaccuracy of the code to read the RFID Passive Tag within each regional zone, as indicated by the inability for the software code to display the tag within the proper zone in the Microsoft Access Interface. While there were instances in which the antennas were able to accurately recognize the tag in the proper zone, the problem became associated with a consistent delay of the visual display of the tag in Microsoft Access. Even with these limitations, there still remained optimism in using RFID components as a real time location tracking system. Thus, significant modifications, to the software code, were considered to improve the performance of the RFID system.

Section 1: Modifications for Ease of Operability of System

An important component of the software code entailed the ability to modify the attenuation levels of each antenna to obtain the desired read range for the testing environment. As previously stated, this specific modification process required for the user to access the software code in Visual Basic and then promptly identifying the command line to modify such a setting. However, such a procedural step limited the ease of operability of this RFID location tracking system. Thus, to establish a more user-

friendly operating system, the user no longer had to identify the specific command line, within the software code, to change the attenuation level. Instead, such a modification setting should be able to be altered in the same Microsoft Access Interface that allowed for the user to view the graphical summary of the location of the tracked object. In order to accommodate such an alteration, the software code was modified in a manner that contained two distinct command lines that both feature the input function. The first “input” command function was associated with a specific text box within the Microsoft Access interface, in which the user was be able to type in the numerical identification of the antenna into the textbox. The second “input” command featured the ability for the user to indicate, within the Microsoft Access interface, the attenuation level in which each of the previously identified antennas possessed. Once complete, the user was able to select the newly established “Set Attenuation” button that enabled the software code to acknowledge and accept the new systemic settings.

In a similar manner, the user could potentially experience some complexity in directing the RFID real time location tracking system in identifying the desired tag to be tracked. Once again, it was recognized that the original software code was designed for the user to be able to identify the specific command window that acknowledged the identification number of RFID Passive Tag to be read. However, such a process could be further simplified. As was done with the attenuation levels, the input function was once again utilized to allow for the user to adjust the identification number of the RFID Passive Tag desired to be tracked. The “Student Info” tab was constructed within the Microsoft Access interface. Within this specific tab, the user was be able to type in the

identification number for the desired Passive RFID tag within the textbox instead of modifying the identification number within the software code in Visual Basic. Once the user completed this task, the software code recognized the specific Passive RFID tag was the one to be tracked once the “tracking” process was initiated.

Section 2: Modifications for Delay of Visual Representation in Microsoft Access Interface

In earlier studies conducted with the original software code, experimental results had indicated that there existed several significant issues regarding the performance of the RFID real time location tracking system. Therefore, modifications to the code had to extend beyond just making the system easier to operate for the user, but in a way that would enhance the performance of the system. One prominent issue that was noted was associated with the notion that there were instances in which the antennas were indeed able to identify the proper regional zone that the desired tags was located within. However, the visual representation, seen on the Microsoft Access, was often delayed in providing a precise real time location of the tag.

In order to resolve this persistent issue, debugging protocols were first conducted upon the “evaluative” phase of the code, which included the command lines that were designated to inform how the software would identify the tag within the appropriate regional zone. As the reason stated previously, this approach was indeed quite pertinent as it provided significant insight upon the process of how the software code truly was functioning. It was recognized that one cycle, which took up to a tenth of a second, was defined as the completion of each of the four antennas broadcasting a signal in an

attempt to read the Passive RFID tag being tracked. Once a cycle had been completed, the software code then underwent a process that analyzed the approximate regional zone in which the object was supposedly located. However, over a time interval of one second, there were approximately ten cycles that occurred. As the number of cycles continued to accumulate over an extended time period, the software code was unable to remain on pace in processing the information and often caused for a delay in the display of the location of the object in the Microsoft Access Interface.

Aside from the overload in analyzing each cycle, the debugging process also illustrated that another prominent affect on the delay of the visual representation was associated with another feature of the software code. More specifically, while the software code was primarily designed on locating the identification number of the desired Passive RFID tag, it still possessed the ability to recognize other Passive RFID tags located within the vicinity of the environmental setting. Even though these specific tags were not acknowledged within the “evaluation” process of the software code, a database was still established, within the Microsoft Access interface, and stored these identification tag numbers within its memory. This additional feature contributed to the delay of the visual representation seen in Microsoft Access.

In order to enhance the response of the visual representation seen in Microsoft Access, modifications to the original code were considered. First, it was highly reasonable to believe that there existed no purpose in maintaining a database that stored the identification numbers of other existing tags, which were located within the vicinity. Therefore, initial efforts were placed upon eliminating such a feature within the

software code. Upon removing the command line responsible for such a feature, it was immediately seen that all antennas, within the environmental systems, were still able to recognize these undesired RFID Passive tags. However, these identification numbers of those undesired tags were no longer being stored within a database established in Microsoft Access, but were rather disregarded by the software code. Such a modification was important as the software code allowed for not only an alleviation of the memory space within Microsoft Access interface, but a greater ability for the system to focus upon locating only the desired RFID Passive Tag that had been acknowledged within the software code.

Yet, even though such a modification showed an enhancement in the performance of the system, it was still of great importance to note that such an alteration only had a minimal effect upon the response time of the visual display. In fact, such an improvement was only seen in the early phases of the testing time interval, as there were only a limited number of cycles in which the software code had to analyze. Once the interface encountered a compilation of additional cycles to evaluate the location of the tag, the system no longer was able to remain proficient in providing such an analysis. As a result, there remained a significant delay in showing the location of the tag on the visual representation in the Microsoft Access interface.

In an attempt to resolve this dilemma, modification was considered with the primary definition of “cycle” within the software code. As previously stated, the original software code consisted of identifying a “cycle” as the process in which each of the four antennas was required to broadcast a signal, under a sequential order, in an attempt to

read the Passive RFID tag being tracked. Once a cycle had been completed, the RFID reader processed which antennas were able to recognize and read the tag being tracked. Such an analysis was transmitted to the visual representation within the Microsoft Access interface. This process continued to occur until the entire system was required to “Stop Tracking.”

To address the limitation, one potential solution was introduced. In such a proposed solution, modification was conducted upon the command line that identified the definition of a “cycle.” As one cycle occurred every tenth of a second, the system had a significant delay in response due to an abundance of cycles being evaluated. Therefore, the suggested modification involved an increase in the time interval of each cycle. More specifically, the new cycle was defined as each of the four antennas broadcasting a signal, under a sequential order, for not only one round, but rather for a process of ten rounds. With such a modification, the software code no longer had to evaluate and display the results onto the interface after just one round, or every tenth of a second. Instead, data was acquired, regarding which antennas recognized the tag being tracked, every second and then results were stored within a database. After ten rounds, an analysis was conducted on the results stored in the database. If results indicated that an antenna were able to recognize the Passive RFID tag all ten rounds, within that cycle, then the object was placed into the corresponding regional zone in the visual representation seen in the Microsoft Access interface. Otherwise, if none of the four antennas were able to recognize the tracked tag for at least all ten rounds, then the

visual representation suggested to the user that the tag is “out of range” and was believed to not be located in any of the regional zones.

Aside from the modification of the definition of the cycle, another prominent change to the software code included the implementation of what was referred to as the “delay” feature. Again, as the goal remained to be alleviating the reader from processing too much analysis simultaneously, the “delay” feature allowed for the reader to have a pre-determined time interval that distinctly separates two vastly different cycles. This time delay interval, suggested to be about 50 milliseconds, allowed additional time for the reader to analyze the data prior to advancing to another cycle that was to be analyzed.

The modification in the meaning of the term “cycle,” as well as the addition of the “delay” feature, in the software code enabled the system to encounter fewer cycles to analyze the approximate position of the RFID Passive Tag being evaluated. As there were fewer cycles and more time between each cycle, the entire system was able to properly maintain a consistent response time for each analysis and this resulted in consistent display of the location in the visual representation without any delay. While these two modifications promoted a more rapid response time to depict the location of the object within the visual representation, the accuracy of the system remained quite suspect.

Section 3: Modifications to Enhance Performance of RFID Real time Location Tracking System

After being able to enhance the response time for the visual schematic of the location of the object, the focus was then shifted toward developing the accuracy of the entire system to provide the precise real time location of the object. At this point in time, the accuracy remained quite limited since results showed that it was a rarity for any of the four antennas to recognize the identification number, of the desired tag, for all ten rounds of each cycle. With this limitation, it was then suggested that modifications were then made to incorporate a command line that identified a new feature referred to as a “cutoff point.”

While a cycle continued to consist of ten rounds of each antenna broadcasting a respective signal, a “cutoff point” was incorporated into the software code. In essence, this new feature allowed for the user to determine whether or not each antenna was able to read a tag all ten times during a cycle to conclude that, with an absolute certainty, the tag was in a specific regional zone within the environmental setting. If it was verified that such a value was indeed quite excessive, the user was given an opportunity, with the “cutoff point” command, to modify such a value to another distinct integer value, which was considered as the “new” acceptable level of reads, for each of the four antennas. Therefore, once a cycle had been completed, the reader determined which antennas were able to recognize the identification number, of the tracked tag, for the desired “cutoff point.” Once such an analysis was complete, the reader provided a communication with the software code. Next, the proper regional zone was determined, through the definitions established within the software code,

before promptly displaying the results on the visual schematic seen in the Microsoft Access Interface.

Following the addition of the “cutoff point” feature within the system, it was suggested that the ease of recognizing the end of cycle could be had by simply having a counter display on the visual representation seen in the Microsoft Access Interface. Thus, five distinct textboxes were designed in this specific interface. The first textbox, showed a visual display of the number of rounds that had been completed within that cycle. With such a display, the user was able to easily recognize when a cycle was about to begin or end. In regards to the other textboxes seen, each textbox corresponded to an Antenna in the environmental setting. Each of these textboxes was able to display a counter of how many times each antenna was able to recognize the tag being tracked within the corresponding cycle.

With the establishment of the counter display, I conducted a test to evaluate an acceptable “cutoff point” value for this specific RFID Real time Location Tracking System. More specifically, the test was designed to evaluate the performance of the system at different integer values between 1 and 10. Thus, it was recommended that testing procedures were once again replicated to those conducted previously in this study. More specifically, I first evaluated the “cutoff value” at the integer value of 10. Once the appropriate settings were properly identified in the software code, an individual was asked to stand within Zone 1, and held the RFID Passive Tag at chest level facing the front direction. Once settled within that position, the user selected “Start Tracking” to begin the communication pathway of the entire system. After the completion of each

cycle, which was indicated by the counter feature that was implemented, the user was asked to record whether or not the software code [through the visual representation seen in Microsoft Access] was able to recognize that the RFID Passive Tag is indeed within Zone 1. After recording the corresponding data, the individual moved into Zone 2 holding the tag in the same orientation. The same procedures were repeated for each of the nine zones. Once completed, the user selected “Stop Tracking” to deactivate the communication pathway. This protocol was repeated for other integer values that were in existence between 1 and 10 [Results from such an analysis can be seen in the Results Section]. Ultimately, it was recognized that the most accurate results were obtained with the “cutoff value” of 3, and therefore was used in this software code. Nonetheless, it was important to note that the user may change this value in the software code if desired. Please Reference Appendix J for A Guidance for the Visual Display Seen in Microsoft Access 2007.

CHAPTER IV: EVALUATION OF MODIFICATION TO COMPUTER SOFTWARE PROGRAM

Even though each modification was believed to ensure an enhancement in the performance of the system, in providing a real time location of a desired object, results were still needed to validate such a claim. Therefore, it was of importance to note that it was highly recommended that the evaluative protocols remained consistent without any significant modifications to establish a correlation between each test. With this in mind, the exact same procedural steps, used to evaluate the original software program, were once again conducted for this specific study. These protocols were previously referenced in Appendix H. While the same procedural steps were implemented in this study, different circumstances were considered and evaluated.

Section 1: Evaluating the Performance of Tracking One Singular Object [with one Passive RFID tag]

The primary purpose of this study was to provide a form of assistance in allowing for an individual, with a visual impairment, to recognize their precise location within an environmental setting. Therefore, with this specific RFID real time tracking location system, the first evaluative performance was conducted upon the accuracy of tracking one singular object, which would be a human subject. However, there were different factors which had profound impact upon the read accuracy of the system. It was also these factors, listed below, that had to be taken into consideration when evaluating the performance of tracking one singular object with only one Passive RFID tag.

- **Different Attenuation Levels of Each Antenna:** The attenuation levels of each antenna had a prominent role, upon this specific system, as an alteration in such a factor affected the read range distance of each antenna. With this, the user had to determine the appropriate read range distance, that best suited the systemic environment, by choosing an attenuation level between the values of 0 [maximum read range distance] to 350 [minimum read range distance].
 - For this specific study, a systemic environment was created with the attenuation levels of 0, 15, 30, 50 and 100 for each of the four antennas. This allowed for distinguishing the maximum read range of the antenna at each of the four levels of attenuation, as well as the accuracy of tracking a singular object by not only maximizing the size of the testing environment, but also by reducing the size of such an environment.
- **Directionality of Passive RFID Tag:** Another potential effect upon the accuracy of this real time tracking location system was the directionality of the Passive RFID tag. While it was known that an individual possessed a Passive RFID tag, it was important to note that not only did the position of the object affect the accuracy of being able to distinguish the location of the object, but also the directionality of the tag.
 - In order to assess the effect of such a factor, the human test subject was asked to remain in the same location of a regional zone, but under six vastly different directions. Images of these directions could be seen in Appendix I.

- **Height Location of Each Antenna:** Similar to that of the directionality of the Passive RFID Tag, the height difference of the antenna, in comparison to that of the tag, was said to be a factor that could alter the accuracy of the system. The reason for this was that readings were more precise if there was a straight line of sight between the tracked Passive RFID tag and the corresponding antennas.
 - Therefore, to investigate such a claim, the three distinct heights were used for each antenna. The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag. The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag. Finally, the third height was one-foot below the straight line of sight to the Passive RFID tag. Visual Representation of different heights can be seen in Appendix G.

Section 2: Evaluating the Performance of Tracking Two Objects Simultaneously [with one Passive RFID tag each]

If an individual, with a visual impairment, were to participate in an activity, such as the sport of basketball, the focus of a real time location tracking system should not be solely based upon identifying the location of just the individual. Instead, it should have the capability of simultaneously being able to track a second object, whether it was another individual or a basketball. In this specific evaluation, each object was identified through only one distinct Passive RFID tag each. Once these tags had been identified, the accuracy of the system was then be evaluated. More specifically, the same factors

that were previously analyzed, in the performance of just tracking one object, were all evaluated for tracking two objects simultaneously. Results can be seen in Appendix R.

Section 3: Evaluating the Performance of Tracking One Singular Object with Multiple RFID Passive Tags

Within the modifications of the new software program, the user now had the ability to recognize a single object with multiple RFID Passive Tags. With such a capability, it was investigated whether or not the performance of the real time location tracking system was enhanced. Thus, in this specific analysis, the user identified a singular object with multiple tags. In the first scenario, a singular object was identified with two different RFID Passive Tags. In the second and third scenarios, a singular object was identified with three and four different RFID Passive Tags, respectively. However, for each scenario, each factor that was considered previously must once again be evaluated. Data was analyzed by identifying the accuracy results from each scenario and results were compared to the performance of tracking one singular object with just one RFID Passive Tag.

CHAPTER V: RESULTS

Section 1: Feasibility Test with RFID System Components

Aside from gaining a sense of familiarity with the array of Radio Frequency

Identification components at PolyGait, a feasibility test was conducted to assess the potential of such a system in being able to first recognize the different tags present within the environmental setting. Therefore, as stated previously, one of the Passive RFID Antenna Placeholder Stand and the pre-assigned program setting, by Sirit, were used to conduct such a feasibility test. Table 3 to Table 6 consists of results of not only the identification number of tags recognized by the Antenna within its read range, but also a numerical count of how many times each of those tags were read over a specified period of time.

Table 3: Feasibility Test for Time Interval of 5 Seconds

	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
	0504300800000000000000BFB	145
	0504300800000000000000BF7	97
	0504300800000000000000BFC	83
	0504300800000000000000BFD	2896
	0504300800000000000000CFF	61
	0504300800000000000000CFG	568
	0504300800000000000000DFA	103
	0504300800000000000000DFB	611
<u>Total Reads:</u>	---	4564

Table 4: Feasibility Test for Time Interval of 15 Seconds

	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
	0504300800000000000000BFB	583
	0504300800000000000000BF7	434
	0504300800000000000000BFC	603
	0504300800000000000000BFD	7895
	0504300800000000000000CFF	252
	0504300800000000000000CFG	1873
	0504300800000000000000DFA	463
	0504300800000000000000DFB	1967
<u>Total Tags Read:</u>	---	14,070

Table 5: Feasibility Test for Time Interval of 30 Seconds

	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
	0504300800000000000000BFB	1233
	0504300800000000000000BF7	1347
	0504300800000000000000BFC	2034
	0504300800000000000000BFD	15,343
	0504300800000000000000CFF	897
	0504300800000000000000CFG	3,278
	0504300800000000000000DFA	923
	0504300800000000000000DFB	3,92
<u>Total Tags Read:</u>	---	28,597

Table 6: Feasibility Test for Time Interval of 60 Seconds

	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
	0504300800000000000000BFB	2583
	0504300800000000000000BF7	2868
	0504300800000000000000BFC	4,239
	0504300800000000000000BFD	30,113
	0504300800000000000000CFF	2,980
	0504300800000000000000CFG	6,432
	0504300800000000000000DFA	2,004
	0504300800000000000000DFB	7,894
<u>Total Tags Read:</u>	---	59,113

While the specific feasibility test was designed to determine the number of times a Passive RFID Tag was read within the range of a Poynting Antenna, it was implemented with different time intervals. Table 3 represented data that was obtained for a time interval of 5 seconds, while Table 4, 5, and 6 represented the time interval of 15 seconds, 30 seconds, and 60 seconds respectively. Even though each of the feasibility tests was conducted with different time intervals, it was evident that there were 8 distinct Passive RFID tags that were continuously identified within the read range of the Poynting Antenna that was used. Under each of the test scenarios conducted in the test, it was seen that all eight of the Passive RFID tags were not read for an identical amount of times. Instead, some tags were read more often than others, as the Passive RFID Tag with the identification number of “0504300800000000000000BFD” was read the most frequently in each of the time intervals. The reason for this could be attributed to the notion that specific tag was closer in proximity to the antenna in comparison to the other tags. As expected, it was seen that, with an increase in the time interval, each of the Passive RFID tags were read at greater quantities.

Section 2: Test of the range of how far the Antenna is able to read a Passive RFID Tag

By simply changing the attenuation levels, one was able to modify the read range of each of the Poynting Antennas. In order to approximate the read range, a protocol was previously established to determine the read distance, at not only a specific attenuation level, but also at different angles. In order to have a standardized measurement for the read distance at each attenuation level, Figure 25 is a depiction of the definition of angles used in this specific protocol. More specifically, 0° was defined to be at the right side of the antenna, the angle of 90° was perpendicular, and the angle of 180° was seen to be at the left side of the antenna. Results from this study are then seen in the Table 7.

