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An Investigation into the Reachability of Radio Frequency Identification (RFID) Technologies in Adverse Conditions

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ABSTRACT

The use of location tracking technology can be applied to industry to improve many areas such as security, safety and the supply chain. The main reason that location tracking systems have not be applied across many applications is due to the number of limitations that restrict the technology. Radio Frequency Identification (RFID) is mainly used in close proximity identification such as entering a building using an RFID enabled swipe card. The technology uses readers and tags to communicate data. Active RFID and passive RFID tags can be used for tracking goods or people within indoor or outdoor environments. The accuracy varies with each system and there are many factors which influence the accuracy such as electromagnetic interference. This paper investigates the accuracy of one RFID indoor tracking system. We develop a location tracking system for the Northern Ireland fire service to test the RFID tracking in a real world scenario.

Key words: RFID, location tracking, wireless interference, indoor localization

1. INTRODUCTION

Tracking technology can range from Global Position System (GPS) which is mainly used in navigation systems for cars, phones, boats, planes. The GPS system works perfectly in an outdoors location as it needs direct view with a satellite to get a signal and give the most accurate information, this can cause issues when tracking is needed indoors. Another widely known technology is Radio Frequency Identification (RFID) this is mainly used on small scale tracking. RFID is mainly used for tacking people or items inside buildings or small areas linked together with a number of buildings. In all probability the most primitive tracking technology is the use of Closed-circuit television (CCTV). This is the use of many strategically placed cameras that monitor an area and can track the movement of people and items in different areas. In many cases a location tracking system will be installed to track the moment of employees, stock in a warehouse, patients in a hospital, children in a school, delivery trucks in transit, taxies in a city, boats at sea, planes in the sky and many more. The evolution of tracking systems has made it cheap and easy to install a tracking system in a small to large scale operation. This means it’s that easy that if you wanted you could track you pets in your house with a simple and cheap system.

Tracking systems on a small scale are being more widely accepted and used in modern day life. Systems are already in place in many work places where employees must swipe an ID badge or card before they can enter a room this keeps a track on where they are in a building. This type of system uses the RFID technology, RFID systems fundamentally consist of four elements: the RFID tags themselves, the RFID readers, the antennas and choice of radio characteristics, and the computer network (if any) that is used to connect the readers (Grafinkel and Rosenberg, 2006). The system is relatively easy to set up and has little to almost no maintenance, the details of RFID systems will be expanded upon in later sections. RFID tracking technology can be used in many different application, some scenarios include the tracking of animals. The tracking of animals is most done in the farming industry when cattle and sheep need to be identified by the framer. Another instance when RFID can be used is in the manufacturing industry, tags can be attached to items that are moving through the factory on conveyer belts or being moved around by staff on trucks or forklifts. As the tags move around the factory floor or the warehouse they pass by readers and the tags can be then tracked using a database or a similar data storage system. RFID systems are also used in almost everyone’s day to day life, anyone who works in a secure office, goes to university, drives a car with an immobiliser, parks in a secure car park. The list of applications that we use every day and are unaware of is endless (Rashid et al., 2006; Bohn, 2004; Floekemeier & Mattern, 2006). Anyone who works in an office that requires them to swipe an ID badge or smart card to gain access into areas is using a RFID system. The tag is in the badge or the card and the readers are the boxes in from of the doors. Once the tag is read by the reader is determines if the tag has the correct level of permissions needed to access the area in question. If the tag is granted permission, the door will open. Almost every university uses a student card system where each student carries a student card and this can enable them access to different resources, in almost every instance the card contains a RFID chip which is used to grant access to the resources. This student card works on the same principle as the smart card in the office. The same applies to most of the other applications in the case of the car; all cars that have a built in immobiliser have a special key that must be used to start the car's engine. This key contains an RFID chip and the lock for the ignition contains a reader, the correct chip must be placed next to the reader in the ignition before the car engine will start.

The scenario that we cover is for the fire service and the tracking of the different pieces of equipment that they use. The scenario is that the fire service is called to out and an engine is dispatched with all the appropriate equipment for the type of call that they have received. Examples of calls could be a fire meaning that they would have to bring equipments to stop a fire such as fire retardant suits, water hose, ladders or axes. Sometimes the call could be a rescue call meaning that the equipment needed would be climbing materials, ladders, tools for lifting rubble if a building has clasped and tools for removing people from vehicles. The main problem is that there is so much equipment for each type of call, in some cases different fire teams are called to the one incident meaning that there is equipment belonging to different stations in the one area and mix over's can occur in many cases one team takes back other teams equipment. As much of the equipment that is used is very expensive it is very hard to replace the equipment. This is a wide spread issue that affects many different organisations, most affected are "on call" services such as roadside repair companies or on call mechanics. The problem is that the main part of the organisation is called out of the office/warehouse/factory/garage and must take the necessary equipment and return with all the equipment. If items go missing on each instance they must be replaced, this cost can build up over a period of time and affect the organisations profits.

