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TRACKING BLOOD UNITS IN MEDICAL CENTERS USING PASSIVE UHF RFID SYSTEMS

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Introduction

Due to the advances in Radio Frequency Identification (RFID) technology, industries utilizing a high level of logistics for their daily operations began considering RFID based systems as a means to implement and automate their operations. One distinct application is in medical centers, where thousands of medical instruments and supplies are transferred throughout the buildings on a daily basis.

The application of RFID systems in medical centers is a recent but not unexplored challenge. In 2003 members of National Taiwan University and Taipei Medical University were tasked with placing RFID tags on patients during the SARS outbreak(a dangerous disease that struck Taiwan in 2003), so that patients could be efficiently tracked and treated, and to minimize staff exposure to the disease[1]. RFID systems are used to track hospital items to increase their operation efficiency; "RFID tags are increasingly being used in health care organizations to reduce errors and to generally increase the effectiveness of the processes" [2]. RFID systems can also be utilized to track controlled substances in medical centers[3]. A. Gutierrez et al. [4] utilized RFID technology for automatic identification, tracking and monitoring of blood products across the blood banking spectrum within blood centers and medical centers. S.-J. Kim et al.[5] developed a blood bag (unit) management system in hospitals to provide suitable blood transfusion to patients utilizing 13.5 MHz RFID system, active RFID tags together with a Sensor Network.

This paper introduces a prototype system utilizing UHF RFID technology in real time for monitoring and tracking of blood units (bags) as they are transferred between the hospital blood bank (BB) to and within the operating rooms. Consulting with the local medical center BB medical officers, the blood unit (BU) storage and handling logistics were defined and an automated process for monitoring and tracking them was suggested. A real time, efficient and cost effective UHF RFID system was proposed. A senior electronic engineering technology (EET) student was tasked with the project while performing independent research under the supervision of the faculty member. This paper presents the research findings, their analysis, and the educational outcomes of performing research at the undergraduate level for EET students. The involvement of students in research is of utmost importance, as it provides an excellent venue for the student to integrate and utilize the theoretical and practical knowledge gained during their educational period.

Process Definition

A local area medical center has expressed their interest in using RFID tags to track blood units throughout the hospital. When a patient requires an operation, a blood transfusion may be necessary or blood may be required as a safety backup. Because of this the BUs are constantly moved between refrigerators or between a refrigerator and the operating room. At present time the BUs movement are managed using a paper log based system, which is maintained by the staff and needs to be timely updated and checked manually. Most importantly the process requires constant monitoring of the blood units that are out of the refrigeration for a period exceeding 30 min which is mandated by the FDA as a round about time that the blood will spoil[6]. However, the staff are very busy and often overlook and lose track of how long a particular blood unit is out of the refrigerator. This causes the blood to go beyond a temperature window of 1- 6 ^{o}C mandated by the FDA[6] and the blood unit must be disposed of. The hospital estimated that this lack of control results in a loss of tens of thousands of dollars each year, and they believe that an automated tracking system for the blood units requiring minimum staff intervention could alert medical staff to place the blood unit back in the refrigerator if necessary, or use it before it expires.

The aim of this project was to determine the logistical feasibility of using an automated passive UHF RFID system to track the BUs throughout the medical center to ensure that no blood units remain outside of refrigeration long enough to be discarded. The project set out to accomplish several goals as a proof-of-concept:

1. Determine which passive RFID tags, amongst several different types, are the most reliable, cost effective, and provide consistent object identification
2. Configure a theoretical layout to determine effective placement of RFID reader antennas to track the tagged blood units as they are transported by the medical staff.
3. Develop a prototype program to track a blood unit's status if it is inside or outside of a refrigerator.
4. Keep track of how long the blood remained outside of the refrigerator and alert staff if a unit has expired.