Figure 25: Angle Measurement for Poynting Antenna

Table 7: Measured Read Distance at Various Attenuation Levels

Attenuation Level	Angle									
	0⁰	20⁰	40⁰	60⁰	80⁰	100⁰	120⁰	140⁰	160⁰	180⁰
0	90.0 in	90.70 in	91.10 in	91.25 in	91.8 in	92.00 in	91.05 in	91.10 in	90.80 in	90.00 in
50	75.3 in	76.10 in	76.50 in	76.80 in	77.0 in	77.00 in	76.80 in	76.45 in	76.10 in	75.40 in
100	51.2 in	51.60 in	51.80 in	52.00 in	52.2 in	52.30 in	52.10 in	51.80 in	51.50 in	51.20 in
150	32.4 in	32.50 in	32.65 in	32.80 in	33.0 in	33.00 in	32.85 in	32.70 in	32.50 in	32.35 in
200	21.6 in	21.80 in	22.00 in	22.10 in	22.3 in	22.25 in	22.20 in	22.10 in	21.75 in	21.60 in
250	12.5 in	12.65 in	12.80 in	12.90 in	13.0 in	13.00 in	12.95 in	12.80 in	12.60 in	12.50 in
300	4.00 in	4.20 in	4.25 in	4.30 in	4.45 in	4.50 in	4.40 in	4.30 in	4.20 in	4.00 in
350	1.00 in	1.10 in	1.20 in	1.20 in	1.50 in	1.45 in	1.20 in	1.20 in	1.10 in	1.00 in

From Table 7, it was quite evident that the greatest read range distance was seen at an attenuation level of 0 as a read range spanned from a distance of between 90 inches to 92 inches. More specifically, the minimum distances were seen at both ends (sides) of the antenna, while the maximum distance was seen at an angle of 90⁰, which was perpendicular to the sides of the antenna. Nonetheless, even though there were slight differences in the read distance at various angles, at an attenuation level of 0, it was quite evident that the read range span seemed to represent that of a hemisphere. This similar pattern continued to be seen at different attenuation levels. In addition, as the attenuation levels were increased, it was recognized that the read range distance continued to decrease significantly.

Section 3: Test of the presence of the vast array of Passive RFID tags within the testing environment

By establishing the maximum distance that the antenna may read at different angles, the user was able to obtain an approximate read range that the antenna was able to identify not only one Passive RFID tag, but rather multiple tags. Therefore, as stated within the protocol stated in Chapter II [Section 5], five distinct tags were placed within the read range of the antenna, which had a pre-defined attenuation level. After a time interval of 15 seconds, it was then determined whether or not each of the five distinct Passive RFID tags were read by the antenna. This was repeated three times for each attenuation level. Results can then be seen within Table 8.

**Table 8: Summarized Table of Number of Tags Read Within Testing Environment
Under Different Attenuation Levels**

<u>Attenuation Level</u>	<u>Test Run Number</u>	<u>Passive RFID Tags</u>					<u>Total Tags Read</u>
		<u>Tag #1</u>	<u>Tag #2</u>	<u>Tag #3</u>	<u>Tag #4</u>	<u>Tag #5</u>	
0	1	1	1	1	1	1	5
	2	1	1	1	1	1	5
	3	1	1	1	1	1	5
<u>Total Tags Read:</u>		3	3	3	3	3	---
50	1	1	1	1	1	1	5
	2	1	1	1	1	1	5
	3	1	1	1	1	1	5
<u>Total Tags Read:</u>		3	3	3	3	3	---
100	1	1	1	1	1	1	5
	2	1	1	1	1	1	5
	3	1	1	1	1	1	5
<u>Total Tags Read:</u>		3	3	3	3	3	---
150	1	1	1	0	1	1	4
	2	1	1	1	1	1	5
	3	1	1	1	1	1	5
<u>Total Tags Read:</u>		3	3	2	3	3	---
200	1	1	1	1	0	1	4
	2	1	1	1	1	1	5
	3	1	1	0	1	1	4
<u>Total Tags Read:</u>		3	3	2	2	3	---
250	1	0	1	1	1	1	4
	2	1	1	1	1	1	5
	3	1	1	1	1	1	5
<u>Total Tags Read:</u>		2	3	3	3	3	---
300	1	1	1	1	1	1	5
	2	1	1	1	1	1	5
	3	1	1	1	1	1	5
<u>Total Tags Read:</u>		3	3	3	3	3	---
350	1	1	1	1	1	1	5
	2	1	0	1	1	1	4
	3	1	1	1	1	1	5
<u>Total Tags Read:</u>		3	2	3	3	3	---

As seen in Table 8, three distinct test runs were conducted for each of the pre-determined attenuation levels. However, for each of the three test runs, the five distinct Passive RFID tags were placed in different locations within the acceptable read range determined in Table 7. At attenuation levels of 0, 50, 100, and 300, it was seen that each of the Passive RFID tags were properly distinguished by the Poynting Antenna of the system. However, at the attenuation levels of 150, 200, 250, and 350, there were several instances in which several of the Passive RFID tags were unable to be identified. Nonetheless, there were no more than two occurrences, in which a tag was unidentifiable, at each attenuation level. Therefore, within this study, it was seen that Passive RFID Tags were identified at least 86.67% (13/15) of the time.

Section 4: Test of the Number of Times a Passive RFID tag is read through different activities

While the last several evaluative tests served the sole purpose of identifying the feasibility of whether or not Passive RFID Tags were read in a pre-defined environment, it was important to recognize that each of the tags remained stationary. Therefore, it was proposed to conduct a series of evaluative tests to analyze whether or not the RFID components would still provide sufficient reads through different activities that incorporate some form of motion. As stated previously, a time interval of 15 seconds was implemented for each activity that was evaluated and results are seen in Table 9 to Table 14.

Table 9: Number of Times Passive RFID Tag is Read for Activity #1- Test Subject Walks, within Environmental Setting, with Passive RFID Tag

Time Interval: 15 Seconds

Attenuation Level: 0

<u>Test Run</u>	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
1	0504300800000000000000BFB	2,348
2	0504300800000000000000BFB	1,674
3	0504300800000000000000BFB	2,229

For data that was obtained for Table 9, a human test subject was asked to walk, with a Passive RFID Tag, within the read range of the system, at an attenuation level of 0, for a time interval of 15 seconds. This test was repeated for three distinct test runs and it was seen that the Passive RFID Tag was read quite frequently by the Poynting Antenna. The minimum number of times read was seen in Test Run #2, as the tag was only read 1,674 times, with the maximum number of reads seen to be at 2,348 times in Test Run #1.

Table 10: Number of Times Passive RFID Tag is Read for Activity #2- Test Subject Jogs, within Environmental Setting, with Passive RFID Tag

Time Interval: 15 Seconds

Attenuation Level: 0

<u>Test Run</u>	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
1	0504300800000000000000BFB	1,228
2	0504300800000000000000BFB	897
3	0504300800000000000000BFB	1,102

For data that was obtained for Table 10, a human test subject was asked to jog, with a Passive RFID Tag, within the read range of the system, at an attenuation level of 0, for a time interval of 15 seconds. This test was repeated for three distinct test runs and it was seen that the Passive RFID Tag was once again read quite frequently by the

Poynting Antenna. The minimum number of times read was seen in Test Run #2, as the tag was only read 897 times, with the maximum number of reads seen to be at 1,228 times in Test Run #1.

Table 11: Number of Times Passive RFID Tag is Read for Activity #3- Test Subject Walks, within Environmental Setting, with Passive RFID Tag inside Nerf Ball

Time Interval: 15 Seconds

Attenuation Level: 0

<u>Test Run</u>	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
1	0504300800000000000000BFB	1,023
2	0504300800000000000000BFB	967
3	0504300800000000000000BFB	899

For data that was obtained for Table 11, a human test subject was asked to walk, with a Passive RFID Tag inside a Nerf Ball, within the read range of the system, at an attenuation level of 0, for a time interval of 15 seconds. This test was once again repeated for three distinct test runs and it was seen that the Passive RFID Tag was often recognized by the Poynting Antenna. The minimum number of times read was seen in Test Run #3, as the tag was only read 899 times, with the maximum number of reads seen to be at 1,023 times in Test Run #1.

Table 12: Number of Times Passive RFID Tag is Read for Activity #4 - Test Subject Jogs, within Environmental Setting, with Passive RFID Tag inside Nerf Ball

Time Interval: 15 Seconds

Attenuation Level: 0

<u>Test Run</u>	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
1	0504300800000000000000BFB	767
2	0504300800000000000000BFB	804
3	0504300800000000000000BFB	732

For data that was obtained for Table 12, a human test subject was asked to jog, with a Passive RFID Tag inside a NERF ball, within the read range of the system, at an attenuation level of 0, for a time interval of 15 seconds. This test was repeated for three distinct test runs and it was seen that the Passive RFID Tag was once again read quite frequently by the Poynting Antenna. The minimum number of times read was seen in Test Run #3, as the tag was only read 732 times, with the maximum number of reads seen to be at 804 times in Test Run #2.

Table 13: Number of Times Passive RFID Tag is Read for Activity #5- Test Subjects Roll Nerf Ball, with Passive RFID Tag inside, Back and Forth within Environmental Setting

Time Interval: 15 Seconds

Attenuation Level: 0

<u>Test Run</u>	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
<i>1</i>	0504300800000000000000BFB	723
<i>2</i>	0504300800000000000000BFB	756
<i>3</i>	0504300800000000000000BFB	747

For data that was obtained for Table 13, a human test subject was asked to roll a NERF ball, with a Passive RFID Tag inside, within the read range of the system, at an attenuation level of 0, for a time interval of 15 seconds. This test was repeated for three distinct test runs and it was seen that the Passive RFID Tag was once again read quite frequently by the Poynting Antenna. The minimum number of times read was seen in Test Run #1, as the tag was only read 723 times, with the maximum number of reads seen to be at 756 times in Test Run #2.

Table 14: Number of Times Passive RFID Tag is Read for Activity #6 - Test Subjects Throws Nerf Ball, with Passive RFID Tag inside, Back and Forth within Environmental Setting

Time Interval: 15 Seconds

Attenuation Level: 0

<u>Test Run</u>	<u>Tag Identification Number</u>	<u>Number of Times Read</u>
<i>1</i>	0504300800000000000000BFB	689
<i>2</i>	0504300800000000000000BFB	704
<i>3</i>	0504300800000000000000BFB	714

For data that was obtained for Table 14, a human test subject was asked to continuously throw the NERF ball, with a Passive RFID Tag inside, within the read range of the system, at an attenuation level of 0, for a time interval of 15 seconds. This test was repeated for three distinct test runs and it was seen that the Passive RFID Tag was once again read quite frequently by the Poynting Antenna. The minimum number of times read was seen in Test Run #1, as the tag was only read 689 times, with the maximum number of reads seen to be at 714 times in Test Run #3.

Overall Summary

The primary purpose of the evaluative tests conducted in this section was to analyze whether or not the RFID components were able to provide sufficient reads through different activities that incorporated some form of motion. It was seen that the Passive RFID Tag was read at a greater rate through the activity of simply just walking in comparison to the other activities. More specifically, once the human test subject was asked to begin jogging within the read range, the read rate decreased slightly due to the rapid movement of the tag causing for the antenna to have more of a difficulty in identifying the tag. In similar manner, since the antenna would be forced to send

radiofrequency signals through the material of the NERF Ball, one expected to have a decrease in read rates and this was indeed seen.

Section 5: Evaluating Performance of Tracking RFID Passive Tag with Software Code by Tyler Peabody

While the original code, provided by Mr. Tyler Peabody, provided a foundation for establishing a Real time Location Tracking System with RFID components, it was important to recognize that it remained far from being ideal. The reason for such pessimism was associated with the notion that previous experimental tests, with this specific code, had shown that the detection rate was quite inaccurate. Therefore, to validate such a claim, evaluative tests, in order to analyze the performance of the system, were conducted for six different tag directions (as seen in Appendix G), at six different attenuation levels (0, 15, 30, 50, 100), and three distinct height levels, which were the following:

- **Height 1:** The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag.
- **Height 2:** The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag.
- **Height 3:** The third height was one-foot below the straight line of sight to the Passive RFID tag.

Table 15 shows the summary of the system's accuracy, while the more in-depth results can be seen Appendix K.

Table 15: Accuracy of Real Time Location Tracking System for Original Software Code

	Height Level	Attenuation Levels	Directionality						Total Objects Read	Accuracy
			1	2	3	4	5	6		
	1	0	0/9	1/9	1/9	0/9	1/9	1/9	4/54	7.41%
		15	1/9	1/9	1/9	1/9	1/9	1/9	6/54	11.11%
		30	1/9	1/9	1/9	1/9	1/9	0/9	5/54	9.26%
		50	0/9	2/9	1/9	1/9	0/9	1/9	5/54	9.26%
		100	0/9	0/9	1/9	1/9	2/9	1/9	5/54	9.26%
Total	---	---	2/45	5/45	5/45	4/45	5/45	4/45	25/270	9.26%
	2	0	0/9	0/9	1/9	0/9	1/9	0/9	2/54	3.70%
		15	0/9	1/9	0/9	0/9	0/9	0/9	1/54	1.85%
		30	0/9	1/9	0/9	0/9	1/9	0/9	2/54	3.70%
		50	1/9	1/9	0/9	1/9	0/9	0/9	3/54	5.56%
		100	1/9	0/9	0/9	0/9	0/9	0/9	1/54	1.85%
Total	---	---	2/45	3/45	1/45	1/45	2/45	0/45	9/270	3.33%
	3	0	1/9	1/9	0/9	0/9	0/9	0/9	2/54	3.70%
		15	2/9	0/9	0/9	0/9	1/9	0/9	3/54	5.56%
		30	1/9	0/9	0/9	0/9	1/9	0/9	2/54	3.70%
		50	0/9	1/9	1/9	0/9	1/9	0/9	3/54	5.56%
		100	0/9	0/9	0/9	0/9	0/9	1/9	1/54	1.85%
Total	---	---	4/45	2/45	1/45	0/45	3/45	1/45	11/270	4.07%

At each of the three distinct height levels, the performance of the system was evaluated by locating a desired object with just one single Passive RFID Tag. Yet, this specific test included six different tag directions at six different attenuation levels each. More specifically, there were nine distinct locations that were tested for each direction evaluated. Therefore, for six different directions at each attenuation level, a total of 54 test points were conducted. In contrast, when evaluating a single directionality, a total of 45 test points were evaluated as there were five attenuation levels that were analyzed per direction. Ultimately, as seen from table 15, a total of 270 tests points were conducted for each height level.

Upon the completion of conducting this specific evaluative test, it was quite evident that the accuracy of the system was greatest at Height Level 1, in which the tag would have a direct line of sight to the antenna. It was seen that the total accuracy read rate was at 9.26% since 25 out of the 270 test points were accurately read by the system. By either increasing or decreasing the height level of antenna, it was seen that the accuracy of the system decreased to 3.33% (9 out of 270 points were accurately read) and 4.07% (11 out of 270 points were accurately read) respectively. In regards to the directionality of the tag, more reads were obtained for Direction 3 and Direction 5 for Height Level 1. However, these directions were not as prominent for Height Level 2 or Height Level 3. Nonetheless, the accuracy results for an RTLTS, based upon the original software code, were quite low. While such low read accuracy rates were undesirable, it remained quite important to recognize the significance of how such a code was still able to provide a basis for how to implement Passive RFID into a real time location tracking system.

Section 6: Evaluating the Performance of Tracking One Singular Object [with one Passive RFID tag]

As stated in the protocols stated in Chapter IV [Section 1], the performance of the modified software code was analyzed in a similar capacity as was done with the evaluation of the software code provided by Mr. Tyler Peabody. Therefore, tests were first conducted within the Cubic Testing Structure at a pre-defined attenuation level of 100 at three distinct height levels. Next, to establish a variable read range, tests were conducted with the four RFID Antenna Placeholder Stands placed in a manner similar to that seen in Figure 26.

Figure 26: Placement of Antennas for Testing Environment

Various attenuation levels were evaluated in the experimental tests, as well as at different height levels. Table 16 summarizes the results, but more detailed results can be seen in Appendix L.

Table 16: Accuracy of Real Time Location Tracking System for Modified Software Code [1 Passive RFID Tag]

			Directionality							
	Height Level	Attenuation Levels	1	2	3	4	5	6	Total Objects Read	Accuracy
	1	0	4/9	2/9	3/9	2/9	2/9	2/9	15/54	27.78%
		15	3/9	3/9	3/9	4/9	1/9	1/9	15/54	27.78%
		30	2/9	2/9	4/9	2/9	2/9	2/9	14/54	25.93%
		50	4/9	2/9	2/9	3/9	2/9	2/9	15/54	27.78%
		100	3/9	2/9	1/9	3/9	2/9	2/9	13/54	24.07%
Total	---	---	16/45	11/45	13/45	14/45	9/45	9/45	72/270	26.67%
	2	0	2/9	1/9	1/9	1/9	0/9	0/9	5/54	9.26%
		15	1/9	1/9	1/9	2/9	1/9	0/9	6/54	11.11%
		30	2/9	2/9	1/9	1/9	0/9	0/9	6/54	11.11%
		50	2/9	1/9	1/9	2/9	0/9	0/9	6/54	11.11%
		100	3/9	1/9	0/9	1/9	1/9	1/9	7/54	12.96%
Total	---	---	10/45	6/45	4/45	7/45	2/45	1/45	30/270	11.11%
	3	0	1/9	2/9	2/9	1/9	1/9	1/9	8/54	14.81%
		15	2/9	2/9	1/9	2/9	0/9	1/9	8/54	14.81%
		30	2/9	2/9	2/9	2/9	1/9	0/9	9/54	16.67%
		50	2/9	2/9	1/9	2/9	1/9	1/9	9/54	16.67%
		100	3/9	1/9	1/9	0/9	1/9	0/9	6/54	11.11%
Total	---	---	10/45	9/45	7/45	7/45	4/45	3/45	40/270	14.81%

At each of the three distinct height levels, the performance of the system was once again evaluated by performing an evaluative test that determined the accuracy of the system in tracking a desired object. In a similar manner, as seen in Table 15, six different directions were evaluated for each of the six attenuation level. Also, three distinct height levels were evaluated. Therefore, once again, a total of 270 test points were evaluated for each height level. However, the primary difference was associated with the notion that the system was based upon the modification to the software code. The results did indeed indicate that the modification allowed for an enhancement of the

accuracy of the system as the accuracy rate was raised to 26.67% for Height level 1.

Again, by either increasing or decreasing the height level of antenna, it was seen that the accuracy of the system decreased to 11.11% and 14.81% respectively. In regards to the directionality of the tag, more reads were obtained for Direction 1 and Direction 4 for Height Level 1.

Section 7: Evaluating the Performance of Tracking One Singular Object [with Multiple Passive RFID tags]

In the modification of the software program, it was established that a singular object, which was desired to be tracked, was able to be identified by multiple Passive RFID tags. By incorporating such a feature, it was believed to improve the accuracy of the real time location tracking system. In order to validate such a claim, experimental simulations were once again conducted with the same protocols that were used previously to analyze the system's accuracy. The data seen in Table 17 to Table 20 summarize the results for tracking one singular object with multiple tags, but more detailed results can be seen in Appendix M to Appendix P.