The main aim of this project is to explore and demonstrate location tracking systems in relation to RFID tag tacking. For the purpose of tracking items on a small scale (i.e. tracking equipment in a building) a RFID system is the best solution. The main objective of the project is to create and implement a system that can be used to track fire fighter equipment. The proposed solution is to create a general purpose system that can be used for the tracking of the different pieces of equipment that the organisation uses when on call, for this scenario it will be the different equipment used by the fire service as previously discussed. The system will be able to identify a number of tags as they pass by the sensor, this will be implemented in the fire station as a set of RFID reader placed at the main door way in which the fire engine enters and leaves the station. Each item of equipment will be tagged and the tag information will be stored on a database or appropriate data storage option. The system will be able to display to the user the current location of the items e.g. "in" or "out"; this is then used to ascertain if items have been lost during a call. The next aim of the project is to test the factors that affect a RFID system, what factors can interfere with the readers and tags of the system. This aim will test the following properties of the RFID system under a number of circumstances and environments such as range, strength, reliability, usability and performance. Each of the previously mentioned factors will be tested under controlled and managed environments to insure the highest standard of results. These results will then be used to improve the current system; this process will be repeated until the system has reached optimum performance or until the process becomes redundant. This will happen only if the changes needed to the system are not possible, such as upgrading the equipment or modifying parts of the scenario that cannot be changed.

2. LOCATION DETERMINATION TECHNOLOGIES

Location tracking can be done with a simple mobile phone. This is done without the use of a built in GPS receiver. All that is needed from the phone is the ability to send a roaming signal to the nearest antenna tower. This roaming signal is used in Global System for Mobile (GSM) systems that can determine the location of the phone using multilateration. This is when the time taken for the signal to travel between the phone and the antenna is used to give an estimated location of the phone, thus tracking the user. In 2005, this technology was used to track and capture the man responsible for the suicide bombings in London in earlier that year. The police were able to track him every time he made a call using the GSM tracking technology. This technology can also be used for security there are a number of companies that provide tracking solution that involve mobile phone tracking these include Child Locate[1] and Mobile Locate[2], these companies offer services where you can use their real time tracking software to track mobile phones.

Bluetooth location tracking technology is a relatively easy and simple technology that could be used by any user, as most people have mobile phones all of which come with Bluetooth as standard. The simplest process of tracking a person or object is turning on your mobile phone and searching for Bluetooth devices. This will display the devices in close range in most cases 10 meters. An example if you knew a friend's mobile phone's Bluetooth name you could search for their device using your phone and following them using this as a guide.

Creating a network of sensors would improve this system; this would involve setting up a network of Bluetooth devices that are constantly searching for Bluetooth devices in range. The sensors would be places strategically so that the entire area is covered, each sensor then tracks any discoverable Bluetooth device and records all of the tracked devices and sends the information back

[1] http://www.childlocate.co.uk
[2] http://www.mobilelocate.co.uk

to a central server or machine. The following explains how the tracking would be implemented. The scenario is of a street 100 meters long in which people needed to be tracked. As each Bluetooth sensor is just a standard Bluetooth reader and the range of which is 20 meters five sensors will be needed to cover the street. This means that every 20 meters there will be a new sensor (Shepard, 2005). This type of system was set up in September of 2007 by a Dutch man who noticed that when he turned on the Bluetooth adaptor for his PC that he was discovering a lot of Bluetooth devices. He then set out to try and track these devices by using friends and family he positioned Bluetooth devices in their homes and connected them to small machines running Linux theses machines would use the internet to report the data on the devices that were discovered.

ZigBee is a specification for a high level set of communication protocols that use low powered digital radios. This is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4-2003 standard for wireless networks for personal use, examples of this are devices in the home that communicate with each other on a short range radio such as wireless headphones that connect to a speaker or a mobile device, these networks are called wireless personal area networks (WPANs) the ZigBee technology is designed to be more simpler and less costly than normal WPANs an example of which was previously mentioned in the last section on Bluetooth tracking. The ZigBee solution is aimed at RF systems with low amounts of data (ZigBee Alliance, 2009).

Wi-Fi or wireless as its commonly called, is everywhere in most schools, universities, shops and even town centres it is not surprising that this technology can be used to track object and people. Every laptop manufactured today has a wireless card installed and is able to connect to a 802.11 a/b/g/n network, which are plentiful in large cities. The Wi-Fi tacking works on the same bases of the Bluetooth tracking, every device sends out signals that broadcast its details. This is normal for the device to connect to a network however in this instance the signal is received by a special wireless receiver which records the details of the device and the location of the receiver this then can be used for the tracking of the device as it moves from each Wi-Fi network. Another method of tracking by using Wi-Fi that resembles the method used in GSM tracking is triangulation, this involves measuring the time that is take for signals to be sent and revived between three different wireless receivers and the wireless device. The times are calculated into the distance. The three distances are triangulated which will then give the position of the wireless device.

Another very basic tracking technology is infrared; this is mainly used for motion detection and not large or small scale tracking of objects. “Infrared radiation exists in the electromagnetic spectrum at a wavelength that is longer than visible light. It cannot be seen but it can be detected.” (Global, 2009). It is this technology that is used for the motion detection, as objects that generate head also generate infrared radiation. The infrared sensor sends out a signal that will be blocked by the other object of infrared light, from this the item can be located and when the item moves the beam of infrared is broken in different sections this detects the movement. One of the most famous applications of this is in the Nintendo Wii games console that using this technology to capture the motion of the controllers that are used for playing games.

3. RFID TECHNOLOGY

RFID systems consist of four elements which are the RFID tags that will be tracked, RFID readers that will detect the tags, antennas and radio and the Computer network used to connect the readers. Each RFID tag consist of the following items, an antenna, small silicon chip including a radio receiver, radio modulator that can send signals back to the reader, internal memory normally a very small amount and most importantly a power supply system unless the tag is a passive tag. Tags can be active, passive or semi-passive.