Project Inception

To develop and implement a solution for this problem a passive UHF RFID device was interfaced with a PC based lab work station. A Visual Basic (VB) program is utilized to implement the control and monitoring of the software part of the project. VB is a widely used industrial software and provides a good solid platform to communicate and implement the RFID based system. The RFID system includes an ALR-9900 reader and two ALR-9611 Antennas. The work station configures the reader as to the type of information to be sent or returned. The reader interrogates the area within the antenna pattern and acquires the list of RFID tags, then provides the user with access to the tag information through the serial port. The reader is also a transceiver with a maximum of four antennas that can be connected to the reader ports via coaxial cables and operates at UHF hopping frequencies of 902-922 MHz; this range of frequencies is widely used for real-time, long range asset tracking. The passive tags vary in size and type depending upon the application and have a very small microchip and an antenna used to harness the RF signal power in their vicinity to power up the microchip and retransmit the RF carrier modulated with the tag information back to the reader antenna to be processed and analyzed by the reader.

UHF Passive RFID System Overview[7]

The two main system components of an RFID system are the RFID reader, and the RFID tags which are attached to the items to be identified (merchandise, people, pets, furniture, instruments etc.), see figure 1. One type, the passive UHF RFID system, is characterized by its agility, relatively long range, very high read rates, and low cost passive tags. The passive tag, which is energized by the electromagnetic RF field transmitted by the reader, is composed of an antenna, an integrated silicon chip that includes the basic modulation circuitry and a non-volatile memory. The RF signal, called the carrier signal, is transmitted by the reader (forward link) at the hopping frequency band of 902-922 MHz. When the RF field reaches the tag it couples with the tag's antenna coil and consequently an AC voltage is generated across the coil. This voltage is rectified to supply power to the tag. As the tag is activated it starts to transmit back the coded information stored in its memory (reverse link) to the reader, using a backscattered modulation technique, where it is decoded and retrieved.

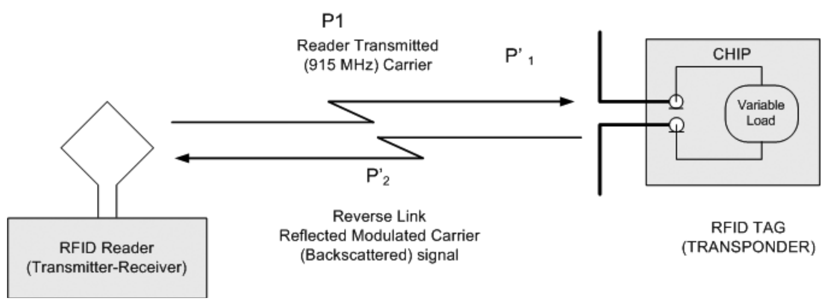


Figure 1, Concept of the passive UHF RFID system

Issues with passive UHF RFID system

The power harnessed by the passive tag is considerably hindered if the RF signal power in its vicinity is significantly attenuated. The RF signal attenuation is attributed to multiple reasons:

- The RF signal power attenuation is inversely proportional to the square of the distance between the transmitter and the receiver.
- The UHF RF signal can be reflected off nearby metal surfaces and concrete walls, which are common in a hospital environment, and cancel the incident signal if it is in anti-phase with incident signal.
- The reader's antenna radiation patterns may also vary in different directions depending on the location and geometry of the room, which consequently influence the reader's performance. Therefore, it is of great importance to adapt the reader's antenna location to properly scan its environment and provide maximum tag detection capability.
- Most important is that the UHF RF signals are easily absorbed by conductive liquids. If the passive UHF RFID tag is mounted directly on a conductive fluid surface (e.g. a blood unit full of saline solution) the reader UHF signal will almost be completely attenuated thereby preventing sufficient energy to be harnessed to activate the RFID tag.

Experimental Approach

Three issues had to be addressed; the location and orientation of the reader antennas to ensure a maximum received signal strength (RSS), determination of the type of tags most suitable for the application, and development of a program efficient enough to track the blood units as they are transported out of or into the refrigerator while simultaneously recording the length of time the unit was outside of the refrigerator, and alerting the medical staff of a possible expiration of a blood unit.