**Table 17: Accuracy of Real Time Location Tracking System for Modified Software Code
[2 Passive RFID Tags]**

			Directionality							
	Height Level	Attenuation Levels	1	2	3	4	5	6	Total Objects Read	Accuracy
	1	0	6/9	5/9	4/9	4/9	3/9	3/9	25/54	46.30%
		15	4/9	4/9	5/9	6/9	4/9	3/9	26/54	48.15%
		30	6/9	6/9	5/9	3/9	3/9	3/9	26/54	48.15%
		50	6/9	5/9	4/9	4/9	4/9	2/9	25/54	46.30%
		100	6/9	5/9	6/9	2/9	3/9	4/9	26/54	48.15%
Total	---	---	28/45	25/45	24/45	19/45	17/45	15/45	128/270	47.41%
	2	0	5/9	4/9	3/9	3/9	2/9	2/9	19/54	35.19%
		15	2/9	3/9	3/9	4/9	2/9	3/9	17/54	31.48%
		30	3/9	4/9	4/9	2/9	2/9	3/9	18/54	33.33%
		50	3/9	3/9	4/9	3/9	2/9	3/9	18/54	33.33%
		100	4/9	3/9	3/9	3/9	3/9	2/9	18/54	33.33%
Total	---	---	17/45	17/45	17/45	15/45	11/45	13/45	90/270	33.33%
	3	0	4/9	4/9	3/9	3/9	2/9	2/9	18/54	33.33%
		15	4/9	3/9	4/9	3/9	3/9	2/9	19/54	35.19%
		30	3/9	3/9	3/9	3/9	3/9	3/9	18/54	33.33%
		50	4/9	4/9	2/9	2/9	3/9	3/9	18/54	33.33%
		100	4/9	3/9	4/9	3/9	3/9	2/9	19/54	35.19%
Total	---	---	19/45	17/45	16/45	14/45	14/45	12/45	92/270	34.07%

**Table 18: Accuracy of Real Time Location Tracking System for Modified Software Code
[3 Passive RFID Tags]**

			Directionality							
	Height Level	Attenuation Levels	1	2	3	4	5	6	Total Objects Read	Accuracy
	1	0	5/9	5/9	6/9	5/9	4/9	5/9	30/54	55.56%
		15	5/9	7/9	4/9	5/9	6/9	5/9	32/54	59.26%
		30	7/9	5/9	5/9	6/9	5/9	6/9	34/54	62.96%
		50	6/9	6/9	5/9	5/9	5/9	5/9	32/54	59.26%
		100	7/9	5/9	6/9	6/9	5/9	4/9	33/54	61.11%
Total	---	---	30/45	28/45	26/45	27/45	25/45	25/45	161/270	59.63%
	2	0	5/9	5/9	3/9	5/9	4/9	4/9	26/54	48.15%
		15	4/9	4/9	4/9	4/9	5/9	5/9	26/54	48.15%
		30	4/9	4/9	5/9	4/9	4/9	5/9	26/54	48.15%
		50	5/9	5/9	4/9	5/9	4/9	3/9	26/54	48.15%
		100	4/9	4/9	3/9	3/9	6/9	5/9	25/54	46.30%
Total	---	---	22/45	22/45	19/45	21/45	23/45	22/45	129/270	47.78%
	3	0	4/9	3/9	5/9	5/9	4/9	5/9	26/54	48.15%
		15	4/9	4/9	5/9	5/9	5/9	4/9	27/54	50.00%
		30	5/9	5/9	4/9	5/9	4/9	4/9	27/54	50.00%
		50	6/9	5/9	4/9	5/9	3/9	3/9	26/54	48.15%
		100	5/9	5/9	5/9	5/9	4/9	3/9	27/54	50.00%
Total	---	---	24/45	22/45	23/45	25/45	20/45	19/45	133/270	49.26%

**Table 19: Accuracy of Real Time Location Tracking System for Modified Software Code
[4 Passive RFID Tags]**

			Directionality							
	Height Level	Attenuation Levels	1	2	3	4	5	6	Total Objects Read	Accuracy
	1	0	7/9	5/9	6/9	7/9	6/9	7/9	38/54	70.37%
		15	7/9	8/9	5/9	7/9	6/9	6/9	39/54	72.22%
		30	8/9	7/9	5/9	7/9	6/9	6/9	39/54	72.22%
		50	7/9	7/9	6/9	7/9	6/9	6/9	39/54	72.22%
		100	7/9	6/9	6/9	9/9	6/9	6/9	40/54	74.07%
Total	---	---	36/45	33/45	28/45	37/45	30/45	31/45	195/270	72.22%
	2	0	5/9	4/9	7/9	6/9	5/9	6/9	33/54	61.11%
		15	6/9	7/9	6/9	4/9	5/9	6/9	34/54	62.96%
		30	6/9	5/9	5/9	7/9	5/9	6/9	34/54	62.96%
		50	5/9	6/9	6/9	7/9	6/9	5/9	35/54	64.81%
		100	6/9	6/9	6/9	6/9	5/9	5/9	34/54	62.96%
Total	---	---	28/45	28/45	30/45	30/45	26/45	28/45	170/270	62.96%
	3	0	5/9	5/9	4/9	6/9	6/9	7/9	33/54	61.11%
		15	8/9	5/9	4/9	4/9	5/9	6/9	32/54	59.26%
		30	6/9	4/9	6/9	7/9	6/9	5/9	34/54	62.96%
		50	7/9	4/9	7/9	6/9	5/9	6/9	35/54	64.81%
		100	5/9	7/9	6/9	5/9	5/9	6/9	34/54	50.00%
Total	---	---	31/45	25/45	27/45	28/45	27/45	30/45	168/270	62.22%

**Table 20: Accuracy of Real Time Location Tracking System for Modified Software Code
[6 Passive RFID Tags]**

			Directionality							
	Height Level	Attenuation Levels	1	2	3	4	5	6	Total Objects Read	Accuracy
	1	0	8/9	8/9	8/9	8/9	7/9	7/9	46/54	85.19%
		15	8/9	8/9	8/9	7/9	7/9	8/9	46/54	85.19%
		30	8/9	7/9	9/9	7/9	8/9	8/9	47/54	87.04%
		50	8/9	9/9	7/9	7/9	8/9	8/9	47/54	87.04%
		100	6/9	8/9	8/9	8/9	8/9	8/9	46/54	85.19%
Total	---	---	38/45	40/45	40/45	37/45	38/45	39/45	232/270	85.93%
	2	0	7/9	7/9	7/9	7/9	5/9	8/9	41/54	75.93%
		15	7/9	7/9	7/9	6/9	5/9	7/9	39/54	72.22%
		30	6/9	7/9	6/9	7/9	6/9	8/9	40/54	74.07%
		50	6/9	7/9	6/9	7/9	7/9	6/9	39/54	72.22%
		100	7/9	7/9	6/9	7/9	7/9	6/9	40/54	74.07%
Total	---	---	33/45	35/45	32/45	34/45	30/45	35/45	199/270	73.70%
	3	0	7/9	7/9	7/9	7/9	5/9	8/9	41/54	75.93%
		15	7/9	7/9	7/9	6/9	5/9	7/9	39/54	72.22%
		30	6/9	7/9	6/9	7/9	6/9	8/9	40/54	74.07%
		50	6/9	7/9	6/9	7/9	7/9	6/9	39/54	72.22%
		100	7/9	7/9	6/9	7/9	7/9	6/9	40/54	74.07%
Total	---	---	33/45	35/45	32/45	34/45	30/45	35/45	199/270	73.70%

One of the most important modifications to the software program was the feature of being able to track a desired object with multiple Passive RFID Tags. Therefore, the performance of the system was once again evaluated through the process of identifying the accuracy read rate of the system. As stated with the evaluative tests seen in Section 5 and Section 6, six different directions were evaluated for each of the six attenuation level. Also, three distinct height levels were evaluated and a total of 270 test points were evaluated for each height level.

Results in this section indicated that the continuous addition of Passive RFID tags, to identify a singular object, allowed for a significant increase in the accuracy rate of the system. As seen in Table 17 for Height Level 1, the use of two Passive RFID Tags obtained an accuracy read rate of 46.3% for the system, which was a significant increase in comparison to an accuracy read rate of only 27.78% seen for the use of tracking an object with only one Passive RFID tag. With the continuous addition of Passive RFID Tags to identify a singular object to be tracked, the accuracy read rate of the system continued to exhibit vast improvement. In Table 20, it was seen that the accuracy of the RTLTS for the modified software code with six distinct Passive RFID Tags was recorded to be at 85.93% at Height Level 1. This result exhibited the highest accuracy read rate, and was indeed comparable to those of other technologies used for RTLTS.

As previously seen, the change in the height level of the Poynting Antenna showed a prominent affect upon the accuracy read rate of the system. Even with the addition of multiple tags to identify a singular object, there continued to be a decrease in the

accuracy read rate of the system when the tag was either one-foot higher or lower than the direct line of sight of the antenna. In regards to the directionality of the tag, there was not necessarily one direction that was more prominent than another. Nonetheless, a statistical analysis had to be conducted to examine whether or not these different factors would have had a prominent effect on the performance of the Real time Location Tracking System.

Section 8: Statistical Analysis on Real Time Location Tracking System

As stated previously in the protocols for the evaluative tests, an assessment was conducted on the performance of the Real time Location Tracking System with not only the modified software code but also with the original software code. The need to evaluate the original software code was attributed with the belief that the new features implemented into the modified software code had a profound effect on enhancing accuracy and performance of the system. In a similar manner, it was believed that factors such as the directionality of the RFID Passive tag, in relation to the Poynting antenna, and the location of the RFID Passive tag, in comparison to the height of the Poynting antenna, had a significant impact on the accuracy and performance of the system as well. Therefore, the primary purpose of a statistical analysis, within Minitab, was to examine whether or not these different factors had a prominent effect on the performance of the Real time Location Tracking System. More specifically, the different types of cases that were considered in this analysis included the following:

- ***Case 0 – Original Software Code [with 1 Passive RFID Tag]:***
 - **Height 1:** The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag.
 - **Height 2:** The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag.
 - **Height 3:** The third height was one-foot below the straight line of sight to the Passive RFID tag.
- ***Case 1 – Modified Software Code [with 1 Passive RFID Tag]:***
 - **Height 1:** The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag.
 - **Height 2:** The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag.
 - **Height 3:** The third height was one-foot below the straight line of sight to the Passive RFID tag.
- ***Case 2 – Modified Software Code [with 2 Passive RFID Tags]:***
 - **Height 1:** The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag.
 - **Height 2:** The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag.
 - **Height 3:** The third height was one-foot below the straight line of sight to the Passive RFID tag.

- ***Case 3 – Modified Software Code [with 3 Passive RFID Tags]:***
 - **Height 1:** The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag.
 - **Height 2:** The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag.
 - **Height 3:** The third height was one-foot below the straight line of sight to the Passive RFID tag.
- ***Case 4 – Modified Software Code [with 4 Passive RFID Tags]:***
 - **Height 1:** The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag.
 - **Height 2:** The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag.
 - **Height 3:** The third height was one-foot below the straight line of sight to the Passive RFID tag.
- ***Case 6 – Modified Software Code [with 6 Passive RFID Tags]:***
 - **Height 1:** The first height corresponded to a measurement in which all four antennas had a straight line of sight to the Passive RFID tag.
 - **Height 2:** The second height, to be evaluated, was one-foot above the straight line of sight to the Passive RFID tag.
 - **Height 3:** The third height was one-foot below the straight line of sight to the Passive RFID tag.

Section 8.1: Graphical Summary

Prior to conducting a Hypothesis Test upon the data set, the software program of Minitab was used to provide a graphical summary of the results of the number of times the system was able to properly recognize an object (identified by the Passive RFID tag) within the pre-defined environmental setting. Provided below are graphical summaries of each of the different cases with the defined condition of Height 1. In order to view the graphical summaries of each of the different conditions with the defined condition of Height 2 and Height 3, please refer to Appendix Q.

Figure 27: Statistical Summary for Case 0 and Height Level 1

From this graphical summary in Figure 27, it was seen that the sample mean of the number of objects read for [Case 0] was 0.8333 objects out of every 9 opportunities, with a sample standard deviation of 0.53067 objects. In addition, we were 95% confident that the population mean number of tags read was between 0.63518 objects and 1.03149 objects.

Figure 28: Statistical Summary for Case 1 and Height Level 1

From this graphical summary in Figure 28, it was seen that the sample mean of the number of objects read for [Case 1] was 2.40 objects out of every 9 opportunities, with a sample standard deviation of 0.8350 objects. In addition, we were 95% confident that the population mean number of objects read were between 2.0807 objects and 2.7193 objects.

Figure 29: Statistical Summary for Case 2 and Height Level 1

From this graphical summary, it was seen that the sample mean of the number of objects for [Case 2] was 4.2667 objects out of every 9 opportunities, with a sample standard deviation 1.2576 objects. In addition, we were 95% confident that the population mean number of objects read were between 3.7971 objects and 4.7363 objects.

Figure 30: Statistical Summary for Case 3 and Height Level 1

From this graphical summary in Figure 30, it was seen that the sample mean of the number of objects read for [Case 3] was 5.3667 objects out of every 9 opportunities, with a sample standard deviation of 0.8087 objects. In addition, we were 95% confident that the population mean number of objects read were between 5.0647 objects and 5.6686 objects.

Figure 31: Statistical Summary for Case 4 and Height Level 1

From this graphical summary, it was seen that the sample mean of the number of objects read for [Case 4] was 6.50 objects out of every 9 opportunities, with a sample standard deviation of 0.9002 objects. In addition, we were 95% confident that the population mean number of objects read were between 6.1639 objects and 6.8361 objects.

Figure 32: Statistical Summary for Case 6 and Height Level 1

From this graphical summary, it was seen that the sample mean of the number of objects read for [Case 6] was 7.7333 objects out of every 9 opportunities, with a sample standard deviation of 0.6397 objects. In addition, we were 95% confident that the population mean number of objects read was between 7.4945 objects and 7.9722 objects.

From the graphical summaries seen in Figure 27 to Figure 32, it was recognized that the mean number of tags read significantly increased when comparing the use of the RTLTS with the Original Software Code and the Modified Software Code. More specifically, with just one Passive RFID Tag, it was seen that only about 0.833 objects were read for every 9 opportunities with the original software code, while there were about 2.40 objects read for every 9 opportunities with the newly modified software code. By identifying an object, with multiple Passive RFID tags, there was an increase in the accuracy of the RTLTS, as it was seen that there were a greater number of times that an object was read. For instance, when comparing Case 1 [1 Passive RFID tag] to Case 6 [6 Passive RFID tag], data showed that 7.7333 objects were read out of every 9 opportunities compared to only 2.40 objects read for every 9 opportunities. In regards to the change in height level, it was seen that Height Level 1 had a greater accuracy in reading an object in comparison to Height Level 2 and Height Level 3.

Section 8.2: Hypothesis Test

While the graphical summaries were indeed able to indicate a difference in the sample means and standard deviations, a Hypothesis Test was conducted. By conducting a Statistical Hypothesis Test one was able to determine, with a 95% confidence level, whether or not there was a significant difference in the accuracy of the RTLTS, under various conditions. More specifically, a **one-way ANOVA** was used for the Hypothesis Test in order to accomplish the following:

- (1) **Hypothesis Test #1:** There exists a significant difference in the Accuracy of the System when Using the Original Code Versus Modified Software Code with the implementation of multiple RFID Passive Tags to Track Object.
- (2) **Hypothesis Test #2:** There exists a significant difference in the Accuracy of the System by Changing Attenuation Levels of Each Antenna.
- (3) **Hypothesis Test #3:** There exists a significant difference in the Accuracy of the System by changing the directionality of RFID Passive tag relative to the position of the Poynting Antenna
- (4) **Hypothesis Test #4:** There exists a significant difference in the Accuracy of the System by changing the Height level of the Poynting Antenna relative to the position of the RFID Passive Tag(s).

Procedural Steps for Hypothesis Test

- Definition of Variables

σ_{Case*} = Standard Deviation for Corresponding Case
 σ_{ATT*} = Standard Deviation for Corresponding Attenuation
 $\sigma_{Direction*}$ = Standard Deviation for Corresponding Direction
 $\sigma_{Height*}$ = Standard Deviation for Corresponding Height Level

μ_{Case*} = Population Mean for Corresponding Case
 μ_{ATT*} = Population Mean for Corresponding Attenuation
 $\mu_{Direction*}$ = Population Mean for Corresponding Direction
 $\mu_{Height*}$ = Population Mean for Corresponding Height Level

- Step 1: State Assumptions that are needed for the Statistical Analysis

- The first assumption was that the sampled data must be random and Independent.
- The second assumption stated that the values in each sampled group must be drawn from a normally distributed population.
- The third assumption stated that the variance within each population should be equal for all populations.

▪ Hypothesis Test #1

$$\sigma_{Case\ 0} = \sigma_{Case\ 1} = \sigma_{Case\ 2} = \sigma_{Case\ 3} = \sigma_{Case\ 4} = \sigma_{Case\ 6}$$

▪ Hypothesis Test #2

$$\sigma_{ATT\ 0} = \sigma_{ATT\ 15} = \sigma_{ATT\ 30} = \sigma_{ATT\ 50} = \sigma_{ATT\ 100}$$

▪ Hypothesis Test #3

$$\begin{aligned}\sigma_{Direction\ 1} &= \sigma_{Direction\ 2} = \sigma_{Direction\ 3} = \sigma_{Direction\ 4} \\ &= \sigma_{Direction\ 5} = \sigma_{Direction\ 6}\end{aligned}$$

▪ Hypothesis Test #4

$$\sigma_{Height\ 1} = \sigma_{Height\ 2} = \sigma_{Height\ 3}$$

- Step 2: State the Null Hypothesis for Each Test

○ Hypothesis Test #1

$$H_0: \mu_{Case\ 1} = \mu_{Case\ 2} = \mu_{Case\ 3} = \mu_{Case\ 4} = \mu_{Case\ 5} = \mu_{Case\ 6}$$

○ Hypothesis Test #2

$$H_0: \mu_{ATT\ 0} = \mu_{ATT\ 15} = \mu_{ATT\ 30} = \mu_{ATT\ 50} = \mu_{ATT\ 100}$$

○ Hypothesis Test #3

$$H_0: \mu_{Direction\ 1} = \mu_{Direction\ 2} = \mu_{Direction\ 3} = \mu_{Direction\ 4} = \mu_{Direction\ 5} = \mu_{Direction\ 6}$$

- **Hypothesis Test #4**

$$H_0: \mu_{\text{Height 1}} = \mu_{\text{Height 2}} = \mu_{\text{Height 3}}$$

- **Step 3: State the Alternative Hypothesis**

- **Hypothesis Test #1**

$$H_1: \mu_i \neq \mu_j \text{ for at least one pair of } [i,j]$$

- **Hypothesis Test #2**

$$H_1: \mu_i \neq \mu_j \text{ for at least one pair of } [i,j]$$

- **Hypothesis Test #3**

$$H_1: \mu_i \neq \mu_j \text{ for at least one pair of } [i,j]$$

- **Hypothesis Test #4**

$$H_1: \mu_i \neq \mu_j \text{ for at least one pair of } [i,j]$$

- **Step 4: Establish a 95% Confidence Interval**

- $\alpha = 0.05$ for each Hypothesis Test

Complete Results from Minitab Can Be Seen in Section 17 of Appendix

Results from One-Way Anova for Each Hypothesis Test [conducted in Minitab]

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	16	2988.03	2988.03	186.752	325.581	0.000000
Case Number	5	2833.99	2833.99	566.797	988.147	0.000000
Attenuation Level	4	0.53	0.53	0.132	0.231	0.921049
Height Level	2	118.06	118.06	59.030	102.911	0.000000
Direction	5	35.45	35.45	7.091	12.362	0.000000
Error	523	299.99	299.99	0.574		
Total	539	3288.02				

From the results obtained from the One-Way Anova, the primary focus was to identify the p-value obtained for each of the categories. More specifically, if a category were to obtain a p-value that is less than 0.05, we concluded that we were 95% confident that we had to reject the null hypothesis. Therefore, if we do reject the null hypothesis, we were 95% confident that there was indeed a significant difference in the mean number of objects read under the specific category. Through the statistical

analysis conducted in Minitab, it was recognized that the categories of case number, height level, and direction all had a p-value of 0.0000. Thus, we were able to conclude that there were indeed significant differences in the mean number of objects read under these categories. In regards to attenuation level, it was seen that the p-value was 0.921049. Since the p-value was greater than 0.05, we accepted the null hypothesis. Thus, there was insufficient data to conclude that there were significant differences in the mean number of objects read under the different attenuation levels evaluated.