An active tag is a tag that contains a power supply system that is powered by a battery. The main advantages to having an active tag are the reading range of the tags. With the power of the battery and a powerful antenna the tag can be read from up to a distance of 30 meters. The battery power also means that the tag will not need to constantly be accessing reader and will give a more reliable reading, the most common application for theses tags are in warehouses where the tag is fitted to pallets and tracked through the warehouse, the tags are also used in cars for toll systems as the reader in toll systems are usually at a distance from the car. The disadvantages to active tags are that the tag can be more bulky after the battery has been fitted (Ward & Van Kranenburg, 2006).

A passive tag is a tag that does not contain a battery to power it. The advantages to passive tags are that the tag can be fitted to smaller object or woven into clothes, in many cases passive tags are used for smart cards and they can put the tag inside the card without making it thicker (Finkenzeller, 1999). The absence of the battery as a power source means that the tag will be cheaper to produce and purchase compared with active tags. The life time of the tag is also longer than an active tag as the life time of an active tag is dependent on its battery which will only last a few years before having to be replaced. Passive tags could be used for decades after being produced. The only disadvantage of using passive tags is the read range, as the tag has no power supply it cannot be read from a distance. This means that the tag must be close approximately 2-3 inches from the reader before it will be read. However there are some applications this can be an advantage as sometime the tag will be in a close range of the read but the user will only want the tag to be read when they intend the tag to be read. In cases that a tag is used to pay for petrol at the petrol pump, if the user is close to another pump while someone else is using the pump they do not want the reader detecting their tag and thus being charged.

The range of sizes of RFID tags is changing all the time and the tags can range from large security chips and cards to small micro chips. “The smallest tag that has ever been produced is the Hitachi mu-chip, which is less than 0.4 millimetres (mm) on a side” (Grafinkel et al., 2006). This tag was created for the purpose of being embedded into a piece of paper and used for tacking documents, the tag can only be read from a distance of a few centimetres (cm). However if a longer antenna was used with this tag the read range would be increased however this would increase the size and thus not make it feasible to embed. There are also other types of smaller tags such as implantable tags which can be the size of a grain of rice, which are implanted under skin. Like the mu-chip the read range of the implant tag is very limited however the proposed application of these chips does not call for a long read range. They are intended to be implanted under the skin of humans; for identification proposes in high security level areas and could also be used in hospitals for identifying patient as mix up could be fatal. Is the tag is under the skin it cannot be easily shared or switched meaning that the identification system would be almost 100% reliable.

All tags have an antenna, the antenna is the tags means of acquiring energy from the RFID reads signal. The antenna is strongly related to the tags ability to operate, without the antenna the tag would not be able to communicate with the RFID reader. The antenna is attached directly to the chip. There are endless number types of antennas that can be used with RFID tags. “The antenna length is directly proportional to the tag’s operating wave length” (Lahiri 2005). The antenna will always be longer that the length of the tag’s microchip, this means that the size of the antenna will determine the size of the resulting tag. This is why smaller tags have a shorter read range than a much larger tags, as the antenna for small tags are short and have a shorter wavelength. The antenna is one of the most fragile parts of the tag, if the antenna is bent or cut this can detune or even break the antenna rendering the tag useless. However there are also ways of modifying existing tag’s antenna to increase the read range. Antenna are currently made from small thin metal strips normally copper or aluminium however it has been predicted that advances will be made that will allow antennas to be printed into the tag itself. The antenna will be printed using an ink containing a light metal such as copper, carbon or nickel, research has also gone into developing ways to print the microchip in the same way as the antenna thus being able to print tags just as easily as printing a barcode onto packaging. This would decrease the time and effort taken to create a normal tag, and would work out cheaper as there would be little to none parts to be used.

The RFID reader can read and write to appropriate RFID tags. The reader is also known as an interrogator. (Lahiri, 2005) the reader doubles up as a writer as it can modify the data on the chip. For the reader to be used in the system the tags must first be commissioned, this involves creating a tag and uniquely associating it with an object. The process of disassociating the tag is called decommission. Once a tag has been commissioned the reader can send a radio frequency (RF) energy signal to the tag, to be able read the tag. This process is called the duty cycle this is repeated many times however it is governed by an international legal limit. The tags in range of the reader receive their clock cycles and alternating current (AC) power from the transmitter on the reader this sends both of theses to the antenna of all the tags in the read range. This is all done in what is called the transceiver unit of the reader, each antenna on the reader is connected through the transceiver unit some readers can have multiple antennas. This component also belongs to the transceiver unit of the reader; this component receives the analogue signal from the tag. The received data is then sent to the reader microprocessor where is it converted into digital (Finkenzeller, 1999).