Tag Analysis

•Read Range vs. Distance

For a successful read to occur, the reader antenna must transmit the signal with sufficient power level to activate the tag to retransmit. In addition the tag backscattered signal must provide sufficient power to ascertain that the reader can receive the signal and interpret the tag data. Since the electromagnetic (EM) wave power intensity decreases in proportion to the square of distance traveled, it is expected that the number of reads will decrease as the distance between the tag and antennae increases.

•Tag Radiation Pattern

It is important to analyze the tag radiation pattern in a real world environment. The tags typically need to be oriented facing the reader antenna such that their maximum power point on its radiation pattern, i.e. the direction of its maximum sensitivity, is aligned with the maximum power point of the reader antenna radiation pattern. A typical tag radiation pattern supplied by the manufacturer tag data sheet is shown in figure 2, which is determined in an echoic chamber isolated from real world physical effects by using RSS measurements. However, the tag radiation pattern can be determined in the lab by rotating the tag at a fixed distance from the reader antenna and monitoring the reads/s, as a qualitative indicator of the RSS, versus the angle of rotation of the tag[7]. This method was successfully used to reproduce the real world radiation pattern of the ALN-9640[8] in an experimental lab environment.

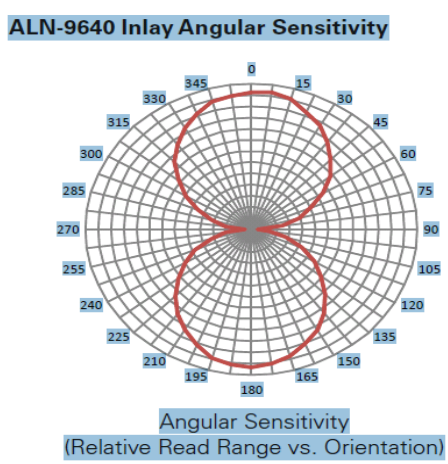


Figure 2, Typical Manufacturer tag radiation pattern

•Tag Performance Evaluation

Different types of tags were procured and tested to evaluate their performance and determine the tag of choice. The Alien Technology tags ALN-9640 (squiggle), 9662, and 9654[8] are very low cost high performance UHF RFID tags ($0.45 per tag), however their performance is considerably degraded when placed close to fluids. A more expensive specially designed tag such as the “Omni ID prox, max, and flex” tag types[9](approximate cost $4 per tag) can operate close to fluid environment. The Confidex Ironside[10] tag ($ 7 per tag) is an industrial type designed to be used directly on metal surfaces, see figures 3a and 3b.

(a)

(b)

Figure 3. (a) ALN 9640 and Omni Tags, (b) 9640 & Confidex tags,

The individual tags performances were evaluated in the lab environment. A “proximity test”, which determines the reads/s as a function of distance between the tag and the reader antenna, is a good qualitative indicator of their sensitivity (RSS) and performance[7]. The tested tag was placed at a distance from the reader antenna and oriented such that its maximum radiated power direction is in line with that of the reader antenna. With The RF power radiated by the reader antenna set to 30 dBm (1 watt) the distance between the tag and the reader antenna was changed in steps while simultaneously recording the reads/s vs. distance at each step. The results of the proximity test for the different types of tags are shown in figure 4, which is considered as their signature pattern.