Results from Regression Coefficient Table for Each Hypothesis Test [conducted in Minitab]

Term	Coef	SE Coef	T	P
Constant	3.85741	0.0325916	118.356	0.000
Case Number				
0	-3.35741	0.0728771	-46.069	0.000
1	-2.27963	0.0728771	-31.280	0.000
2	-0.41296	0.0728771	-5.667	0.000
3	0.84259	0.0728771	11.562	0.000
4	2.06481	0.0728771	28.333	0.000

$$\sum_{i=0}^n \text{Coefficient} = 0$$

$$\text{Coefficient}_{\text{Case } 0} + \text{Coefficient}_{\text{Case } 1} + \text{Coefficient}_{\text{Case } 2} + \text{Coefficient}_{\text{Case } 3} + \text{Coefficient}_{\text{Case } 4} + \text{Coefficient}_{\text{Case } 6} = 0$$

$$-3.35741 + (-2.27963) + (-0.41296) + (0.84259) + (2.06481) + \text{Coefficient}_{\text{Case } 6} = 0$$

$$\text{Coefficient}_{\text{Case } 6} = 3.1426$$

In order to obtain the regression coefficient of Case Number 6, it was of necessity to sum all of the coefficient values to the value of 0, and solve for the unknown variable (Coefficient for Case 6). Through this, we obtained the coefficient value to be 3.1426, which represented the greatest coefficient value among all of the case categories. With

this, we were 95% confident that Case 6 had the most prominent affect, among all of the cases, in being able to obtain the greatest accuracy read rates for the system.

Attenuation Level

In regards to Attenuation Level, there was insufficient data in determining to conclude there existed significant difference in the mean number of objects read under this specific category. Therefore, there exists no maximum regression coefficient for the category of Attenuation Level.

Height Level

1	0.65926	0.0460915	14.303	0.000
2	-0.37407	0.0460915	-8.116	0.000

$$\sum_{i=0}^n Coefficient = 0$$

$$Coefficient_{Height\ 1} + Coefficient_{Height\ 2} + Coefficient_{Height\ 3} = 0$$

$$0.65926 + (-0.37407) + Coefficient_{Height\ 3} = 0$$

$$Coefficient_{Height\ 3} = -0.28519$$

In order to obtain the regression coefficient of Height Level 3, it was once again of necessity to sum all of the coefficient values to the value of 0, and solve for the unknown variable (Coefficient for Height Level 3). Through this, we obtained the coefficient value to be -0.28519. From this data set, it was seen that the greatest coefficient value among all of the Attenuation Level was seen to be at Height Level 1 at a value of 0.65926. Therefore, we were 95% confident that Height Level 1 had the most prominent affect, among all of the cases, in being able to obtain the greatest accuracy read rates for the system.

Direction

1	0.39815	0.0728771	5.463	0.000
2	0.17593	0.0728771	2.414	0.016
3	-0.02407	0.0728771	-0.330	0.741
4	0.07593	0.0728771	1.042	0.298
5	-0.34630	0.0728771	-4.752	0.000

$$\sum_{i=0}^n Coefficient = 0$$

$$Coefficient_{Direction 1} + Coefficient_{Direction 1} + Coefficient_{Direction 3} + Coefficient_{Direction 4} + Coefficient_{Direction 5} + Coefficient_{Direction 6} = 0$$

$$0.39815 + (0.17593) + (-0.02407) + (0.07593) + (-0.34630) + Coefficient_{Direction 6} = 0$$

$$Coefficient_{Direction 6} = 0.122780$$

In order to obtain the regression coefficient of Direction 6, it was once again of necessity to sum all of the coefficient values to the value of 0, and solve for the unknown variable (Coefficient for Direction 6). Through this, we obtained the coefficient value to be 0.122780. From this data set, it was seen that the greatest coefficient value among all of the Attenuation Level was seen to be at Direction 1 at a value of 0.39815. Therefore, we were 95% confident that Direction 1 had the most prominent affect, among all of the cases, in being able to obtain the greatest accuracy read rates for the system.

Check the Validity of the Assumptions

In order to validate whether or not the variance within each population were equal for all populations, the Bartlett and Levene Tests were conducted on the data sets.

Hypothesis Test #1

- **State the Null Hypothesis**

$$\sigma_{Case\ 0} = \sigma_{Case\ 1} = \sigma_{Case\ 2} = \sigma_{Case\ 3} = \sigma_{Case\ 4} = \sigma_{Case\ 6}$$

- **State the Alternative Hypothesis**

$$H_1: \sigma_i \neq \sigma_j \text{ for at least one pair of } [i,j]$$

- **In order to establish a 95% Confidence Interval, a value of 0.05 was selected for α .**

$$\alpha = 0.05$$

Figure 33: Test for Equal Variances for Objects Read (Case Number)

From the Bartlett's Test, it was seen that a p-value of 0.8975 was obtained for this data set. Since the p-value (0.8975) was greater than the alpha value (0.05), we failed to reject the null hypothesis. Thus, we were 95% confident that the variances, within each population [Objects Read and Case Number], were equal for all populations. Therefore, this assumption was valid.

Hypothesis Test #2

- State the Null Hypothesis

$$\sigma_{ATT\ 0} = \sigma_{ATT\ 15} = \sigma_{ATT\ 30} = \sigma_{ATT\ 50} = \sigma_{ATT\ 100}$$

- State the Alternative Hypothesis

$$H_1: \sigma_i \neq \sigma_j \text{ for at least one pair of } [i,j]$$

- In order to establish a 95% Confidence Interval, a value of 0.05 was selected for α .

$$\alpha = 0.05$$

Figure 34: Test for Equal Variances for Objects Read (Attenuation Level)

From the Bartlett's Test, it was seen that a p-value of 0.991 was obtained for this data set. Since the p-value (0.991) was greater than the alpha value (0.05), we failed to reject the null hypothesis. Thus, we were 95% confident that the variances, within each population [Objects Read and Attenuation Level], were equal for all populations. Therefore, this assumption was valid.

Hypothesis Test #3

- State the Null Hypothesis

$$\sigma_{\text{Direction 1}} = \sigma_{\text{Direction 2}} = \sigma_{\text{Direction 3}} = \sigma_{\text{Direction 4}} = \sigma_{\text{Direction 5}} \\ = \sigma_{\text{Direction 6}}$$

- State the Alternative Hypothesis

$$H_1: \sigma_i \neq \sigma_j \text{ for at least one pair of } [i,j]$$

- In order to establish a 95% Confidence Interval, a value of 0.05 was selected for α .

$$\alpha = 0.05$$

Figure 35: Test for Equal Variances for Objects Read (Direction)

From the Bartlett's Test, it was seen that a p-value of 0.886 was obtained for this data set. Since the p-value (0.886) was greater than the alpha value (0.05), we failed to reject the null hypothesis. Thus, we were 95% confident that the variances, within each population [Objects Read and Direction], were equal for all populations. Therefore, this assumption was valid.

Hypothesis Test #4

- State the Null Hypothesis

$$\sigma_{Height\ 1} = \sigma_{Height\ 2} = \sigma_{Height\ 3}$$

- State the Alternative Hypothesis

$$H_1: \sigma_i \neq \sigma_j \text{ for at least one pair of } [i,j]$$

- In order to establish a 95% Confidence Interval, a value of 0.05 was selected for α .

$$\alpha = 0.05$$

Figure 36: Test for Equal Variances for Objects Read (Height Level)

From the Bartlett's Test, it was seen that a p-value of 0.731 was obtained for this data set. Since the p-value (0.731) was greater than the alpha value (0.05), we failed to reject the null hypothesis. Thus, we were 95% confident that the variances, within each population [Objects Read and Height Level], were equal for all populations. Therefore, this assumption was valid.

In order to validate whether or not the values in each sampled group were normally distributed, a normality test was conducted upon the residual values.

- **State the Null Hypothesis**
 - H_0 : Population is Normally Distributed
- **State the Alternative Hypothesis**
 - H_1 : Population is not Normally Distributed
- **In order to establish a 95% Confidence Interval, a value of 0.05 was selected for α .**
 - $\alpha = 0.05$

Figure 37: Normal Probability Plot (Anderson Darling Test)

From the Normality Test, it was seen that a p-value of 0.086 was obtained for this data set. Since the p-value (0.086) was greater than the alpha value (0.05), we failed to reject the null hypothesis. Thus, we were 95% confident that the population was indeed normally distributed. Therefore, this assumption was valid.

CHAPTER VI: CONCLUSION

As stated previously, the goal of this study was to establish a RFID system that was able to provide real time location tracking of a pre-determined object. While the software code, provided by Mr. Tyler Peabody, provided a substantial basis in accomplishing such a feat, modifications were still needed to improve the accuracy read rate of the system. This modified software code then underwent several evaluative tests to not only analyze the potential of RFID technology in a Real Time Location Tracking System, but also to evaluate how factors such as directionality of the tag, height level of the antenna, as well as attenuation levels could affect the performance of the system. Upon the tabulation of the results, a One-Way ANOVA test was used as the statistical analysis method with Minitab.

In this specific chapter, the results from the One-Way ANOVA test were first discussed, as well as interpreted for each of the categorical factors that were evaluated. While the statistical analysis showed that many of these categorical factors had a prominent effect upon the performance of the system, it was important to recognize that the accuracy read rates were substantially improved through the modifications of the software code. In effect, the accuracy read rates, which were seen, were indeed quite comparable to that of other technologies used for RTLTS and will be further discussed in this chapter. Nonetheless, it should be recognized that several limitations were experienced and should be considered in future work.

Section 1: Interpretation of Statistical Analysis

In order to analyze and determine, with a 95% confidence level, whether or not there was a significant difference in the number of times an object was read by the system, a one-way ANOVA test was performed, with Minitab, upon four distinct conditions. In addition, Minitab was also used to obtain Regression Coefficient values as a means to determine which variable obtained the best results from each of the corresponding conditions. Below is an interpretation of the statistical analysis for each of the four hypothesis tests that were conducted.

Hypothesis Test #1

From the results obtained from the One-Way Anova Test conducted on this specific data set, it was seen that the p-value was recognized to be 0.000. Thus, since the p-value [0.000] was less than α [0.05], we rejected the null hypothesis. Therefore, we were 95% confident that there was a significant difference in the mean number of objects read under various cases that were studied. The statistical results suggested that not only did the modifications, within the software code, result in a significant change in number of objects being read by the system, but similar results were seen with the implementation of multiple tags to track a singular object. In order to determine which of the cases resulted in a greater number of objects being read by the system, Minitab was used to obtain Regression Coefficient Values. Results indicated that Case Number 6 had the greatest Regression Coefficient Value. Thus, we were 95% confident to conclude that the greatest number of objects read with six Passive RFID tags to track a singular object.

Hypothesis Test #2

From the results obtained from the One-Way Anova Test conducted on this specific data set, it was seen that the p-value was recognized to be 0.921049. Thus, since the p-value [0.921049] was greater than α [0.05], we failed to reject the null hypothesis. Therefore, there was insufficient data to conclude that there existed significant differences in the mean number of objects read under different attenuation levels that were evaluated.

Hypothesis Test #3

From the results obtained from the One-Way Anova Test conducted on this specific data set, it was seen that the p-value was recognized to be 0.000. Thus, since the p-value [0.000] was less than α [0.05], we rejected the null hypothesis. Therefore, we were 95% confident that there was also a significant difference in the mean number of objects read with a change of the directionality of the Passive RFID tags in relation to the antennas of the system. Minitab was once again used in order to observe the Regression Coefficient Values for this specific data set. From the results, it was seen that Direction 1 had the greatest Regression Coefficient Value. Thus, we were 95% confident to conclude that the greatest number of objects read would have the tag in a similar direction to that of Direction 1.

Hypothesis Test #4

From the results obtained from the One-Way Anova Test conducted on this specific data set, it was seen that the p-value was recognized to be 0.000. Thus, since the p-value [0.000] was less than α [0.05], we rejected the null hypothesis. Therefore, we were 95% confident that there was also a significant difference in the mean number of objects read with a change of the height level of the antenna in relation to the Passive RFID Tags. More specifically, by changing the height level of the antenna to one that prevented the Passive RFID tags from having a direct line of sight to the antenna, there was a significant decrease in the number of objects read by the system. Minitab was once again used to observe the Regression Coefficient Values for this specific data set. From the results, it was seen that Height Level 1 had the greatest Regression Coefficient Value. Thus, we were 95% confident to conclude that the greatest number of objects read would have a height level in which the Passive RFID tags would have a direct line of sight to the antennas.

Section 2: Discussion of Results

The primary purpose of this study was to evaluate and analyze the performance of Passive Radio Frequency technology as a basis for a real time location tracking system. Even though the results did not yield the ideal read accuracy of 100%, for the Passive RFID technology, optimism remained for such technology to be considered for a real time location tracking system. From the statistical analysis, it was seen that the original software code [Code 0], provided by Mr. Tyler Peabody, exhibited the lowest read accuracy rates as only about 9.26% were recognized in the proper zone. While such low read accuracy rates were undesirable, it remained quite important to recognize the significance of how such a code was still able to provide a basis for how to implement Passive RFID into a real time location tracking system.

In order to address the low read accuracy rates, several modifications were made to the original software code to try to enhance the performance and accuracy level of the system. Such modifications included some features that enhanced the speed of the visual display on the graphical representation, as well as incorporated a 'cutoff point' and a new definition of a 'cycle' to improve the accuracy of the system. However, it was the ability to track a singular object with multiple Passive RFID tags that had the most prominent effect upon improvement of the performance.

By implementing a real time location tracking system that allowed for a singular object to be identified and tracked by multiple Passive RFID tags, the results had indicated there was a statistical significance difference in the amount of the read accuracy rate of the system [Hypothesis Test #1]. More specifically, from the statistical

analysis conducted in Hypothesis Test #1, we were 95% confident to conclude that there was indeed a significant increase in the read accuracy rates of the system as more Passive RFID tags were used to identify and track a singular object. It was seen that, with the modified software code, the read accuracy rates were only about 26.67% with the use of only one Passive RFID tag, but such a value rose to approximately an accuracy rate of 85.93% with six Passive RFID tags. Through statistical analysis, it was validated that the use of six Passive RFID tags yielded the best accuracy results, as it obtained the highest Regression Coefficient Values, among all of the cases in Hypothesis Test #1.

With the results obtained from the statistical analysis from Hypothesis Test #1, it was suggested that the implementation of more Passive RFID tags to identify a singular object led to a more accurate real time location tracking system. The reason for such a belief was associated with the notion that the incorporation of more Passive RFID tags, to identify a singular object, allowed for a greater likelihood in which the antennas recognized one of the corresponding tags. It was the increase in the recognition of the corresponding tags that ensured the system to have a greater accuracy in analyzing which of the four antennas are able to identify the object. Such a process allowed for this specific real time location tracking system to provide a more precise determination of which zone the singular object was located within. However, while it was recognized that the identification of a singular object with multiple tags had a prominent effect upon the read accuracy of the system, it was important to acknowledge that other factors altered the precision of the real time location tracking system.

Through the evaluation of the statistical analysis conducted upon the experimental data set, we were also 95% confident that the change in the height level of the four antennas [Hypothesis Test #4], in relation to the position of the Passive RFID tags, also exhibited significant differences in read accuracy of the real time location tracking system. When observing the case in which six tags were used to identify a singular object, it was seen that that the read accuracy rate was approximately 85.93% when the antenna was at the same height level as that of the Passive RFID tags. However, by lowering or raising the antennas by a distance of one-foot, it was seen that the read accuracy rate declined to approximately about 73.70% for both scenarios. A similar pattern was seen, with the change of height levels, for each of the cases explored in Hypothesis Test #1. Thus, one may conclude that as the height of the antenna got further and further away from the position of the Passive RFID tags, the system obtained a significantly worse read accuracy rate. A potential reason for such a justification was that, while the Poynting Antenna was able to broadcast a radiofrequency signal with a range of 180^0 , it was only able to do so in a singular plane. Therefore, if the Passive RFID tags were in the same plane or height level as that of the Poynting Antennas, there was an increased probability that system precisely recognized the proper location of the tracked object.

Aside from the change in the height level of the four antennas, another factor that indicated a significant change in the accuracy read rate of this specific real time location tracking system was the direction of Passive RFID tags, in relation to the position of the antenna. In this specific study, Passive RFID tags were placed upon a singular object and

were kept in the same location for each of the repetitive trials. However, the singular object was required, within each regional zone, to be positioned into six distinct orientations. With 95% confidence, we were able to conclude that there was a significant difference in the read accuracy rate of the system upon changing the directionality of the tag.

Through the evaluation process, it was quite evident that the read accuracy of the system was more prominent when the Passive RFID tags were positioned in a manner in which there exist no other components that would obstruct the pathway between itself and the antennas. In a scenario in which an individual was to be tracked with only one passive RFID tag, there was a potential for the body of the human specimen to be turned in an orientation that prevented the tag from having a direct line of sight from the antenna. In such a situation, the antenna emitted radiofrequency signals that passed through the human body, and often times the signal was unable to reach the Passive RFID tags. Therefore, such an action ultimately caused for inaccuracy in the read rates of this system. Similar problems continued to arise if the antennas were required to continuously emit these signals through other dense objects. However, to prevent such a dilemma, it was essential for the Passive RFID tags to be in the same line of sight as the antennas. Therefore, it was highly suggested for multiple tags to be strategically placed onto an object, which was to be tracked, to allow for each of the antennas to have the opportunity to be able to read at least one of those Passive RFID tags located on the object. If it were undesirable to use multiple tags, it would then be essential for the tag to be in a direct sight of the antenna to achieve the greatest accuracy read rate.