Readers can acquire their power from a standard power source from a power cord that is attached to an appropriate external electrical socket. Similar to tags readers can also be classified by using criteria, in the case of the reader there are two criteria that the readers can be sorted by, the first is the communication interface. In the network connection there can be either a wired connection or a wireless connection between the reader and the computer. In simple terms the reader is a network device and can be connected to the network like any other device such as a computer. The one advantage to this type of reader is that there is no limit to the length of the cable that connects the reader to the computer. This means that the number of host machines will be lower compared to the serial approach. This also affects the maintenance of the readers as the firmware and other components can be accessed remotely across the network and they can be updated or changed remotely. The main disadvantage to this approach is that the connection is not a reliable as the serial connection, if the connection is broken the back end of the reader cannot be accessed as a result the system could come to a stop, even if the reader has its internal memory this will only last for a short network outage, after this short period of time data will be lost. Stationary readers also know as fixed readers, are normally mounted to a wall, portal, or some appropriate structure in the area where tags will need to be read. The name stationary does not mean that the reader has to be completely stationary as in some cases the structure that the reader is attached to could be mobile, such as attaching the reader to a truck or crane. Stationary reader require external antennas to read tags, in most cases the reader can support up-to four antennas (Finkenzeller, 1999).

The handheld RFID reader is a mobile version of the stationary reader. The reader is operated through a handheld device, which normally has a built-in antenna. This type of reader is more expensive and thus not as widely used however as the RFID technology advances more and more the price of producing these types of reader is becoming lower. Input/output Channel for External Sensors, Actuators and Annunciators are mainly used for optimising the performance of the reader, as the reader will not be reading tags constantly. In most applications tags will only come in contact with the reader at specific times, thus if the reader was constantly on then it would be a waste of energy. This component provides a means of turning the reader on or off in reaction to external events, such as attaching a light or motion sensor to the tag and once the sensor is triggered the reader is set to read any tags in range.

3.1 RFID and Tracking

Radar was the precursor to RFID, some people who were responsible for the development of radar where, Heinrich Hertz who was a German physicist who clarified and expanded the electromagnetic theory of light, he also was awarded with the SI unit hertz (Hz) being established in his honour by the International Electrotechnical Commission (IEC) in 1930 for frequency, a measurement of the number of times that a repeated event occurs per unit of time (also called "cycles per sec" (cps)). It was adopted by the Conférence générale des poids et mesures (CGPM) in 1964. Heinrich identified and studied the wave –based nature of radio (Riggins et al., 2007). One result of the research carried out by Heinrich, was that some radio waves where able to pass through solid objects while others where reflected by the object. As a result of this Heinrich was able to develop a technology that could measure the distance the waves had travelled thus giving the distance between him and the object. It wasn't until the Second World War before Radar was used on a larger scale. It was during the war that countries worried about invading army's travelling at night time or during foggy conditions when they would not be seen, radar systems where deployed to act as early detection systems. These systems where implemented by the United States, the United Kingdom, Germany, France, USSR, Italy and Japan. This technology then leads into the days of RFID. RFID is part of automated identification and data collection (AIDC) technology that has become so wildly used in past and modern society. This technology is everywhere in the scanner at the checkout in a supermarket that reads the barcode from an item and can retrieve more information on the product that the actual product packaging can give. The magnetic strip on a credit card or bank card is also an example as it can give information with only a swipe and even the tags that are attached to electronic items in shops that alert security if the item has left the store without the tag being deactivated. Any item of technology that automatically retrieves information or performs an automated process can be classed as an AIDC technology.

AIDC technologies date back to the 1930's and 1940's other types of AIDC technologies include optical character recognition (ORC) and magnetic ink character recognition (MICR) however MICR and RFID have become the most popular (Waldner, 2008). RFID technology has its roots in early military identification systems in the early 1940's. It was the British that pioneered RFID during the Second World War; they used the technology to identify their own aircraft as they flew above. The problem that the British military faced was that the current radar system that was in use could only detect incoming aircraft however could not detect if it was a friendly aircraft. The new transponders in the Royal Air Force (RAF) planes could be used to determine if the plane was allied or enemy. At the same time the Soviet Union was also developing there AIDC technologies, a Russian inventor Léon Theremin, developed a covert listing device that retransmitted incident radio waves with audio information. These radio waves where then put though a diaphragm which altered the shape of the resonator which modulated the reflected radio frequency. This however was not a tracking device but was still an evolution on the ACID technology and one step closer to RFID technology. The next development in RFID technology was in 1948 a white paper was released by Harry Stockman, titled "Communication by Means of Reflected Power". This white paper delved into the development of RFID technology and how much work would have to be carried out to get the technology to the stage where it could be easily used.

RFID technology has grown to be part of normal life for many people and some without knowing about it. The toll system that Cardullo proposed has been implemented in many states in America and in many European countries (Shepard, 2005). It has come under many different names such as "Etoll" and "E-Z pass" but they all perform the same basic function as the car passes on the road a camera photographs the car including the registration plate and the RFID reader scans the tag mounted to the car. The tag is normally mounted to the windscreen or the dash board. The reader reads the tag information and verifies the registration matches the photo of the car then bills the appropriate account for the amount of the toll, if the account is not active or the car was not fitted with a tag the registration is used to bill the driver for the price of the toll. This system speeds up travel times as there is no need for a toll booth and for drivers to stop and manually pay a toll. Tags can be read from distances up to 20 meters and at speeds up to 80km/h (kilometre per hour) this prevents drivers having to slow down and causing delays in traffic (Bendavid et al, 2009). Other applications of RFID technology is the use of smart cards, or ID cards. These are cards that contain an RFID tag and usually some information on the front such as a photo and name of the holder. The RFID tag is programmed with their details and when this is passed by a reader it will validate the details with the system details, e.g. if a door is locked it will only open for valid tags or for a small array of selected tags. There are thousands of examples of RFID applications, anywhere were a process needs to be automated or information needs to be retrieved quickly RFID technology can be used.