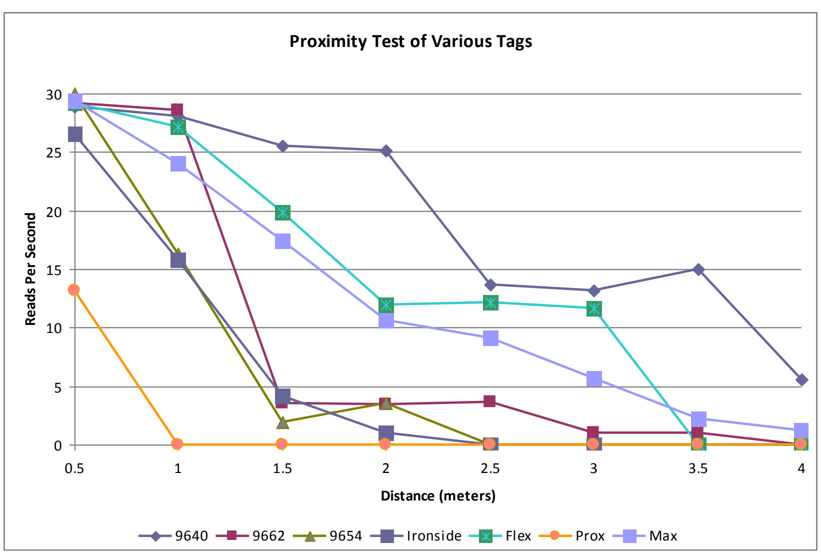


Figure 4, Tag performance comparison

It can be seen that the ALN-9640 tag performed best in the proximity test, while the Omni flex tag type is the second-best and the max type tag is third. The ALN-9662 had a high read rate at 1 meter or less, but dropped off dramatically at greater distances. The Ironside and the ALN 9654's showed similar performances, while the prox tag type was almost always at 0 reads per second beyond a distance of 1m. Although the ALN-9640 outperformed and has a better range than each of the Omni ID tags, the Omni ID tags are specifically designed to operate in RF-hostile environments, e.g. being in close proximity to fluids.

With the tags' signature patterns determined, next their individual performance needed to be evaluated when attached to a saline solution-filled BU to select the tag of choice under the set of constraints demanded by the proposed application.

•Tag Work-around

Initial analysis indicated that the ALN-9640 is the best choice based on its relatively low cost, high sensitivity and long range; however, its performance when placed close to a fluid environment was poor. The proximity test curve of an Alien ALN-9640 tag attached to an empty BU shown in figure 4 was considered as the tag's signature pattern. When the tag was placed on a saline filled BU, (see figure 5) and tested, the reads/s were consistently at or near 0 at all ranges, as shown by the "Fluid" curve in figure 6, illustrating the fact that the RF signal power was completely absorbed by the fluid in the bag.

Consequently it was decided to investigate the possibility of developing a work-around to improve the ALN-9640 performance when placed directly on the saline filled BU.

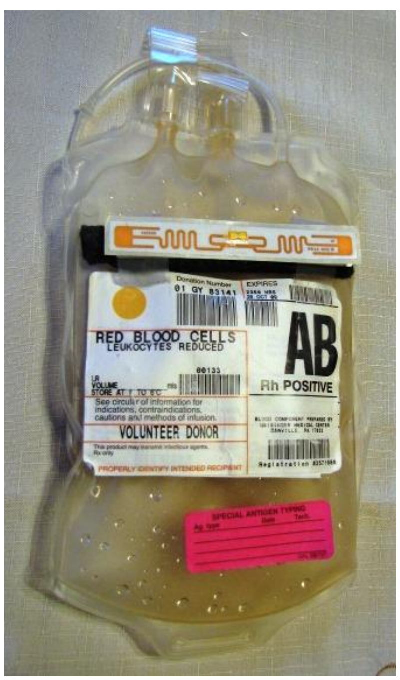


Figure 5, BU with 9640 on eraser material (synthetic polymer)