Another potential factor that had a potential impact upon the read accuracy rate of this real time location tracking was the ability to modify the attenuation levels of the antenna. However, through statistical analysis, there was insufficient data to conclude there existed significant differences in the read accuracy rates by simply changing the attenuation levels of all four antennas within a system. Through this study, it was now understood that it was important to attenuate the signals of the antennas to obtain the proper size of each of the regional zones within the environmental setting. More specifically, it was through the process of finding the maximum read range of each antenna, under a specific attenuation level, which enabled an individual to create and identify the size of a proper regional zone. Therefore, since the change in the attenuation levels only increased or decreased the size of each regional zone, it should be believed that such a factor did not have a prominent affect upon the read accuracy rates of the entire system.

Section 3: Comparison to Other Real time Location Tracking Systems

As stated previously, the purpose of this study was to evaluate the potential of using Passive RFID technology as a basis for a real time location tracking system. Experimental tests were indeed conducted in this study to assess the accuracy of the system in being able to recognize the location of an object being tracked. However, such results were compared to that of other real time location tracking system to validate the potential of such a technology. Therefore, below is a table that provides a summary of the accuracy of several real time location tracking systems.

Table 21: Comparison of Accuracy Rates of Various Real Time Tracking Location Systems

Technology	Real Amount of Objects	Mean Amount of Objects Read	Accuracy Rate	Percentage Error
Active RFID	190	150	78.95%	21.05%
Indoor GPS	200	102	51.00%	49.00%
Infrared	140	118	84.29%	15.71%
Passive RFID	270	232	85.93%	14.07%
Ultra-Wideband	210	189	90.00%	10.00%

From the table above, it was seen that the read accuracy rate of a real time location tracking system based upon the use of Passive RFID technology was indeed quite comparable to those other systems. From Table 21, it was recognized that the use of Passive RFID technology resulted in better results than that of technologies, such as Active RFID, Indoor GPS, and Infrared. The read accuracy rates of this specific real time location tracking system could even be further enhanced through the consideration of several factors. As previously stated, it was the factors of the proper placement of the Passive RFID tags and antennas, as well as the use of multiple tags, that had the most prominent affect upon the read accuracy rates. Nonetheless, results, from this study, have indicated that a system based upon Passive RFID technology yielded acceptable read accuracy rates, especially with the appropriate considerations of several factors. Therefore, it should be concluded that use of Passive RFID technology for a real time location tracking system was a viable option for being used as a directional guidance, for an individual with a visual impairment, of where they are located within the court.

Section 4: Limitations

In regards to this study, several limitations were encountered during the process of analyzing the performance of the Passive RFID technology based real time location tracking system. One of the most pronounced restraints was associated with inability to secure an environmental setting that did not contain any materials that had the ability to interfere with the system. Instead, my experimental tests were limited to being conducted in the PolyGait laboratory, which was operated by the Industrial and Manufacturing Engineering Department. While such a laboratory possessed sufficient surface area to conduct the necessary tests for the study, the environmental setting often contained a vast array of elements that were not considered to be beneficiary for the system. For instance, the environmental setting contained additional Passive RFID tags that were often recognized by the four antennas of the system. This could be seen as a hindrance as the recognition of additional Passive RFID tags caused for a delay in the functionality of the system.

Another limitation associated with conducting the study in the PolyGait laboratory was the presence of various structures composed of metallic components. While these structures were not located within any of the regional zones, their presence outside of the pre-determined environmental settings was still believed to have an effect upon the performance of the system. The reason for such a belief was that the radiofrequency signals emitted by the antennas could reflect upon the metallic components and change the trajectory of such signals. Aside from the various metallic components potentially affecting the accuracy read rates of the system, another source of interference could be

attributed with the emission of signals from a cellular phone. Such occurrences had a profound effect upon the accuracy read rate of the system.

In this specific study, the components of the Passive RFID technology, such as the Poynting Antennas, the Sirit Reader, and several Passive RFID tags, were provided by the IME Department. These components were then used to evaluate the performance of such technology for the purpose of a real time location tracking system. However, due to the expensive nature of these components, my study was unable to evaluate different models of Passive RFID Antennas and Readers. Thus, a limitation was then associated with the assumption that most Passive RFID components will function in a similar manner, and will result in comparable accuracy read rates.

Another limitation associated with the use of Passive RFID technology, for RTLTS, was the idea that substantially long wires and cables, such as the BNC cable and Ethernet cords, had to be used for the system to establish the communication pathway between the components. If such technology were to be used for an activity such as assisting an individual, with a visual impairment, in playing the sport of basketball, those cables and wires would become a detriment. The reason for such pessimism was due to the potential that it could hinder the movement of an individual due to the fear of tripping over such components. Therefore, a series of safety protocols should be implemented to ensure that no such events could potentially occur.

Section 5: Future Work

The primary purpose of this study was to evaluate and analyze the use of Passive RFID technology to serve as a basis for a real time location tracking system. This study was able to validate the claim that such a technology was indeed a viable option by confirming that the accuracy read rates were indeed comparable to other technologies. However, such a validation should not prevent any further research from being conducted. Instead, there should continue to be different areas that could be further investigated and researched.

As stated previously, the availability of different models and brands for the Passive RFID readers, antennas, and tags were quite limited in the PolyGait laboratory. However, there exists a vast array of brands and models that are available, on the market, for the different components of the Passive RFID technology. If additional funds were used to purchase these different brands and models, evaluative tests should be conducted to analyze whether or not the performance of the components are relatively similar to that of the Poynting Antennas and Sirit Readers that are present in the PolyGait laboratory. If statistical analysis does indeed show that there exist significant differences in the performance of these different brands and models, it should then be determined which corresponding antennas and readers could help enhance the performance of the real time location tracking system.

Another aspect that could be studied in the near future would be to evaluate this specific system in an outdoor setting. In regards to this research, the performance of the system was only tested and evaluated in the PolyGait laboratory, which is an indoor

environmental setting. Therefore, if such a system were to be considered for an outdoor activity, similar tests would need to be conducted upon the system. These evaluative tests would be of importance in recognizing whether or not the accuracy read rates would remain comparable to that those results obtained for an indoor setting. If the read accuracy rates were to exhibit significant decline, research could assist in determining the reason for such different results, and corresponding modifications could then be made to the software code to enhance the system's performance.

If Passive RFID technology is indeed chosen to assist an individual, with a visual impairment, in performing the motions in the sport of basketball, the current set-up would not be ideal. As stated earlier, the components of the system, due to their size, may interfere during the activity, and could ultimately pose a potential hazard to an individual. Therefore, future work may include designing and developing a portable real time location tracking system based upon Passive RFID technology. In such an approach, the ultimate goal would be to eliminate the excess cords and wires that could possess tripping hazards, as well as limit the number of components, such as the stands for the antennas, that an individual may accidentally bump into. If such a portable structure is designed, an individual will not only have a device that could help provide the user with an estimate of their precise location, but also a device that will not interfere during the motions of the activity.

The primary purpose of a real time location tracking system is to provide a user a visual display of their precise location within an environmental setting. However, for an individual diagnosed with a visual impairment, the user may not have the ability to

acknowledge these visual displays. With this in mind, this specific system may be deemed irrelevant for such an individual. Therefore, it should be suggested that one design a form of sensory stimulation that could work in parallel with the real time location tracking system. For instance, a wristband device could be designed to provide some tactical feedback that could help guide an individual in some manner. In such a design, the real time location tracking system will analyze the position of the individual and send this analysis to the wristband device. This device will then have a tactical feedback, which could be in the form of vibration, which could vibrate in different regions of the lower arm that could suggest the user to move in a specific direction to reach the basketball hoop. With a sensory stimulation device and real time location tracking system functioning as a partnership, one could have a prominent system that will be quite useful in assisting an individual, with a visual impairment, in participating in various sporting activities, such as basketball.

It should be noted that such a technology should not be limited to being used for various sporting activities, such as the sport of basketball. Instead, it should be determined whether or not a RTLTS, based upon Passive RFID technology, could be used in a different capacity. One potential application of such a system could be implemented to determine whether or not an increase in interaction activity between a patient and doctor, within a hospital setting, could lead to an increase in health. In order to accomplish a task, the patient and doctor would each be identified with a distinct Passive RFID Tag. The tags would then be continuously tracked by the system within the systematic environment. Once these tags are within a pre-determined

distance from one another, the system could then have a feature that would allow for a time interval to be measured. This time interval could then be used by the hospital staff to determine how much time is truly spent between the patient and doctor. Therefore, it should be noted that the use of Passive RFID, as the technological basis for a RTLTS, could potentially provide for a vast array of applications, which is not limited to just various sporting activities, but also for use in the clinical setting.

Appendix A: SolidWorks Design and Construction of Passive RFID Placeholder Stand

Materials to be used in
Construction of Passive RFID
Placeholder Stand

Cutting 1" PVC Pipe into a Proper
Length of Two Feet

Attaching a PVC Elbow to one end
and a PVC T-Joint to the other end
of the Two Foot Long 1" PVC Pipe

Completed Base of Passive RFID
Antenna Placeholder Stand

Using Quarter Inch Drill Bit into
PVC T-Joint

Fitting Wingnut into Quarter Inch
Hole in PVC T-Joint

Use Quarter Inch Drill Bit to Create Corresponding Hole into 8" by 8" Plywood

Attachment of Poynting Antenna onto 8" by 8" Plywood with PVC Structure

Final Attachment of Antenna onto Passive RFID Antenna Placeholder Stand

Passive RFID Placeholder Stand

Front View of SolidWorks Design of
Passive RFID Placeholder Stand

Top View of SolidWorks Design of
Passive RFID Placeholder Stand

Appendix B: Visual Representation of Conducting Feasibility Test

1. Connect one end of Ethernet Cord into Laptop, and other end of Ethernet Cord into the Sirit Reader. Also, insert power cord into a electrical outlet, as well as into the Sirit Reader

2. Connect the appropriate end of the BNC Cable into the Poynting Antenna attached to the RFID Antenna Placeholder Stand.

3. Connect other end of BNC cable into one of the four inputs of Sirit Reader

4. Install Sirit Program into Laptop

5. Open Sirit Program and Home Screen of Program will be displayed. Next, select “Configure.”

6. Once user selects “Configure,” program will direct user to a designated website provided by Sirit. Under this new screen, user must select “View Tags”

7. Once under the Reader Operating mode, user must sign log into the program with the following.

User name: Admin
Password: readeradmin

Once logged in, select “Active” Mode and the user may change the time interval in the same screen. User may then click “Start” in order to begin the reading of tags.

8. Summary of “View Tags” after a completed time interval is the provided.

Reader Operating Mode

The current reader operating mode is displayed as the default item in the pull-down list. To change the operating mode, highlight and select the desired mode from the list.

Select	Operating Mode	?
☒	Active Mode	?
☐	Stand By Mode	?

Tag Database Display

Click on the 'Start' button to begin a display of the reader tag database and continuously refresh the display for the specified polling period. The 'Stop' button stops updating the display of the reader tag database. The 'Get Once' button can be used to display the reader tag database a single time. The 'Purge' button purges all tags from the reader tag database.

Tag ID	Protocol	Antenna	Repeat Counts	First Read Time	Last Read Time
0x11111111111111111111111111111111	ISOC	1	61	2011-06-25T03:47:59.242	2011-06-25T03:48:20.739
0xE20074118002011111363441	ISOC	1	611	2011-06-25T03:47:54.245	2011-06-25T03:48:24.561
0x300033820009014035050000	ISOC	1	2896	2011-06-25T03:46:44.012	2011-06-25T03:48:24.562
0x050430000000000000000000C03	ISOC	1	144	2011-06-25T03:47:46.912	2011-06-25T03:48:03.624
0x050430000000000000000000C04	ISOC	1	36	2011-06-25T03:48:01.378	2011-06-25T03:48:03.100
0x050430000000000000000000C05	ISOC	1	48	2011-06-25T03:48:01.284	2011-06-25T03:48:03.544
0x050430000000000000000000C06	ISOC	1	66	2011-06-25T03:48:00.944	2011-06-25T03:48:03.284
0x050430000000000000000000C07	ISOC	1	97	2011-06-25T03:48:00.800	2011-06-25T03:48:03.430
0x050430000000000000000000C08	ISOC	1	83	2011-06-25T03:48:01.190	2011-06-25T03:48:03.467
0x050430000000000000000000C09	ISOC	1	145	2011-06-25T03:48:00.356	2011-06-25T03:48:03.513
0x050430000000000000000000C0A	ISOC	1	100	2011-06-25T03:48:00.516	2011-06-25T03:48:03.534
0x0504300000000000000000000BF5	ISOC	1	560	2011-06-25T03:47:55.023	2011-06-25T03:48:24.561

Polling Period (seconds): 5

Appendix C: Visual Representation of Protocol for Testing Read Range of Poynting Antenna

1. Begin Testing for Range by having the AD-224 Passive RFID tag flesh with the right side of the Poynting Antenna. This will be then be referred to as the angle of 0° .

2. Continue to move backwards in the same angle until the tag is no longer read by the Poynting Antenna. Measure the distance in which the tag is no longer read

3. Repeat same test for every angle between 0° and 180° at every interval of 20° .

Appendix D: Visual Representation of Protocol for Testing Readability of Passive RFID Tags within Testing Environment

<p>1. In order to recognize whether or not tags could be read within a pre-defined read range of the Poynting Antenna, a test should be conducted.</p> <p>First, determine identification number of each of the AD-224 Passive RFID tags that are to be used with a handheld portable</p>	<p>The diagram shows a Poynting Antenna at the top, which is a black rectangular device with a central orange antenna element. Below it is a handheld portable reader, identified as a Symbol MC 9060. The reader is a ruggedized device with a color screen displaying a blue interface, a numeric keypad, and various function buttons. The text 'Symbol MC 9060 Portable Reader' is printed below the device.</p>
<p>2. Place multiple tags within the read range of the Poynting Antenna and used Sirit Program to determine whether or not the tags are indeed read by the RFID components.</p>	<p>The photograph shows a testing environment. A yellow line is drawn on a dark carpeted floor, starting from a red circular marker and extending towards a white metal frame structure. Several small white rectangular tags are placed along this line. In the background, there is a white wall, a metal shelving unit, and a brown trash can.</p>

Appendix E: Testing the Number of Times a Passive RFID tag is read through different activities

<p>Activity #1: Test Subject Walks, within Environmental Setting, with Passive RFID Tag</p>	A man in a black t-shirt and dark shorts is walking on a white treadmill. He is looking towards the camera. The background shows a laboratory or office environment with various equipment and a desk.
<p>Activity#2: Test Subject Jogs, within Environmental Setting, with Passive RFID Tag</p>	A man in a black t-shirt and blue shorts is jogging in place. He is looking to his left. The background shows a laboratory or office environment with desks, chairs, and various equipment.
<p>Activity #3: Test Subject Walks, within Environmental Setting, with Passive RFID Tag inside Nerf Ball</p>	A man in a black t-shirt and glasses is holding a yellow Nerf ball with black patterns. He is looking at the ball. The background shows a laboratory or office environment with desks, chairs, and various equipment.

<p>Activity #4: Test Subject Runs, within Environmental Setting, with Passive RFID Tag inside Nerf Ball</p>	
<p>Activity #5: Test Subjects Roll Nerf Ball, with Passive RFID Tag inside, Back and Forth within Environmental Setting</p>
<p>Activity #6: Test Subjects Throws Nerf Ball, with Passive RFID Tag inside, Back and Forth within Environmental Setting</p>

Appendix F: Directionality in Testing Cubic Structure

Direction 1: Front Direction

Direction 2: Backward Direction

Direction 3: Right Direction

Direction 4: Left Direction

Direction 5: 45° Direction

Direction 6: 135° Direction

Appendix G: Height Change For Antenna

**Height 1: Direct Line of Sight
Between Antenna and RFID Passive
Tag**

**Height 2: One-foot Above Direct
Line of Sight Between Antenna and
RFID Passive Tag**

**Height 3: One-foot Below Direct
Line of Sight Between Antenna and
RFID Passive Tag**

Appendix H: Testing Protocol for Original Software Code [by Mr. Tyler Peabody] and Modified Software Code

Establishing Connection of all RFID Components of the System

1. Connect the power source cord into an electrical outlet and into the back end of the Sirit Reader.
2. Connect one end of the Ethernet Cord to a port of a laptop, and the other end of the Ethernet Cord to the port on the back end of the Sirit Reader.
3. Obtain four BNC cables. And, for each of the four antennas, connect the corresponding end of the BNC cable to the Poynting Antenna, and the other end into an input port of the Sirit Reader.
 - a. Reminder: Input 1 will correspond to Antenna 1, Input 2 will correspond to Antenna 2, Input 3 will correspond to Antenna 3, and Input 4 will correspond to Antenna 4.
4. To ensure that all connections are properly made, the use must look observe whether or not all LED lights [on the Sirit Reader] are green.
 - a. If a red LED light continues to flash, make sure that all connections are properly attached.

Creating Regional Zones for Testing Environment

1. In order to establish regional zones, it should be noted that three of the four antennas should be disconnected [remove the BNC cable from the inputs of the Sirit Reader]
2. Set attenuation of antenna at a desired value.
 - a. For original software code, attenuation of antenna must be changed in the Visual Basic command window.
 - b. For modified software code, attenuation of antenna may be changed on visual display in Visual Basic.
3. Begin testing by having the individual hold the tag flesh with the side of the antenna, which is at a corresponding angle of 0^0 in relation to the side of the antenna.
4. Once in the proper position, record the number of times that specific tag is read by the Antenna over a five second time interval.
5. Next, have the individual take a one inch step backwards and once again record the number of times that specific tag is read.
6. Repeat this step in the same line of path until the tag is no longer reader by the antenna, which corresponds to the identification tag no longer being seen in the summary page of the software program.
7. Record the distance
8. Repeat same procedural step at an angle of 90^0 and 180^0 , with respect to the other end of the antenna, and measure the corresponding distances
9. Once complete, do the same procedure for the other three Poynting Antennas.
10. Creation of Zones

- a. To indicate the max distance, place a tape on the ground at that specific distance and consider this length $[L_1]$.
- b. Next, once again use a measuring tape to identify the max read range of Antenna 2 [from the direction of Antenna 2 to Antenna 1].
 - i. Indicate this distance with another piece of tape and this distance will be referred to as length $[L_2]$.
- c. To determine the zone between Antenna 1 and Antenna 2, use the guidance of the placements of the tape.
 - i. With this, it is determined that Zone 1 will only be the region that corresponds to $[L_1]$, while Zone 2 corresponds to the overlap of the lengths $[L_1 - L_2]$, and Zone 3 will be the length that only has L_2 .
- d. Next, repeat the these procedural steps for each side of the Testing Cubic Structure [i.e. for the side of Antenna 1 and Antenna 3, Antenna 2 and Antenna 4, and also Antenna 3 and Antenna 4].
- e. By doing this, nine distinct zones will be established as the “regional zones” of the environmental setting.