4. RFID SYSTEM

The main scenario that the project is addressing is of the Northern Ireland fire service, the current issue is that the tracking of equipment across the fire server in Northern Ireland can be very problematic. The current system in place is a written system that involves a member of staff that is in charge of a fire engine to manually check that all the necessary equipment needed for each job is present on the engine before it leaves the station. When the engine returns to the station the member of staff must then manually check that all the equipment that left the station on the engine is still present on the engine when it returned. The process of checking the equipment involves looking at equipment and checking if the serial number (if the item has one) matches with the number that the engine should have, or if no serial number is present then as piece of coloured tape will be present on the item (each station uses a different colour). The main issue with this is that the serial numbers can easily wear away from regular use and in some cases two stations can use the same colour tape and/or the tape could fall off the item. This means the item cannot be identified, and the relation between station and item cannot be made. The exchange or borrowing of equipment is very common in the fire service as some stations do not stock all the needed items for more rare jobs. This means that equipment will be passing through other stations and be used on other fire engines regularly. Without a solid system to identify each item of equipment and the relationship between station and item, mix ups can happen far too often.

The Northern Ireland fire service is broken down into 4 operational commands area (north, south, east and west). There are a total of 68 stations across the 4 areas, each of these stations network together and share services and equipment. The proposed system will need to allow the networking of all these stations and the sharing of data. The system will be placed at the main entrance and exit of the fire station, the system will scan each time as fire engine leaves or enters the station. This will detect all the equipment that is on the engine and will add this information to a database of all the currently tracked equipment that is associated with the fire engine. The user interface of the system will be a fully accessible interface that will provide the user with a method of adding tagged items to the database, editing tagged items on the database and removing tagged items from the database. The interface will also provide an up-to-date status of each item on the database e.g. "in" or "out". There will also be an ability to search for items in the database thus being able to view the search items details and location status. If items have been flagged as "out" when an engine has left and not flagged as "in" when the engine returns, this item will be flagged as missing and a notice will be displayed to the user to draw this to their attention. The unique ID of each available RFID tag will also be stored in the database and the tag will be given to one of the tracked subjects. The tag is assigned to that individual in the application. The tags will be detected by the Trolley Scan system, which will send the location data of any tags in the monitored area to the system. The fire service scenario is a common problem in industry, is many large companies' time, money and effort can be wasted trying to manage inventory or stock. In many cases the stock management is done manually which is highly susceptible to human error. The solution of using RFID tags to track stock could save large amounts of money and time as the system could be fully automated.

Figure 1: Trolley Scan RFID-Radar System [3]

The Trolley Scan RFID-Radar system, shown in figure 1 consists of a reader, tags and antenna array. The reader connects to the computer via an RS232 port. It measures the signals travelling from transponders and provides an energy field to power the passive tags. The reader's processor operational frequency can be set anywhere in the range of 860MHz to 960MHz. The tags are passive backscatter Ecotag UHF transponders. The credit-card-sized 200uW EcochipTags have a range of ten metres, while the 5uW stick tags have a maximum operating range of forty metres. The antenna array contains one transmit antenna for energising the passive transponders and one antenna for each receiver, giving a total of three antennas in the array. For the scenario that this project addresses, the system will need to be placed at the main entrance/exit of the building for the fire engine.

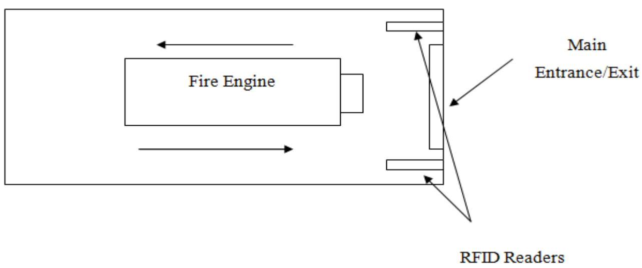

Figure 2: RFID System for Fire Service

[3] http://www.rfid-radar.com/introduc.html

Figure **2** shows the layout of the proposed system, the RFID reader will be at each side of the main entrance/exit and will have the set of three antennas previously mentioned attached to the reader. Both readers will then attach to a local machine that will be used by the staff in the station to check the tagged items. The user interface will use tabs for ease of browsing through the different screens. Each tab will give the user a number of different options and varied information from the database. There will be three main tabs that the user will be provided with, once they have successfully logged into the system. After the user logs into the system using their personal username and password, they will be directed to the main system screen. This will contain the company logo which can be changed using the accompanying configuration files instructions on how to change this will be supplied in the system manual. The main screen will also contain the tab control; this will have three following tabs however there will be the ability to add more tabs later if the user decides to expand the system.

The status tab will contain an up-to-date status of the tags that are being monitored by the system. There will be a section that will show the list of vehicles and their status e.g. "in" or "out". There will also be a section that will show a list of tags that have not returned but their associated vehicle has returned. These tags will be considered missing, along the bottom of the screen there will be buttons provided options for each section. The user options will include an update button that will update all the information on the screen; this will also be done at 10 minute intervals (the reason for the interval is to save on process power as each update will take up process power). An example of the status screen is shown in

Figure **3**.