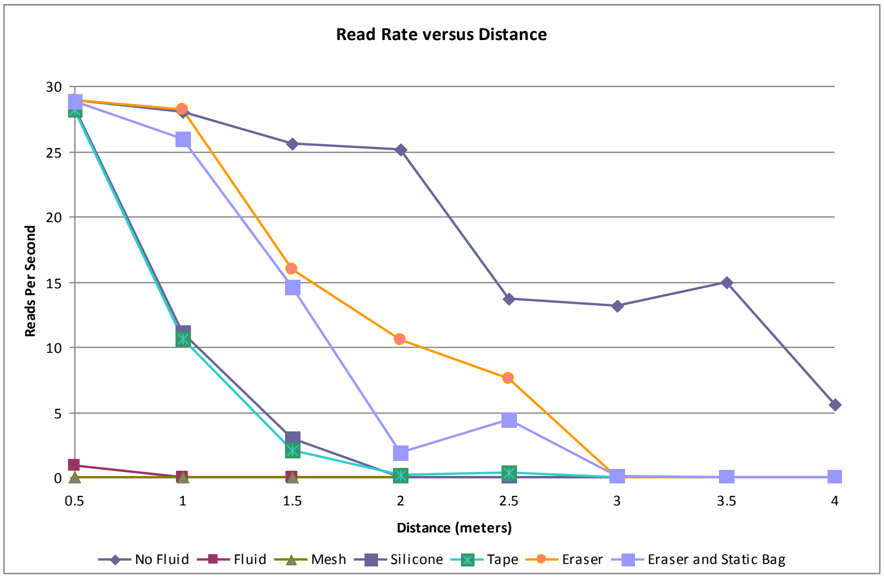


Figure 6, 9640 tag proximity test results

The antenna of the passive UHF RFID tag, which is generally λ/2 dipole[11], is the power harnessing element and its design is affected by the dielectric material it's on, which is why it doesn't work close to metals and fluids. When placed on a conductive saline fluid unit the RF signal power is attenuated and absorbed causing the backscattered signal power to be considerably reduced. However, with proper spacing between the tag and the fluid surface the RF signal power in the vicinity of the tag can be preserved and harnessed by the tag. The spacer material choice and its thickness are important. Its dielectric properties can affect the propagation speed of the incident UHF RF signal thereby changing its wavelength and causing a mismatch at the tag antenna. Different insulating materials with different thicknesses were used as spacers e.g. silicone from a caulk gun, duct tape, and a synthetic polymer fiber from a blackboard eraser material. Test results for various types of tag/material configurations are shown in figure 6. The eraser served as the best spacing material and the silicone and tape both showed noticeable improvement but at shorter ranges. Since these materials are inexpensive and very thin, they could serve as possible spacers for the ALN-9640 to prevent the loss of RF signal power in the vicinity of tag.

•Work-around tag performance vs. Omni ID tags

It was decided to compare the Omni ID tags against the various ALN-9640 tag/spacer configurations to determine which one presented the most effective solution. Proximity tests were carried out with the tags attached to a saline filled BU and their performance were evaluated. The results are illustrated below in figure 7.

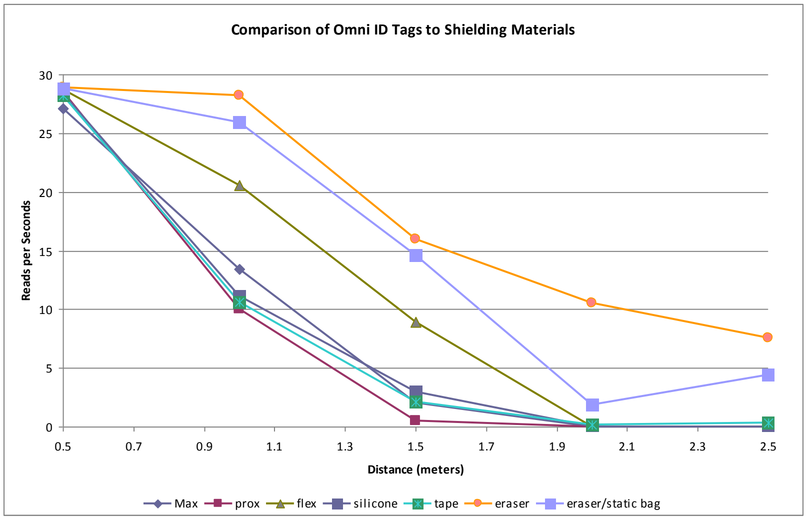


Figure 7, Comparison of Omni ID tags and the 9640 placed on insulating Materials

As seen, the performance of the 9640 tag/eraser configuration, named the "Eraser", was the best based on its highest read/s at the longest range of greater than 2.5m. The "Omni flex" tag performed equally well, considering that it was attached directly to the blood bag with no spacing material. The Omni max tag, the silicone and tape- spaced ALN 9640 tags had similar responses but at a much shorter range, with the "prox" tag losing its response signal at1.5 m.

Based on the sensitivity and long range of the tags, the above analysis indicated that the best choices were the Omni ID tags and the developed ALN 9640/eraser configuration (Eraser). The latter was more favorable for our application due to its very low cost which one tenth that of the Omni tags is.