Testing Accuracy of System

1. Prior to performing experimental tests on the accuracy of the system, one must ensure that all four of the Poynting Antennas have the desired Attenuation Levels.
2. Next, identify the identification tag number of the tag, to be tracked, with the use of a handheld RFID reader.
3. Once the ID number of tag has been identified, ensure that tag is recognized by system.
 - a. For original software code, the tag ID may be placed inside the code located in the Visual Basic command window.
 - b. For modified software code, select “StudentInfo” tab in Microsoft Access and place ID number into corresponding box.
4. Next, have the test subject enter zone 1 of the environmental setting.
 - a. The first direction that is to be evaluated should be Direction 1[Front Direction].
5. The user may then select “Register” followed by “Start Tracking” in order to begin testing.
 - a. After a time period of five seconds, record whether or not the software code [through the visual representation seen in Microsoft Access] is able to recognize that the RFID Passive Tag is indeed within Zone 1.
6. Next, have the test subject then move into Zone 2 holding the tag in the exact same position and direction and once again recording the accuracy of the detection process.
7. Repeat the same procedures for each of the nine zones.
8. Once complete, select “Stop Tracking” in order to deactivate the communication pathway.

9. Repeat the same steps [1-8] for different directional positions as identified in Section 9 of Appendix .
10. Repeat the same steps [1-9] for different attenuation levels
 - a. Attenuation Levels of 0, 15, 30, 50, and 100.

Appendix I: Directionality with Passive RFID Antenna Placeholder Stand

Direction 1: Front Direction

Direction 2: Backward Direction

Direction 3: Right Direction

Direction 4: Left Direction

Direction 5: 45⁰ Direction

Direction 6: 135⁰ Direction

Appendix J: Guide to New Modifications in Visual Display Seen in Microsoft Access 2007

Summary Key

1. Represents Object 1 Being Tracked
2. Represents Object 2 Being Tracked
3. Visual Display that shows the number of objects being seen in at least one of the nine zones.
4. Text Box that allows for the user to modify the Attenuation Level
5. Text Box that identifies the Antenna number that will be modified
6. Visual Display of the number of rounds that have been completed within that cycle
 - a. Pre-assigned to have 10 rounds per cycle.
7. Visual Display of the number of times each Antenna is able to read the corresponding Tag

- a. First row represents a display that exhibits the number of times each antenna recognizes the first object.
 - i. First Box = First Antenna
 - ii. Second Box = Second Antenna
 - iii. Third Box = Third Antenna
 - iv. Fourth Box = Fourth Antenna
- b. First row represents a display that exhibits the number of times each antenna recognizes the second object.
 - i. First Box = First Antenna
 - ii. Second Box = Second Antenna
 - iii. Third Box = Third Antenna
 - iv. Fourth Box = Fourth Antenna

Appendix K: Results for Read Accuracy Rate for Original Software Code

Test Conducted in Cubic Testing Structure

Height Level 1: Antenna and RFID Passive tag have direct line of sight

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	100	1	1	1	0	0	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	0	0	0	0	0	0	0	0
			4	1	0	0	0	0	0	0	0	0	1
			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	2	0	0	0	0	0	1	0	0	3
	100	2	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	1	0	1	0	0	0	0	0	0	2
	100	3	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	1	1
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	0	0	0	0	0	0	0	0	1	1

Test Conducted with the Four RFID Antenna Placeholder Stands

Height Level 1: Antenna and RFID Passive tag have direct line of sight

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	1	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	1	1
			3	0	0	1	0	0	0	0	0	0	1
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	1	0	2	0	0	0	0	0	1	4
	15	1	1	1	0	0	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	0	0	1	1
			3	0	0	1	0	0	0	0	0	0	1
			4	1	0	0	0	0	0	0	0	0	1
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	3	0	2	0	0	0	0	0	1	6
	30	1	1	0	0	0	0	0	0	0	1	0	1
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	0	0	0	0	0	0	1	1
			4	1	0	0	0	0	0	0	0	0	1
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	1	0	1	0	0	0	1	1	1	5
	50	1	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	0	0	0	0	0	0	1	1
			4	1	0	0	0	0	0	0	0	0	1
			5	0	0	0	0	0	0	0	0	0	0
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	2	0	0	0	0	0	1	0	2	5
	100	1	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0

			3	0	0	0	0	0	0	0	0	1	1
			4	0	0	0	0	0	0	1	0	0	1
			5	0	0	1	0	0	0	0	0	1	2
			6	0	0	0	0	0	0	1	0	0	1
Total Objects Read	---	---	---	0	0	1	0	0	0	2	0	2	5

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	2	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0
			3	0	0	1	0	0	0	0	0	0	1
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	0	0	2	0	0	0	0	0	0	2
	15	2	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	1	1
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	0	0	0	0	0	0	0	0	1	1
	30	2	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	0	0	1	0	0	0	1	0	0	2
	50	2	1	1	0	0	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	0	0	0	0	0	0	0	0
			4	1	0	0	0	0	0	0	0	0	1

			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	2	0	0	0	0	0	1	0	0	3
	100	2	1	1	0	0	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	1	0	0	0	0	0	0	0	0	1

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	3	1	0	0	1	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	0	0	1	1
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	0	0	1	0	0	0	0	0	1	2
	15	3	1	1	0	1	0	0	0	0	0	0	2
			2	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	1	0	2	0	0	0	0	0	0	3
	30	3	1	0	0	1	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	1	1
			6	0	0	0	0	0	0	0	0	0	0

Total Objects Read	---	---	---	0	0	1	0	0	0	0	0	1	2
	50	3	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	1	1
			3	0	0	0	0	0	0	0	0	1	1
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	0	0	1	0	0	0	0	0	2	3
	100	3	1	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	0	0	0	0	0	0	0
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	1	0	0	0	0	0	0	0	0	1

Appendix L: Results for Read Accuracy Rate for Modified Software Code [with one Passive RFID tag]

Test Conducted in Cubic Testing Structure

Height Level 1: Antenna and RFID Passive tag have direct line of sight

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	100	1	1	1	0	1	0	0	0	1	0	1	4
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	1	0	0	0	0	0	1	2
			4	1	0	1	0	0	0	1	0	0	3
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	3	0	4	0	0	0	3	0	2	12
	100	2	1	1	0	1	0	0	0	0	0	0	2
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	1	0	0	0	0	0	0	1
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	3	0	3	0	0	0	2	0	0	8
	100	3	1	1	0	0	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	0	0	1	1
			3	1	0	0	0	0	0	0	0	0	1
			4	0	0	1	0	0	0	1	0	0	2
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	3	0	2	0	0	0	1	0	1	7

Test Conducted with the Four RFID Antenna Placeholder Stands

Height Level 1: Antenna and RFID Passive tag have direct line of sight

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	1	1	1	0	0	1	0	0	1	0	1	4
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	1	0	0	0	1	0	1	3
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	1	0	0	0	1	0	0	2
			6	1	0	1	0	0	0	0	0	0	2
Total Objects Read	---	---	---	3	0	3	1	0	0	5	0	3	15
	15	1	1	1	0	1	0	0	0	0	0	1	3
			2	0	0	1	0	0	0	1	0	1	3
			3	0	0	1	0	0	0	1	0	1	3
			4	1	0	1	0	0	0	1	0	1	4
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	3	0	5	0	0	0	3	0	4	15
	30	1	1	1	0	0	0	0	0	0	1	0	2
			2	0	0	0	0	0	0	1	0	1	2
			3	1	0	1	0	1	0	0	0	1	4
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	1	0	0	1	0	0	0	2
			6	1	0	0	0	0	0	1	0	0	2
Total Objects Read	---	---	---	4	0	2	0	1	1	3	1	2	14
	50	1	1	1	0	1	0	0	0	1	0	1	4
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	1	0	0	0	0	0	1	2
			4	1	0	1	0	0	0	1	0	0	3
			5	0	0	1	0	0	0	0	0	1	2
			6	1	0	1	0	0	0	0	0	0	2
Total Objects Read	---	---	---	3	0	5	0	0	0	3	0	4	15
	100	1	1	1	0	1	0	0	0	1	0	0	3
			2	0	0	0	0	0	0	1	0	1	2

			3	0	0	1	0	0	0	0	0	0	1
			4	1	0	1	0	0	0	1	0	0	3
			5	0	0	1	0	0	0	0	0	1	2
			6	1	0	0	0	0	0	1	0	0	2
Total Objects Read	---	---	---	3	0	4	0	0	0	4	0	2	13

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	2	1	0	0	0	1	0	0	0	0	1	2
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	0	0	0	0	0	0	1	1
			4	1	0	0	0	0	0	0	0	0	1
			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	1	0	0	1	0	0	1	0	2	5
	15	2	1	0	0	1	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	0	0	1	1
			3	0	0	0	0	0	0	0	0	1	1
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	0	0	0	0	0	0	1	1
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	1	0	1	0	0	0	1	0	3	6
	30	2	1	1	0	1	0	0	0	0	0	0	2
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	1	0	0	0	0	0	0	1
			4	0	0	0	0	0	0	1	0	0	1
			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	1	0	2	0	0	0	2	0	1	6
	50	2	1	1	0	1	0	0	0	0	0	0	2
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	0	0	0	0	0	0	1	1
			4	1	0	0	0	0	0	1	0	0	2

			5	0	0	0	0	0	0	0	0	0	0
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	2	0	1	0	0	0	2	0	1	6
	100	2	1	1	0	1	0	0	0	1	0	0	3
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	0	0	0	0	0	0	0	0
			4	1	0	0	0	0	0	0	0	0	1
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	3	0	2	0	0	0	2	0	0	7

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	3	1	0	0	1	0	0	0	0	0	0	1
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	1	0	0	0	0	0	1	2
			4	0	0	0	0	0	0	1	0	0	1
			5	0	0	1	0	0	0	0	0	0	1
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	1	0	3	0	0	0	2	0	2	8
	15	3	1	1	0	1	0	0	0	0	0	0	2
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	1	0	0	0	0	0	0	1
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	0	0	0	0	0	0	0	0
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	3	0	2	0	0	0	2	0	1	8
	30	3	1	1	0	1	0	0	0	0	0	0	2
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	1	0	0	0	0	0	1	2
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	0	0	0	0

Total Objects Read	---	---	---	2	0	3	0	0	0	2	0	2	9
	50	3	1	1	0	1	0	0	0	0	0	0	2
			2	0	0	0	0	0	0	1	0	1	2
			3	0	0	0	0	0	0	0	0	1	1
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	1	0	0	1
Total Objects Read	---	---	---	2	0	2	0	0	0	3	0	2	9
	100	3	1	1	0	1	0	0	0	1	0	0	3
			2	0	0	0	0	0	0	1	0	0	1
			3	0	0	1	0	0	0	0	0	0	1
			4	0	0	0	0	0	0	0	0	0	0
			5	0	0	1	0	0	0	0	0	0	1
			6	0	0	0	0	0	0	0	0	0	0
Total Objects Read	---	---	---	1	0	3	0	0	0	2	0	0	6

Appendix M: Results for Read Accuracy Rate for Modified Software Code [with two Passive RFID tag]

Test Conducted in Cubic Testing Structure

Height Level 1: Antenna and RFID Passive tag have direct line of sight

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	100	1	1	1	1	1	0	0	0	0	1	0	4
			2	1	1	1	0	0	0	0	1	0	4
			3	1	0	0	1	1	1	1	0	1	6
			4	1	0	0	0	1	1	0	0	1	4
			5	1	0	0	0	1	0	1	0	0	3
			6	1	0	1	0	0	0	0	0	1	3
Total Objects Read	---	---	---	6	2	3	1	3	2	2	2	3	24
	100	2	1	1	0	1	0	0	0	0	1	0	3
			2	1	1	1	0	0	0	0	0	0	3
			3	0	0	0	1	1	1	1	0	0	4
			4	0	0	0	0	1	1	0	0	0	2
			5	1	0	0	0	0	0	1	0	0	2
			6	1	0	1	0	0	0	0	0	0	2
Total Objects Read	---	---	---	4	1	3	1	2	2	2	1	0	16
	100	3	1	0	0	1	0	0	0	0	1	1	3
			2	1	0	1	0	0	0	1	0	0	3
			3	0	0	0	1	1	1	0	0	0	3
			4	1	0	0	0	0	1	0	0	1	3
			5	1	0	0	0	0	0	1	0	1	3
			6	1	0	0	0	0	0	0	0	0	1
Total Objects Read	---	---	---	4	0	2	1	1	2	2	1	3	16

Test Conducted with the Four RFID Antenna Placeholder Stands

Height Level 1: Antenna and RFID Passive tag have direct line of sight

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	1	1	1	1	1	0	0	0	1	1	1	6
			2	1	1	1	0	1	0	0	1	0	5
			3	1	0	0	1	1	0	0	0	1	4
			4	1	0	1	0	1	1	0	0	0	4
			5	1	0	0	0	1	0	0	0	1	3
			6	1	0	0	0	0	0	1	0	1	3
Total Objects Read	---	---	---	6	2	3	1	4	1	2	2	4	25
	15	1	1	1	0	1	0	0	0	1	0	1	4
			2	1	0	1	0	0	0	1	0	1	4
			3	1	0	1	0	1	0	1	0	1	5
			4	1	1	1	0	1	0	1	0	1	6
			5	1	0	1	0	0	0	1	0	1	4
			6	1	0	1	0	0	0	1	0	0	3
Total Objects Read	---	---	---	6	1	6	0	2	0	6	0	5	26
	30	1	1	1	1	1	0	1	0	0	1	1	6
			2	1	1	0	0	1	1	1	0	1	6
			3	1	0	1	0	1	0	1	0	1	5
			4	1	0	0	0	1	0	1	0	0	3
			5	0	1	1	0	0	1	0	0	0	3
			6	1	0	0	1	0	0	1	0	0	3
Total Objects Read	---	---	---	5	3	3	1	4	2	4	1	3	26
	50	1	1	1	0	1	1	1	0	1	0	1	6
			2	1	0	1	0	1	0	1	0	1	5
			3	0	0	1	0	1	0	1	0	1	4
			4	1	0	1	0	0	0	1	0	1	4
			5	0	0	1	1	0	1	0	0	1	4
			6	1	0	0	0	0	0	0	1	0	2
Total Objects Read	---	---	---	4	0	5	2	3	1	4	1	5	25
	100	1	1	1	1	1	0	0	0	1	1	1	6
			2	1	1	1	0	0	0	1	0	1	5

			3	1	0	1	1	0	1	1	0	1	6
			4	0	0	0	0	0	0	1	0	1	2
			5	1	0	0	0	0	0	1	0	1	3
			6	1	0	0	1	0	0	1	0	1	4
Total Objects Read	---	---	---	5	2	3	2	0	1	6	1	6	26

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	2	1	1	1	0	0	1	0	1	0	1	5
			2	0	1	1	1	0	0	0	1	0	4
			3	1	0	0	0	1	0	0	0	1	3
			4	0	0	1	1	1	0	0	0	0	3
			5	0	0	0	0	1	0	0	0	1	2
			6	1	0	0	0	0	0	1	0	0	2
Total Objects Read	---	---	---	3	2	2	2	4	0	2	1	3	19
	15	2	1	0	0	1	0	0	0	1	0	0	2
			2	1	0	0	0	1	0	0	0	1	3
			3	1	0	1	0	0	0	0	0	1	3
			4	0	1	1	0	1	0	0	0	1	4
			5	1	0	0	0	0	0	1	0	0	2
			6	1	0	1	0	0	0	1	0	0	3
Total Objects Read	---	---	---	4	1	4	0	2	0	3	0	3	17
	30	2	1	0	1	0	0	1	0	0	0	1	3
			2	1	1	0	0	1	0	0	0	1	4
			3	1	0	1	0	0	0	1	0	1	4
			4	1	0	0	0	0	0	1	0	0	2
			5	0	1	1	0	0	0	0	0	0	2
			6	1	0	0	1	0	0	1	0	0	3
Total Objects Read	---	---	---	4	3	2	1	2	0	3	0	3	18
	50	2	1	0	0	1	0	1	0	0	0	1	3
			2	1	0	0	0	0	0	1	0	1	3
			3	1	0	1	0	1	0	0	0	1	4
			4	1	0	1	0	0	0	1	0	0	3

			5	0	0	1	0	0	0	0	0	1	2
			6	1	0	0	0	1	0	0	1	0	3
Total Objects Read	---	---	---	4	0	4	0	3	0	2	1	4	18
	100	2	1	0	0	1	0	1	1	0	1	0	4
			2	1	1	0	0	0	0	0	0	1	3
			3	0	0	1	0	0	1	1	0	0	3
			4	1	0	0	0	1	0	1	0	0	3
			5	0	1	1	0	0	0	0	0	1	3
			6	1	0	0	0	1	0	0	0	0	2
Total Objects Read	---	---	---	3	2	3	0	3	2	2	1	2	18

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	3	1	1	0	1	0	1	0	1	0	0	4
			2	0	1	0	1	0	0	0	1	1	4
			3	0	0	1	0	1	0	0	0	1	3
			4	1	0	0	0	1	0	1	0	0	3
			5	0	0	1	0	0	0	0	0	1	2
			6	1	0	0	0	0	0	0	1	0	2
Total Objects Read	---	---	---	3	1	3	1	3	0	2	2	3	18
	15	3	1	1	0	1	0	0	1	1	0	0	4
			2	0	0	0	0	1	0	1	0	1	3
			3	0	0	1	0	1	0	1	0	1	4
			4	0	1	0	0	1	0	0	0	1	3
			5	1	0	0	0	0	0	1	0	1	3
			6	0	0	1	0	0	0	1	0	0	2
Total Objects Read	---	---	---	2	1	3	0	3	1	5	0	4	19
	30	1	1	1	1	0	0	1	0	0	0	0	3
			2	0	1	0	0	1	0	0	0	1	3
			3	1	0	1	0	0	1	0	0	0	3
			4	0	0	1	0	0	0	1	1	0	3
			5	1	0	1	0	0	0	1	0	0	3
			6	1	0	0	1	0	0	1	0	0	3

Total Objects Read	---	---	---	4	2	3	1	2	1	3	1	1	18
	50	1	1	1	0	1	0	1	0	0	0	1	4
			2	1	0	0	0	1	0	1	0	1	4
			3	1	0	0	0	1	0	0	0	0	2
			4	1	0	0	0	0	0	1	0	0	2
			5	0	0	1	0	0	1	0	0	1	3
			6	1	0	0	1	0	0	0	1	0	3
Total Objects Read	---	---	---	5	0	2	1	3	1	2	1	3	18
	100	1	1	0	0	0	1	1	1	0	1	0	4
			2	1	0	0	1	0	0	0	0	1	3
			3	0	0	1	1	0	1	1	0	0	4
			4	1	1	0	0	0	0	1	0	0	3
			5	0	0	1	1	0	0	0	1	0	3
			6	0	1	0	0	1	0	0	0	0	2
Total Objects Read	---	---	---	2	2	2	4	2	2	2	2	1	19