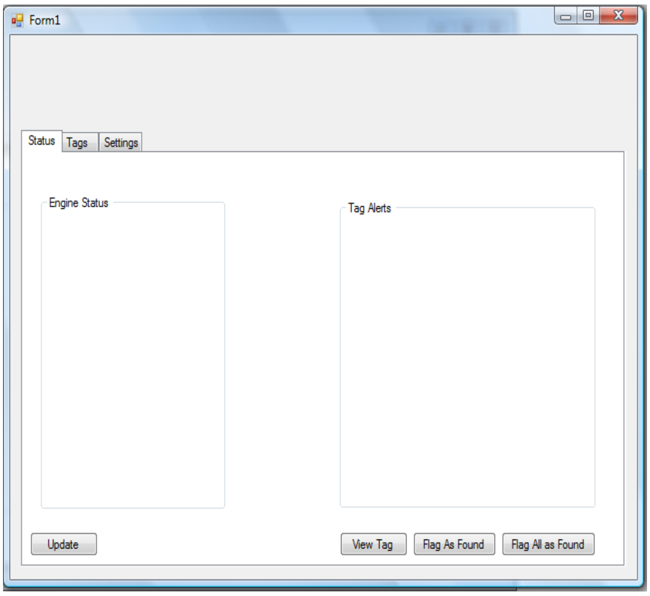

Figure 3: Status Screen

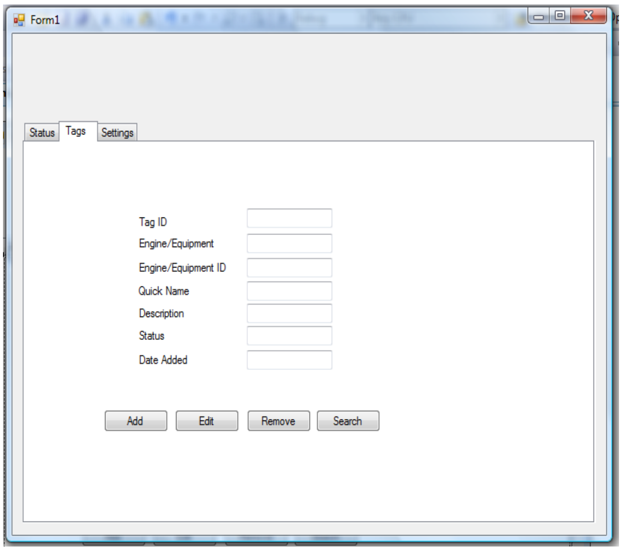

Figure 4: Tag Management Screen

The tag screen allows the user to add, edit, remove and search for a tag each of these options will display the tags information. The user can navigate to this screen by clicking on the tab called "Tags" the user will also be directed here from the status tab if the "View Tag" button is selected. An example of the tags screen is shown in Figure 4. The last tab is the setting tab this will contain all the options for the user and will allow them to change many factors of the system such as the time interval for updating the system, the look and feel of the system, add users to the system. They user will also have the ability to set constrains on the system such as limit the number of tags that can be on the system or limit the users that can access the system. The options in this screen reflect the setting stored on the applications accompanying configuration files. As setting are changed on this screen the configuration file will be updated thus saving the setting for the next time the application is started. The first stage when connecting the equipment is to choose the correct location to set up the RFID Radar equipment. The perfect location for any RFID radar system is to have the antenna high above the ground, with no obstacle in the radio path of the antenna. Figure 5 shows the ideal position of the antenna.

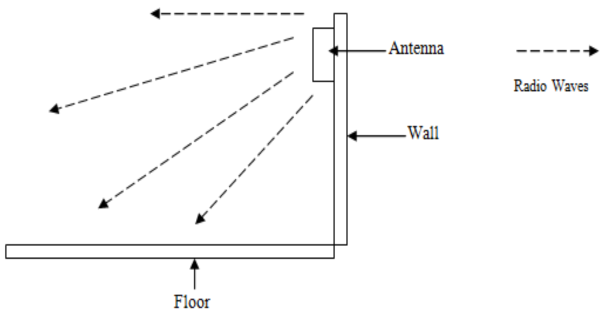

Figure 5: Ideal Radio Setup

In Figure 5, the antenna is set at a height so that the radio waves have a long path before they reach an obstruction. This will provide the RFID radar with strong signals and give accurate readings. Once the antenna is in the optimum place for the location that tags will be tracked the next step is to set up the antenna with the reader to retrieve data. The first stage is to connect the reader with a computer. In this case a standard laptop was used to connect with the reader. Once the connection is made between the reader and the laptop the reader will shown on the device manager as a "COM" port, the software that was supplied with the reader using the COM port to communicate with the reader. Once the user has successful logged in, they will be able to view the current tags being passed through the range radar and also see any issues with tags from this screen. If there is an issue with a tag or the user needs to edit, add or remove a tag they can do so from the "Manage Tags" tab. This screen is shown in figure 6.

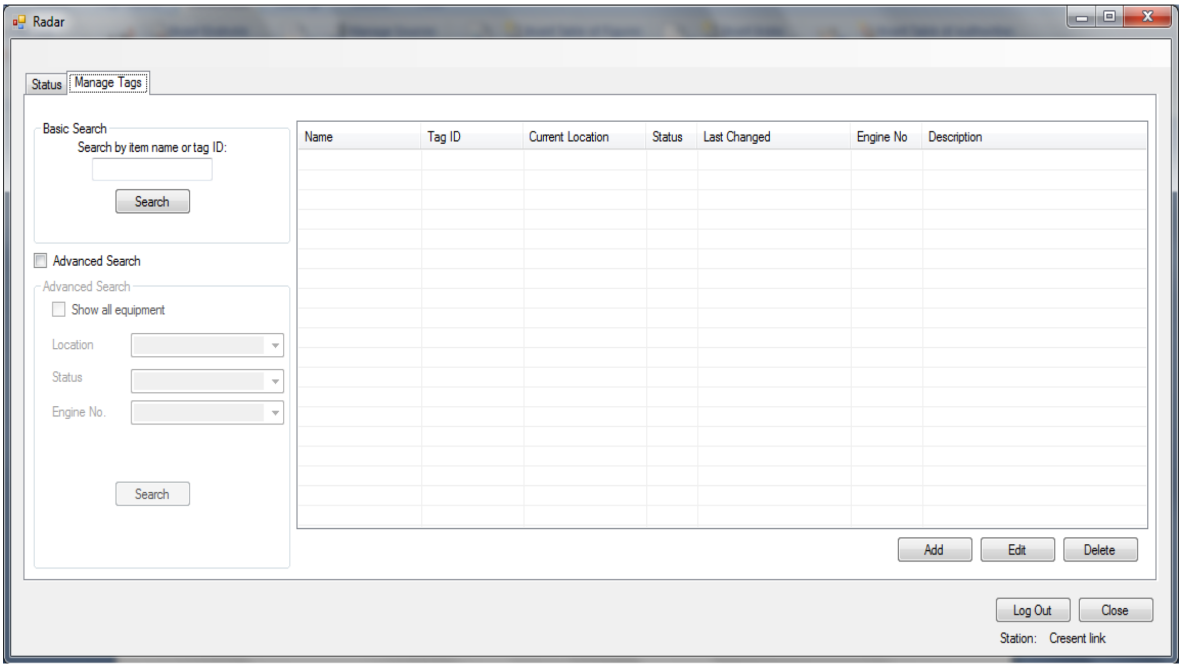

Figure 6: Main Screen - Manage Tags Tab

If the user selects the add button they will be presented with the add dialog to fill out all the needed details on the tag such as Name, Tag ID, Station, Status (IN/OUT), Engine No an Description. Once all the mandatory details have been added to the form the user will be able to save the details to the database. The edit button on the main screen will also open the same dialog however the details of the tag will be in the provided slots in the form and the user will be able to edit each of these. Some validation rules have been applied to the form, such as if the user changes the station of the tag the engine drop down will update to display only the engines that belong to that station. When the user adds edits or removes tags in the application the changes are written directly to the database that the application uses. Even when the user starts the radar application the database is used to check the users login credentials before the can be successfully logged into the system. The engine table holds the data on each engine across all the stations, the data that is held is shown in table 1.

Table 1: Engine Database Table

Name	Data Type	Length	Comment
Tag ID	Text	9	The RFID tag ID of the engine
Location	Text	20	The current station that the engine is located in
RegNumber	Text	8	The registration number of the engine
Status	Text	3	The status of the engine either IN/OUT
Station	Text	7	The station that the engine belongs to
LastStatusChange	Text	N/A	The last time, status of engine was changed. This is used so as to stop errors in the status updates

Testing

Test cases were created that would test the radar and tags to their limit and expose factors that can cause the system to fail or lower the performance of the system. The list of test cases for both passive and active tags are shown in appendix A and B, the next sections will explore some of the test cases and give more information on how the tag and the radar were affected by the conditions and how the conditions affected the tag and radar.

Test Case 4 Active and Passive

Test case 4 involves grouping the tags both passive and active together and check if the radar can read all the tags at the same time. This test tries to discover if the radar can handle stress by over loading the read area with a large number of tags. For the test to be carried out the tags where all mounted to a cardboard box, the box would not reflect the radio signal thus making it the perfect mount. In total 11 tags were used 9 active tags and 2 passive. The tags are shown in figure 7.

Figure 7: Tags Mounted to Cardboard Box

This box was then moved into range of the radar and the results were logged. When the test started all 11 tags where detected and showed on the radars range however as the test continued some tags dropped out of range.

7.1.2 Test Case 8 Active

In this test case the active tags where place in different locations in the testing room, some were placed on desks, chairs, boxes, on the floors and on the roof. The first ten seconds of this test log is checked to see which of the tags are most read. During the rest of the test other tags such as BBBFL3175 are read although not to as a high degree as the previously mentioned tags, as the time progresses the most read tags are BCBBB4691 with the most reads, BCBBB4688 with the second most and BCBBB4684 as the third most. Using this data an imaginary read zone can be formed, this zone is a place that tags can be read with the best radio signal.

7.1.3 Test Case 10 Active /Passive

In this test case the tag is attached to a bottle of water, the bottle is opaque however the water is clear. The bottle was then held at a level height as the radar approx 174cm high from the floor and moved slowly away from the radar. In this case the tag was facing away from the radar thus making the radio signal have to travel through the bottle and the water to reach the tag. The tag was detect by the radar however the radio signal was very weak and at a distance of 2 meters the tag could no longer be read as the signal was too weak. The test was also repeated using a clear bottle with and without paper covering it. When the same test was carried out using a passive tag the results were very similar results in both cases the signal was very weak and in both cases the signal dropped.