Appendix N: Results for Read Accuracy Rate for Modified Software Code [with three Passive RFID tag]

Test Conducted in Cubic Testing Structure

Height Level 1: Antenna and RFID Passive tag have direct line of sight

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	100	1	1	1	0	1	1	0	0	0	1	1	5
			2	1	1	0	0	1	0	1	1	1	6
			3	1	1	1	0	1	1	1	0	1	7
			4	1	1	0	0	1	1	1	0	1	6
			5	1	0	1	0	0	1	0	0	1	4
			6	1	1	0	0	0	1	1	0	0	4
Total Objects Read	---	---	---	6	3	3	1	3	4	4	2	5	32
	100	2	1	1	0	0	1	0	0	0	1	0	3
			2	1	0	0	0	1	0	0	1	1	4
			3	1	1	1	0	0	1	1	0	1	6
			4	1	1	0	0	1	0	1	0	1	5
			5	0	0	1	0	0	1	0	0	1	3
			6	1	1	0	0	0	1	1	0	0	4
Total Objects Read	---	---	---	5	3	2	1	2	3	3	2	4	25
	100	3	1	1	0	1	1	0	0	0	1	0	4
			2	0	0	0	0	1	0	1	1	1	4
			3	0	1	1	0	0	1	1	0	0	4
			4	1	0	0	1	1	0	1	0	1	5
			5	0	0	1	0	1	1	0	0	1	4
			6	1	1	1	0	0	1	1	0	0	5
Total Objects Read	---	---	---	3	2	4	2	3	3	4	2	3	26

Test Conducted with the Four RFID Antenna Placeholder Stands

Height Level 1: Antenna and RFID Passive tag have direct line of sight

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	1	1	1	0	1	0	1	0	0	1	1	5
			2	1	0	1	0	1	0	0	1	1	5
			3	1	0	1	0	1	1	1	0	1	6
			4	1	0	1	1	1	0	0	0	1	5
			5	1	0	0	0	1	0	1	0	1	4
			6	0	0	1	0	1	0	1	1	1	5
Total Objects Read	---	---	---	5	0	5	1	6	1	3	3	6	30
	15	1	1	1	0	0	1	1	0	1	0	1	5
			2	1	1	1	0	1	0	1	1	1	7
			3	1	0	1	0	1	0	0	0	1	4
			4	1	0	1	0	1	0	0	1	1	5
			5	1	0	1	1	0	1	1	0	1	6
			6	1	0	1	0	1	0	1	1	0	5
Total Objects Read	---	---	---	6	1	5	2	5	1	4	3	5	32
	30	1	1	1	1	1	0	1	1	0	1	1	7
			2	1	0	0	1	1	1	1	0	0	5
			3	1	0	1	1	1	0	0	0	1	5
			4	1	0	0	1	1	1	1	0	1	6
			5	0	1	1	0	0	1	1	0	1	5
			6	1	1	0	1	1	0	1	1	0	6
Total Objects Read	---	---	---	5	3	3	4	5	4	4	2	4	34
	50	1	1	1	1	0	1	1	1	1	0	0	6
			2	1	0	1	0	1	1	0	1	1	6
			3	1	0	1	0	1	0	0	1	1	5
			4	1	1	1	1	0	0	0	0	1	5
			5	0	0	1	1	1	1	0	0	1	5
			6	1	1	0	1	0	0	1	1	0	5
Total Objects Read	---	---	---	5	3	4	4	4	3	2	3	4	32
	100	1	1	1	1	1	0	1	0	1	1	1	7
			2	1	0	1	1	0	0	1	0	1	5

			3	1	0	1	1	1	1	0	0	1	6
			4	1	1	1	0	0	1	1	1	0	6
			5	1	0	1	1	0	0	1	0	1	5
			6	1	0	0	1	1	0	0	1	0	4
Total Objects Read	---	---	---	6	2	5	4	3	2	4	3	4	33

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	2	1	1	1	0	1	1	0	1	0	0	5
			2	0	0	1	1	0	1	1	1	0	5
			3	1	0	0	0	0	1	0	0	1	3
			4	1	0	1	1	1	0	1	0	0	5
			5	0	1	0	0	1	0	1	0	1	4
			6	1	0	0	1	0	0	1	1	0	4
Total Objects Read	---	---	---	4	2	2	4	3	2	5	2	2	26
	15	2	1	0	0	1	0	0	1	1	0	1	4
			2	1	0	0	1	0	0	1	0	1	4
			3	1	0	0	1	0	1	0	0	1	4
			4	0	0	1	0	1	0	1	0	1	4
			5	0	1	0	0	1	1	1	1	0	5
			6	1	0	1	1	0	1	0	1	0	5
Total Objects Read	---	---	---	3	1	3	3	2	4	4	2	4	26
	30	2	1	1	1	0	0	0	1	0	0	1	4
			2	1	0	1	1	0	0	1	0	0	4
			3	1	0	1	0	1	0	1	0	1	5
			4	1	0	1	0	0	0	1	0	1	4
			5	0	1	1	0	0	1	0	1	0	4
			6	1	0	0	1	1	1	1	0	0	5
Total Objects Read	---	---	---	5	2	4	2	3	3	4	1	3	26
	50	2	1	1	0	1	0	1	0	1	0	1	5
			2	1	1	0	0	1	0	1	0	1	5
			3	0	0	1	1	1	0	0	0	1	4
			4	1	0	1	0	1	0	1	1	0	5

			5	1	0	1	0	0	1	0	0	1	4
			6	1	0	0	1	0	0	0	1	0	3
Total Objects Read	---	---	---	5	1	4	2	4	1	3	2	4	26
	100	2	1	0	1	0	1	0	1	0	1	0	4
			2	1	1	0	0	1	0	0	0	1	4
			3	0	1	0	0	0	1	0	1	0	3
			4	0	1	0	0	1	0	0	0	1	3
			5	1	1	1	0	1	0	1	0	1	6
			6	1	0	0	0	1	1	1	0	1	5
Total Objects Read	---	---	---	3	5	1	1	4	3	2	2	4	25

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	3	1	1	0	0	1	1	0	1	0	0	4
			2	1	0	0	0	1	0	0	0	1	3
			3	1	0	1	0	1	0	1	0	1	5
			4	1	1	0	0	1	0	1	1	0	5
			5	0	0	1	0	1	1	0	0	1	4
			6	1	0	1	0	1	0	1	1	0	5
Total Objects Read	---	---	---	5	1	3	1	6	1	4	2	3	26
	15	3	1	1	0	1	0	0	1	0	1	0	4
			2	0	1	0	1	0	0	1	0	1	4
			3	0	0	1	0	1	1	1	0	1	5
			4	1	1	0	1	1	0	0	0	1	5
			5	1	0	0	1	0	1	1	0	1	5
			6	0	1	1	0	1	0	1	0	0	4
Total Objects Read	---	---	---	3	3	3	3	3	3	4	1	4	27
	30	1	1	1	1	0	0	1	0	0	1	1	5
			2	0	1	1	0	1	1	1	0	0	5
			3	1	0	1	0	0	1	0	1	0	4
			4	1	0	1	1	0	0	1	1	0	5
			5	0	0	1	1	1	0	1	0	0	4
			6	1	0	0	1	0	0	1	0	1	4

Total Objects Read	---	---	---	4	2	4	3	3	2	4	3	2	27
	50	1	1	1	0	1	1	1	1	0	0	1	6
			2	1	1	0	1	0	0	1	0	1	5
			3	0	0	1	1	1	0	0	1	0	4
			4	1	1	1	0	1	0	0	0	1	5
			5	0	1	0	0	0	1	0	0	1	3
			6	0	0	0	1	0	0	1	1	0	3
Total Objects Read	---	---	---	3	3	3	4	3	2	2	2	4	26
	100	1	1	0	1	0	1	1	1	0	1	0	5
			2	1	0	0	1	1	0	1	0	1	5
			3	0	0	1	1	0	1	1	1	0	5
			4	1	0	1	0	1	0	1	1	0	5
			5	1	0	0	1	0	1	0	1	0	4
			6	0	1	0	0	1	0	0	0	1	3
Total Objects Read	---	---	---	3	2	2	4	4	3	3	4	2	27

Appendix O: Results for Read Accuracy Rate for Modified Software Code [with four Passive RFID tag]

Test Conducted in Cubic Testing Structure

Height Level 1: Antenna and RFID Passive tag have direct line of sight

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	100	1	1	1	0	1	1	1	1	0	1	1	7
			2	1	0	0	1	1	0	1	1	1	6
			3	1	1	1	0	1	1	1	1	1	8
			4	1	1	0	0	1	1	1	0	1	6
			5	1	0	1	1	0	1	1	0	1	6
			6	1	1	0	1	0	1	1	0	1	6
Total Objects Read	---	---	---	6	3	3	4	4	5	5	3	6	39
	100	2	1	1	0	0	1	0	1	0	1	1	5
			2	1	1	0	0	1	1	0	1	1	6
			3	1	1	0	0	1	1	1	0	1	6
			4	1	0	1	0	1	0	1	0	1	5
			5	0	1	1	0	0	1	1	0	1	5
			6	1	1	0	1	0	1	1	0	0	5
Total Objects Read	---	---	---	5	4	2	2	3	5	4	2	5	32
	100	3	1	1	1	1	1	0	1	0	1	0	6
			2	0	1	0	1	1	0	1	0	1	5
			3	0	1	0	1	0	1	1	0	1	5
			4	1	0	1	0	1	0	1	0	1	5
			5	1	0	1	0	1	1	0	1	1	6
			6	1	0	1	0	1	1	1	1	0	6
Total Objects Read	---	---	---	4	3	4	3	4	4	4	3	4	33

Test Conducted with the Four RFID Antenna Placeholder Stands

Height Level 1: Antenna and RFID Passive Tag have direct line of sight

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	1	1	1	1	1	0	1	0	1	1	1	7
			2	1	0	0	1	1	0	0	1	1	5
			3	1	1	1	0	0	1	1	0	1	6
			4	1	0	1	1	1	1	0	1	1	7
			5	1	1	0	1	1	0	1	0	1	6
			6	1	1	1	0	1	0	1	1	1	7
Total Objects Read	---	---	---	6	4	4	3	5	2	4	4	6	38
	15	1	1	1	1	0	1	1	1	1	0	1	7
			2	1	0	1	1	1	1	1	1	1	8
			3	1	1	1	0	0	0	1	0	1	5
			4	1	0	1	1	1	0	1	1	1	7
			5	1	1	0	1	0	1	1	0	1	6
			6	1	0	1	0	1	1	1	1	0	6
Total Objects Read	---	---	---	6	3	4	4	4	4	6	3	5	39
	30	1	1	1	1	1	1	1	1	0	1	1	8
			2	1	1	0	1	1	1	1	0	1	7
			3	1	0	1	1	1	0	1	0	0	5
			4	1	1	0	1	1	1	1	0	1	7
			5	0	1	1	1	0	1	0	1	1	6
			6	1	1	0	1	0	0	1	1	1	6
Total Objects Read	---	---	---	5	5	3	6	4	4	4	3	5	39
	50	1	1	1	1	0	1	1	1	1	1	0	7
			2	1	1	1	0	1	1	0	1	1	7
			3	1	0	1	0	1	0	1	1	1	6
			4	1	1	1	1	1	0	0	1	1	7
			5	0	0	1	1	1	1	1	0	1	6
			6	1	1	0	1	0	1	1	1	0	6
Total Objects Read	---	---	---	5	4	4	4	5	4	4	5	4	39
	100	1	1	1	1	1	0	1	1	1	0	1	7
			2	1	0	1	1	0	1	1	0	1	6

			3	1	0	1	0	1	1	0	1	1	6
			4	1	1	1	1	1	1	1	1	1	9
			5	1	0	0	1	1	0	1	1	1	6
			6	1	1	0	1	1	0	1	1	0	6
Total Objects Read	---	---	---	6	3	4	4	5	4	5	4	5	40

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	2	1	1	0	0	1	1	0	1	0	1	5
			2	1	0	0	0	1	0	0	1	1	4
			3	1	0	1	0	1	1	1	1	1	7
			4	1	1	1	1	1	0	0	0	1	6
			5	1	0	1	0	1	0	1	0	1	5
			6	0	1	1	0	1	0	1	1	1	6
Total Objects Read	---	---	---	5	2	4	2	6	1	4	3	6	33
	15	2	1	1	1	0	1	1	0	1	0	1	6
			2	1	1	1	0	1	1	0	1	1	7
			3	1	0	1	1	1	0	1	0	1	6
			4	0	1	1	0	0	0	0	1	1	4
			5	1	0	1	0	0	1	1	0	1	5
			6	1	1	1	0	1	0	1	1	0	6
Total Objects Read	---	---	---	5	4	5	2	4	2	4	3	5	34
	30	2	1	0	1	1	0	1	1	0	1	1	6
			2	1	1	0	0	1	1	1	0	0	5
			3	1	0	1	1	0	0	1	0	1	5
			4	1	0	0	1	1	1	1	1	1	7
			5	0	1	1	0	0	1	0	1	1	5
			6	0	1	1	1	1	0	1	1	0	6
Total Objects Read	---	---	---	3	4	4	3	4	4	4	4	4	34
	50	2	1	1	1	0	1	0	1	1	0	0	5
			2	1	0	1	0	0	1	1	1	1	6
			3	1	0	1	0	1	1	0	1	1	6
			4	1	1	1	1	0	1	1	0	1	7

			5	1	0	1	1	1	1	0	0	1	6
			6	1	0	0	1	1	0	1	1	0	5
Total Objects Read	---	---	---	6	2	4	4	3	5	4	3	4	35
	100	2	1	1	1	1	0	1	0	0	1	1	6
			2	1	1	1	1	0	0	1	0	1	6
			3	0	0	1	1	1	1	0	1	1	6
			4	1	1	0	0	1	1	1	1	0	6
			5	1	0	1	1	0	0	1	0	1	5
			6	0	1	1	1	1	0	0	1	0	5
Total Objects Read	---	---	---	4	4	5	4	4	2	3	4	4	34

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	3	1	1	0	1	0	1	0	0	1	1	5
			2	1	1	0	0	1	1	0	0	1	5
			3	0	0	1	0	0	0	1	1	1	4
			4	1	1	1	1	0	1	0	0	1	6
			5	1	0	1	1	1	0	1	0	1	6
			6	0	1	1	0	1	1	1	1	1	7
Total Objects Read	---	---	---	4	3	5	2	4	3	3	3	6	33
	15	3	1	1	1	1	1	1	0	1	1	1	8
			2	1	0	1	0	1	1	0	1	0	5
			3	1	0	0	1	1	0	1	0	0	4
			4	0	1	0	0	0	1	0	1	1	4
			5	0	0	1	1	0	1	1	0	1	5
			6	1	1	0	0	1	1	1	1	0	6
Total Objects Read	---	---	---	4	3	3	3	4	4	4	4	3	32
	30	1	1	0	0	1	1	1	1	0	1	1	6
			2	1	1	0	0	0	1	1	0	0	4
			3	1	0	1	1	1	0	1	0	1	6
			4	1	1	0	1	0	1	1	1	1	7
			5	1	1	1	0	0	1	0	1	1	6
			6	0	0	1	1	1	0	1	1	0	5

Total Objects Read	---	---	---	4	3	4	4	3	4	4	4	4	34
	50	1	1	1	1	0	1	1	1	1	0	1	7
			2	1	0	0	0	0	0	1	1	1	4
			3	1	1	1	0	1	1	0	1	1	7
			4	0	1	1	1	0	1	1	0	1	6
			5	1	0	1	1	1	1	0	0	0	5
			6	1	1	0	1	1	0	1	1	0	6
Total Objects Read	---	---	---	5	4	3	4	4	4	4	3	4	35
	100	1	1	1	0	1	0	1	0	0	1	1	5
			2	1	1	1	1	0	1	1	0	1	7
			3	0	0	0	1	1	1	1	1	1	6
			4	1	0	0	0	1	1	1	1	0	5
			5	1	1	1	1	0	0	1	0	0	5
			6	0	1	1	1	1	0	0	1	1	6
Total Objects Read	---	---	---	4	3	4	4	4	3	4	4	4	34

Appendix P: Results for Read Accuracy Rate for Modified Software Code [with six Passive RFID tag]

Test Conducted in Cubic Testing Structure

Height Level 1: Antenna and RFID Passive tag have direct line of sight

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	100	1	1	1	1	1	1	1	1	0	1	1	8
			2	1	0	1	1	1	0	1	1	1	7
			3	1	1	1	1	1	1	1	1	1	9
			4	1	1	1	0	1	1	1	0	1	7
			5	1	0	1	1	0	1	1	1	1	7
			6	1	1	0	1	1	1	1	1	1	8
Total Objects Read	---	---	---	6	4	5	5	5	5	5	5	6	46
	100	2	1	1	0	1	1	0	1	0	1	0	5
			2	1	1	1	0	1	1	1	1	1	8
			3	0	1	0	1	1	1	1	0	1	6
			4	1	1	1	0	1	1	1	0	1	7
			5	1	0	1	1	0	1	1	1	1	7
			6	1	1	0	1	1	1	1	1	0	7
Total Objects Read	---	---	---	5	4	4	4	4	6	5	4	4	40
	100	3	1	1	1	1	1	0	1	0	1	0	6
			2	1	1	0	1	1	1	1	0	1	7
			3	0	1	0	1	0	1	1	1	1	6
			4	1	0	1	0	1	0	1	1	1	6
			5	1	1	1	0	1	1	0	1	1	7
			6	1	1	1	0	1	1	1	1	0	7
Total Objects Read	---	---	---	5	5	4	3	4	5	4	5	4	39

Test Conducted with the Four RFID Antenna Placeholder Stands

Height Level 1: Antenna and RFID Passive Tag have direct line of sight

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	1	1	1	1	1	1	1	0	1	1	1	8
			2	1	1	1	1	1	1	0	1	1	8
			3	1	1	1	1	1	1	1	0	1	8
			4	1	0	1	1	1	1	1	1	1	8
			5	1	1	0	1	1	0	1	1	1	7
			6	1	1	1	0	1	1	0	1	1	7
Total Objects Read	---	---	---	6	5	5	5	6	4	4	5	6	46
	15	1	1	1	0	1	1	1	1	1	1	1	8
			2	1	1	1	1	1	1	1	0	1	8
			3	1	1	1	1	1	0	1	1	1	8
			4	1	0	1	1	1	0	1	1	1	7
			5	1	1	1	1	0	1	1	0	1	7
			6	1	1	1	0	1	1	1	1	1	8
Total Objects Read	---	---	---	6	4	6	5	5	4	6	4	6	46
	30	1	1	1	0	1	1	1	1	1	1	1	8
			2	1	1	1	1	1	0	1	0	1	7
			3	1	1	1	1	1	1	1	1	1	9
			4	1	0	1	0	1	1	1	1	1	7
			5	1	1	1	1	1	1	0	1	1	8
			6	1	1	1	1	0	1	1	1	1	8
Total Objects Read	---	---	---	6	4	6	5	5	5	5	5	6	47
	50	1	1	1	1	1	1	0	1	1	1	1	8
			2	1	1	1	1	1	1	1	1	1	9
			3	1	0	1	0	1	1	1	1	1	7
			4	1	1	1	0	1	0	1	1	1	7
			5	1	1	1	1	1	1	1	0	1	8
			6	1	1	1	1	0	1	1	1	1	8
Total Objects Read	---	---	---	6	5	6	4	4	5	6	5	6	47
	100	1	1	1	0	1	1	0	1	1	0	1	6
			2	1	1	1	1	0	1	1	1	1	8