7.1.4 Test Case 16.00 – 16.02 Active and Passive

In the test cases of 16.00 till 16.02 the tags and the radar are testing against the signal blocking ability of aluminium foil. For the tests the tags active and passive are placed in front of foil with the matt side facing the radar and again with the shiny side of the foil facing the radar. The last test carried out was to place the tag inside the foil with the shiny side facing out. The three test sets are shown in Figure 8, Figure 9 and Figure 10.

Figure 8: Test 16: Active Tag on Foil

Figure 9: Test 16: Passive Tag on Foil

Figure 10: Test 16: Wrapped in Foil

The results of the tests show that when the foil is used as an obstruction between the radar and the tag with the matt side facing, the radar that the tag can still be read (active/passive) with a weak signal of up to 4 meters. However if the foil is used with the shiny side facing the radar the results are different, for the active tag the tag could be read but with a very weak signal and the tag could not be read at a distance of 30cm. For the passive the signal was very weak again but still getting reads however the tag could not be read at a distance of 15cm. The final test with the foil was to place the tag inside the foil with the shiny side facing out. For both active and passive the results were the same, the tag could not be read no matter what the distance was from the radar.

For the purpose of testing the RFID equipment was set up in a lab, which caused a number of issues with the equipment. As the lab was an ideal location for a close indoor RFID application the equipment in use was very sensitive and worked at optimum performance in a wide open space with either the radar mounted very high above the ground or the ground to be a soft area such as a field or grass area. The main reason the equipment worked better in a wide open space was that the radio waves would not have any hard obstacles in their path and could have a long strong wave to gather accurate data.

In test case 4, the environment variables that can affect the RFID equipment was first tested and during the test a number of tags dropped in and out of read, this may have been due to the placement of the radars antenna. As the location with solid floors and walls close by could have caused the miss reads on the radar. Although the 11 tags showed on the log at the start some of the tags had the "^P" at the end, meaning that the reader was predicting the location and reading of the tag based on previous readings. This is a standard practice for the reader being used when the signal is weak, the reader will predict the location and reading of tags. The fact that some tags had weak readings showed, that the radar in its current environments found it hard to detect a large number of tags. This could be due the number of factors such as the radio signal bouncing off the walls in close proximity and the hard floor and roof. It could also be caused by the interference of other tags in close proximity each tag had a distance of 8 centimetres around it.

In test case 8 the tags were placed in different location, however five tags where the most common read tags. The similarities between the five previously mentioned tags have to be taken into consideration, the height of BCBBB4684, BCBBB4691 and BCBBB4682 are close as two are 70cm and one 74cm, this shows that tags at this height have a higher chance of being read. However this could be contradicted by the BBBFL6030 and BCBBB4688 tags as they are close to the floor, with one being at floor level and the other at only 15cm high. The factors that might affect the radio signal can give more information on the findings, the tags close to the floor did not have hard reflective object in the radio path giving a good strong radio signal. The same applies to the other tags on a higher level; the two tags at 70cm high were placed on top of cardboard boxes which don't reflect radio signal giving a good radio path and a good radio signal. The only irregularity is with tag BCBBB4691as it was placed onto of a hard wood table that would be a strong radio reflector however as the tag was placed at the edge of the table the signal did not have to travel across the table which would have caused radio path issues.

One other environmentally factor that was tested against the radar was water. In test cases 10, 11 and 11.01 the tag was placed on the other side of a water bottle when the clear bottle was used the radar could get a good strong signal and be able to read the tag at all distances. This shows that water alone does not disturb the radio wave, however when the radio wave has to travel through and object that is not transparent the radio signal is affected. This is also shown in the test with the bottle covered in paper as the radio signal was weak and lost read at 2 meters. The results of the test when carried out using passives were very similar. This shows that the water can affect the signal for passive tags, passive tags use the signal from the radar thus if the signal from the radar has to pass through more obstacles then the signal is going to be very weak.

The last and most powerful factor tested on the radar was the use of aluminum foil, as this is widely used to prevent the read of RFID tags. The foil was most effective when used with the shiny side facing towards the radar, as this will give the most amount of radio wave reflection. When the tag was placed inside the foil the radar could not read the tag no matter how close the tag was to the radar. This was due to the foil reflecting all the radio waves back towards the radar.

CONCLUSION

Location determination can be carried out with the aid of many different technologies, across a number of scenarios. Many of the most popular and easy to use technologies have proved to have major flaws in scalability, reliability and accuracy. We investigated here the use and implementation of RFID systems in small and large scale operations. The actual scenario was an inventory management system for the fire service. In the process of creating and testing the RFID system, the system was able to demonstrate the limitations of RFID for location determination. The system was required to interface with the RFID radar and reader to give data on the location of RFID tags. The system then worked with a database to provide more information on each tag that was detected by the RFID radar. The application also tracked multiple tags and how some tags related to each other.

During the testing, it was discovered that the RFID equipment cannot work efficiently in environments with large amounts of metal objects that could block radio signals. This means that the system would not be able to meet the needs of a fire service as the tags what would be needed to track would all be inside of a fire engine. A standard fire engine has a thick metal shell which would block all RFID radio signals. The tests also found that large bodies of water with opaque containers can affect the readability of RFID tags. This would also apply to the fire server scenario as the fire engine would be carrying large bodies of water. RFID technology however is evolving therefore perhaps in the future RFID technology will be able to overcome the issues found in the testing of the system and could someday be deployed as a low cost location detection system.

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