			3	1	1	1	0	1	1	1	1	1	8
			4	1	0	1	1	1	1	1	1	1	8
			5	1	1	1	1	1	0	1	1	1	8
			6	1	1	1	1	1	1	1	0	1	8
Total Objects Read	---	---	---	6	4	6	5	4	5	6	4	6	46

Height Level 2: Antenna one-foot above the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	2	1	1	1	1	1	1	0	1	0	1	7
			2	1	0	1	0	1	1	1	1	1	7
			3	1	0	1	0	1	1	1	1	1	7
			4	1	1	1	1	1	0	1	0	1	7
			5	1	0	1	0	1	0	1	0	1	5
			6	1	1	1	1	1	0	1	1	1	8
Total Objects Read	---	---	---	6	3	6	3	6	2	6	3	6	41
	15	2	1	1	1	1	1	1	0	1	0	1	7
			2	1	0	0	1	1	1	1	1	1	7
			3	1	1	1	0	1	1	0	1	1	7
			4	1	1	1	1	0	0	1	0	1	6
			5	0	1	1	0	1	0	1	0	1	5
			6	1	0	1	1	1	0	1	1	1	7
Total Objects Read	---	---	---	5	4	5	4	5	2	5	3	6	39
	30	2	1	0	1	1	1	1	0	1	0	1	6
			2	1	0	0	1	1	1	1	1	1	7
			3	1	1	1	0	1	1	0	1	0	6
			4	1	1	1	1	0	0	1	1	1	7
			5	1	1	1	0	1	0	1	0	1	6
			6	1	0	1	1	1	1	1	1	1	8
Total Objects Read	---	---	---	5	4	5	4	5	3	5	3	6	40
	50	2	1	1	0	1	1	1	0	1	0	1	6
			2	1	0	1	1	1	1	1	0	1	7
			3	1	1	1	0	1	1	0	1	0	6
			4	1	1	0	1	0	1	1	1	1	7

			5	1	1	1	0	1	1	1	0	1	7
			6	1	0	0	1	1	0	1	1	1	6
Total Objects Read	---	---	---	6	3	4	4	5	4	5	3	5	39
	100	2	1	1	1	1	1	1	0	1	0	1	7
			2	1	0	1	1	1	1	1	0	1	7
			3	1	1	1	0	1	1	0	1	0	6
			4	0	1	1	1	0	1	1	1	1	7
			5	0	1	1	0	1	1	1	1	1	7
			6	1	0	0	1	1	0	1	1	1	6
Total Objects Read	---	---	---	5	4	4	4	5	4	5	4	5	40

Height Level 3: Antenna one-foot below the straight line of sight to the Passive RFID tag

				Zone									
	Attenuation Level	Height Level	Direction	1	2	3	4	5	6	7	8	9	Total Objects Read
	0	2	1	1	1	1	1	1	0	1	0	1	7
			2	1	0	1	0	1	1	1	1	1	7
			3	1	0	1	0	1	1	1	1	1	7
			4	1	1	1	1	1	0	1	0	1	7
			5	1	0	1	0	1	0	1	0	1	5
			6	1	1	1	1	1	0	1	1	1	8
Total Objects Read	---	---	---	6	3	6	3	6	2	6	3	6	41
	15	2	1	1	1	1	1	1	0	1	0	1	7
			2	1	0	0	1	1	1	1	1	1	7
			3	1	1	1	0	1	1	0	1	1	7
			4	1	1	1	1	0	0	1	0	1	6
			5	0	1	1	0	1	0	1	0	1	5
			6	1	0	1	1	1	0	1	1	1	7
Total Objects Read	---	---	---	5	4	5	4	5	2	5	3	6	39
	30	2	1	0	1	1	1	1	0	1	0	1	6
			2	1	0	0	1	1	1	1	1	1	7
			3	1	1	1	0	1	1	0	1	0	6
			4	1	1	1	1	0	0	1	1	1	7
			5	1	1	1	0	1	0	1	0	1	6
			6	1	0	1	1	1	1	1	1	1	8

Total Objects Read	---	---	---	5	4	5	4	5	3	5	3	6	40
	50	2	1	1	0	1	1	1	0	1	0	1	6
			2	1	0	1	1	1	1	1	0	1	7
			3	1	1	1	0	1	1	0	1	0	6
			4	1	1	0	1	0	1	1	1	1	7
			5	1	1	1	0	1	1	1	0	1	7
			6	1	0	0	1	1	0	1	1	1	6
Total Objects Read	---	---	---	6	3	4	4	5	4	5	3	5	39
	100	2	1	1	1	1	1	1	0	1	0	1	7
			2	1	0	1	1	1	1	1	0	1	7
			3	1	1	1	0	1	1	0	1	0	6
			4	0	1	1	1	0	1	1	1	1	7
			5	0	1	1	0	1	1	1	1	1	7
			6	1	0	0	1	1	0	1	1	1	6
Total Objects Read	---	---	---	4	4	5	4	5	4	5	4	5	40

Appendix Q: Statistical Analysis Results From Minitab

General Regression Analysis: Tags Read versus Code Number, Height Level, ...

Coefficients

Term	Coef	SE Coef	T	P
Constant	3.85741	0.0325916	118.356	0.000
Code Number				
0	-3.35741	0.0728771	-46.069	0.000
1	-2.27963	0.0728771	-31.280	0.000
2	-0.41296	0.0728771	-5.667	0.000
3	0.84259	0.0728771	11.562	0.000
4	2.06481	0.0728771	28.333	0.000
Attenuation Level				
0	-0.04259	0.0651833	-0.653	0.514
15	-0.01481	0.0651833	-0.227	0.820
30	0.04074	0.0651833	0.625	0.532
50	0.03148	0.0651833	0.483	0.629
Height Level				
1	0.65926	0.0460915	14.303	0.000
2	-0.37407	0.0460915	-8.116	0.000
Direction				
1	0.39815	0.0728771	5.463	0.000
2	0.17593	0.0728771	2.414	0.016
3	-0.02407	0.0728771	-0.330	0.741
4	0.07593	0.0728771	1.042	0.298
5	-0.34630	0.0728771	-4.752	0.000

Summary of Model

S = 0.757361 R-Sq = 90.88% R-Sq(adj) = 90.60%
PRESS = 319.810 R-Sq(pred) = 90.27%

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	16	2988.03	2988.03	186.752	325.581	0.000000
Code Number	5	2833.99	2833.99	566.797	988.147	0.000000
Attenuation Level	4	0.53	0.53	0.132	0.231	0.921049
Height Level	2	118.06	118.06	59.030	102.911	0.000000
Direction	5	35.45	35.45	7.091	12.362	0.000000
Error	523	299.99	299.99	0.574		
Total	539	3288.02				

Fits and Diagnostics for Unusual Observations

Obs	Tags Read	Fit	SE Fit	Residual	St Resid	
1	0	1.51481	0.134379	-1.51481	-2.03237	R
19	0	1.58889	0.134379	-1.58889	-2.13175	R
25	0	1.9259	0.134379	-1.9259	-2.06964	R
100	4	2.29815	0.134379	1.70185	2.28331	R
105	4	2.25370	0.134379	1.74630	2.34294	R
181	6	4.45926	0.134379	1.9074	2.06715	R
190	6	4.16481	0.134379	1.83519	2.46220	R
194	6	4.32037	0.134379	1.67963	2.25349	R
204	2	3.85556	0.134379	-1.85556	-2.48953	R
205	6	4.48704	0.134379	1.51296	2.02988	R

207	6	4.06481	0.134379	1.93519	2.59636	R
208	2	4.16481	0.134379	-2.16481	-2.90445	R
211	5	3.42593	0.134379	1.57407	2.11187	R
329	6	3.96481	0.134379	2.03519	2.73053	R
332	3	4.9815	0.134379	-1.9815	-2.07709	R
362	5	6.71481	0.134379	-1.71481	-2.30070	R
369	5	6.9259	0.134379	-1.9259	-2.06964	R
375	5	6.59815	0.134379	-1.59815	-2.14417	R
388	9	6.64259	0.134379	2.35741	3.16284	R
392	4	5.68148	0.134379	-1.68148	-2.25598	R
393	7	5.48148	0.134379	1.51852	2.03734	R
400	4	5.60926	0.134379	-1.60926	-2.15908	R
423	4	5.57037	0.134379	-1.57037	-2.10691	R
426	7	5.31481	0.134379	1.68519	2.26095	R
427	8	6.02037	0.134379	1.97963	2.65599	R
429	4	5.59815	0.134379	-1.59815	-2.14417	R
430	4	5.69815	0.134379	-1.69815	-2.27834	R
434	4	5.85370	0.134379	-1.85370	-2.48704	R
440	4	5.84444	0.134379	-1.84444	-2.47462	R
475	6	8.04259	0.134379	-2.04259	-2.74047	R
486	8	6.30370	0.134379	1.69630	2.27586	R
498	8	6.38704	0.134379	1.61296	2.16405	R
516	8	6.39259	0.134379	1.60741	2.15660	R
528	8	6.47593	0.134379	1.52407	2.04479	R

R denotes an observation with a large standardized residual.

Appendix R: Test Regarding Feasibility of Reading Multiple Objects with Modified Software Code Used in Visual Basic

1	2	3
4	5	6
7	8	9

3	4	1	0
1	0	2	7

10

Current Read:

1	2	3
4	5	6
7	8	9

3	4	7	5
4	6	3	3

10

Current Read:

1	2	3
4	5	6
7	8	9

2062

10

Current Read:

Refresh

Start Tracking

Connect

Set Attenuation

Register

15

1 2 3 4

1	2	3
4	5	6
7	8	9

1811

10

Current Read:

Refresh

Start Tracking

Connect

Set Attenuation

Register

15

1 2 3 4

1	2	3
4	5	6
7	8	9

0

0

8

9

10

7

4

1

1

Current Read: 2

Refresh
Start Tracking

Connect
Set Attenuation

Register
30

1 2 3 4

1	2	3
4	5	6
7	8	9

0

1

0

9

10

8

2

0

0

Current Read: 2

Refresh
Start Tracking

Connect
Set Attenuation

Register
30

1 2 3 4

1	2	3
4	5	6
7	8	9

6	3	1	0
5	0	1	0

10

Current Read:

Refresh

Connect

Register

Start Tracking

Set Attenuation

1	2	3
4	5	6
7	8	9

4	0	7	1
0	0	0	0

10

Current Read:

Refresh

Connect

Register

Start Tracking

Set Attenuation

1	2	3
4	5	6
7	8	9

0	0	0	0
4	5	6	5

10

Current Read:

Refresh

Connect

Register

Start Tracking

Set Attenuation

100

1 2 3 4

1	2	3
4	5	6
7	8	9

4	1	6	0
1	5	1	6

10

Current Read:

Refresh

Connect

Register

Start Tracking

Set Attenuation

100

1 2 3 4

Appendix S: Modified Software Code Used in Visual Basic

```
Option Compare Database
Option Explicit
Private WithEvents sockmain As Winsock
Private WithEvents sockRecv As Winsock
Dim ActiveMode As Boolean, KeepAlive As Boolean, SkipData As Boolean, andy As Boolean
Dim strData As String
Dim antenna As Single
Dim all_ants(3)
Dim testnum As String

Private Sub cboSend_AfterUpdate()
If Len(Me.cboSend) > 0 Then Me.txtArgs = DLookup("arguments", "sirit_commands", "command = """" & Me.cboSend & """"")
End Sub

Private Sub cmdActiveMode_Click()
Me.txtStatus = ""
If Me.cmdActiveMode.Caption = "Active mode=off" Then
    Me.cmdActiveMode.Caption = "Active mode=on"
    Call Sirit_send("tag.reporting.report_fields=tag_id antenna time")
    Call Sirit_send("reader.events.register(id=" & Val(Me.txtSessionID) & ",name=event.tag.report)")
    Call Sirit_send("setup.operating_mode=active")
    ActiveMode = True
    GoTo ending
End If
If Me.cmdActiveMode.Caption = "Active mode=on" Then
    Me.cmdActiveMode.Caption = "Active mode=off"
    Call Sirit_send("reader.events.unregister(id=" & Val(Me.txtSessionID) & ",name=event.tag.report)")
    Call Sirit_send("setup.operating_mode=standby")
    ActiveMode = False
End If
GoTo ending
ending:
DoEvents
End Sub

Private Sub cmdClear_Click()
Me.txtStatus = ""
End Sub
```

```

Private Sub cmdConnect_Click()
Call Sirit_connect
Me.txtSessionID = ""
KeepAlive = True
Me.Form.TimerInterval = 3000
End Sub

```

```

Private Sub cmdScanLoc_Click()
antenna = 0
'prepare tables
With DoCmd
    .SetWarnings False
    .OpenQuery "SendToHistory", acViewNormal, acAdd
    .OpenQuery "purgelocation", acViewNormal, acAdd
    .SetWarnings True
End With
testnum = InputBox("Please enter a test name", "Test Name")
andy = True
'gather data
'Call Sirit_send("modem.antennas.perform_check()")
all_ants(0) = 1
all_ants(1) = 2
all_ants(2) = 3
all_ants(3) = 4
Call Sirit_send("antennas.mux_sequence=1")
Call Sirit_send("tag.reporting.report_fields=tag_id antenna")
Call Sirit_send("reader.events.register(id=" & Val(Me.txtSessionID) &
",name=event.tag.report)")
Call Sirit_send("setup.operating_mode=active")
Form.TimerInterval = 2000
End Sub

```

```

Private Sub cmdSend_Click()
Me.txtStatus = ""
Call Sirit_send(Me.cboSend)
End Sub

```

```

Private Sub Form_Load()
ActiveMode = False
KeepAlive = False
andy = False
antenna = 0
End Sub

```



```

Private Sub Form_Timer()
If andy = False Then
    Call Sirit_send("reader.is_alive()")
    SkipData = True
End If
If andy = True Then
    ' If antenna < UBound(all_ants) Then
    '     Call Sirit_send("antennas.mux_sequence=" & all_ants(antenna))
    '     antenna = antenna + 1
    ' Else
    '     Call Sirit_send("setup.operating_mode=standby")
    '     andy = False
    '     Me.Form.TimerInterval = 2000
    '     DoCmd.OpenQuery "UniqueLocations", acViewNormal
    '     DoCmd.OpenForm "ZoneTracker", acNormal
    ' End If
End If
End Sub

Private Sub sockMain_Close()
Call Sirit_connect
End Sub

Private Sub sockRecv_DataArrival(ByVal bytesTotal As Long)
If andy = True Then
    Call sockRecv.GetData(strData)
    Call loc_data
    Exit Sub
End If

Call sockRecv.GetData(strData)
If ActiveMode = True Then Call add_data
If ActiveMode = False Then
    If Left(strData, 22) = "event.connection id = " Then Me.txtSessionID = Right(strData,
Len(strData) - 22)
End If
End Sub

'Private Sub sockmain_DataArrival(ByVal bytesTotal As Long)
',
'If andy = True Then
'    Call sockmain.GetData(strData)
'    'all_ants = Split(Right(strData, Len(strData) - 3), " ")
'    'Debug.Print Right(strData, Len(strData) - 2)

```

```

'End If
'If SkipData = True Then
'  SkipData = False
'  Call sockmain.GetData(strData)
'  Exit Sub
'End If
'
'Call sockmain.GetData(strData)
'Me.txtStatus = strData
'
'End Sub

Sub Sirit_connect()
Me.txtSessionID = ""
Set sockmain = New Winsock
Set sockRecv = New Winsock
With sockmain
.RemoteHost = DLookup("host", "sirit_settings")
.RemotePort = DLookup("portSend", "sirit_settings")
.Connect
End With
With sockRecv
.RemoteHost = DLookup("host", "sirit_settings")
.RemotePort = DLookup("portRecv", "sirit_settings")
.Connect
End With
End Sub

Sub Sirit_send(strCommand As String)
sockmain.SendData strCommand & Chr(10)
End Sub

Sub loc_data()
Dim TagAry As Variant
Dim x As Integer
Dim rst As ADODB.Recordset, rst1 As ADODB.Recordset
Set rst = New ADODB.Recordset
Set rst1 = New ADODB.Recordset
rst.Open "[location]", CurrentProject.Connection, adOpenStatic, adLockOptimistic
Dim fields(2)
fields(0) = "TagID"
fields(1) = "Antenna"
fields(2) = "TestNumber"
Dim values(2)

```

```

TagAry = Split(strData, "event.tag.report tag_id=0x")
If IsArray(TagAry) = False Then Exit Sub
For x = 1 To UBound(TagAry)
    values(0) = Left(TagAry(x), 24)
    values(1) = Mid(TagAry(x), 35, 1)
    values(2) = testnum
    If Len(values(0)) = 24 And Not (Left(values(1), 1) = " ") = True Then
        rst1.Open "SELECT DISTINCT * FROM [Location] WHERE TagID = "" & values(0) &
        "" AND Antenna= " & all_ants(antenna), CurrentProject.Connection, adOpenStatic,
adLockOptimistic
        If rst1.RecordCount = 0 Then rst.AddNew fields, values
        rst1.Close
    End If
Next
rst.Close
End Sub

Sub add_data()
Dim TagAry As Variant
Dim x As Integer
Dim rst As ADODB.Recordset, rst1 As ADODB.Recordset
Set rst = New ADODB.Recordset
Set rst1 = New ADODB.Recordset
rst.Open "[read]", CurrentProject.Connection, adOpenStatic, adLockOptimistic
Dim fields(2)
    fields(0) = "TagID"
    fields(1) = "TimeRead"
    fields(2) = "Antenna"
Dim values(2)
TagAry = Split(strData, "event.tag.report tag_id=0x")
If IsArray(TagAry) = False Then Exit Sub
For x = 1 To UBound(TagAry)
    values(0) = Left(TagAry(x), 24)
    values(1) = Mid(TagAry(x), 9, 12) & " " & Date
    values(2) = Mid(TagAry(x), 35, 1)
    If Len(values(0)) = 24 And Len(values(1)) > 0 And Not (Left(values(2), 1) = " ") = True
Then
        rst1.Open "SELECT DISTINCT * FROM [Read] WHERE TagID = "" & values(0) & """,
CurrentProject.Connection, adOpenStatic, adLockOptimistic
        If rst1.RecordCount = 0 Then
            rst.AddNew fields, values
            rst1.Close
        Else
            rst1.Close
        End If
    End If
Next
rst.Close
End Sub

```

```
        rst1.Open "UPDATE [Read] SET [Read].TimeRead = '''' & values(1) & '''' WHERE  
(Read.TagID)= '''' & values(0) & ''''"  
    End If  
End If  
Next  
rst.Close  
End Sub
```

Appendix T: References

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