Experimental Model

A basic experimental model replicating the process requirements was set up in the university lab environment using a large lab cabinet as storage for the saline filled BUs, one Alien technology reader and two RFID antennas, see figure 8. The first antenna (Ant#0) was set to monitor the cabinet door, which represented a refrigerator that contains the blood units, to detect if any tag is being removed or returned. The second antenna (Ant#1) was located to the right of the cabinet facing down with its radiation pattern slightly overlapping the Ant#0 pattern to monitor the BU's location when transported. However, a larger overlap area must be avoided to prevent Ant#1 from simultaneously reading a tag detected by Ant#0. When the BU inside the cabinet it was not detected by any of the reader's antennas. However, when removed from or placed into the cabinet it was only detected by Ant#0. When transported it was detected by the Ant#1 field only. This basic model simulates the procedure to be followed to determine if a blood unit is in or out of the cabinet and track its location as it is transported. A Visual Basic program was then developed to analyze the reads/s data from the two antennas to determine the location of the blood unit at any given time.

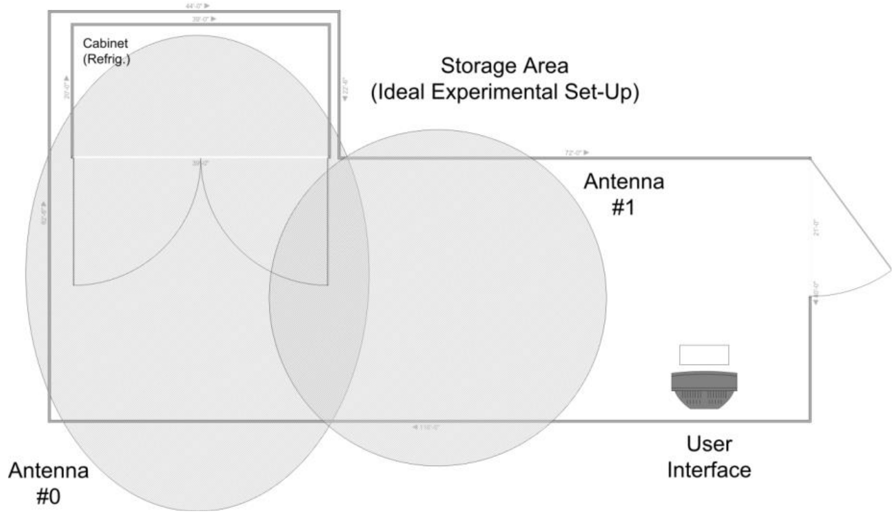


Figure 8, Layout of the basic experimental set up

The Software

A Visual Basic program was developed to communicate with the reader/interrogator gateway through its serial port. The program's algorithm includes the following functions:

The "matching the patients" function enters the patient information into arrays. The arrays can be edited and printed at different sections of the program. On the "form load event" the reader is configured to return tag list information in a text format and display it as a string in the textboxes in the form, together with the time and date information.

The "main timer tick" event is the main part of the program, see figure 9. It runs every 8 seconds and retrieves the tag list information from the reader. Based on the information returned the program determines which of the two antennas detected the BU tag, the Electronic Product Code (EPC) which identifies the tag, and the time and date information. It then places the antenna number into a sequence which only writes new data when the reader antenna number changes. So even though it might read five times while the tag is traveling through the first zone, the program will display only when the tag enters a different zone. The simplified data analyzed three characters at a time to determine the location of the blood unit. When the unit is removed the time is noted, and a name then must be entered to identify the person who removed the unit. When the unit is returned the name and time is recorded again. This information is entered into the arrays and is displayed on screen at the user interface, see figure 10. The sheet displayed on the user interface was designed to mimic the form currently hand written by the staff. The displayed data can then be analyzed by the blood bank staff to determine what blood units need to be discarded.

"The end of day procedure" determines which BU was out of the refrigerator for more than the mandated time of 30 minutes and flag the BU to be discarded.

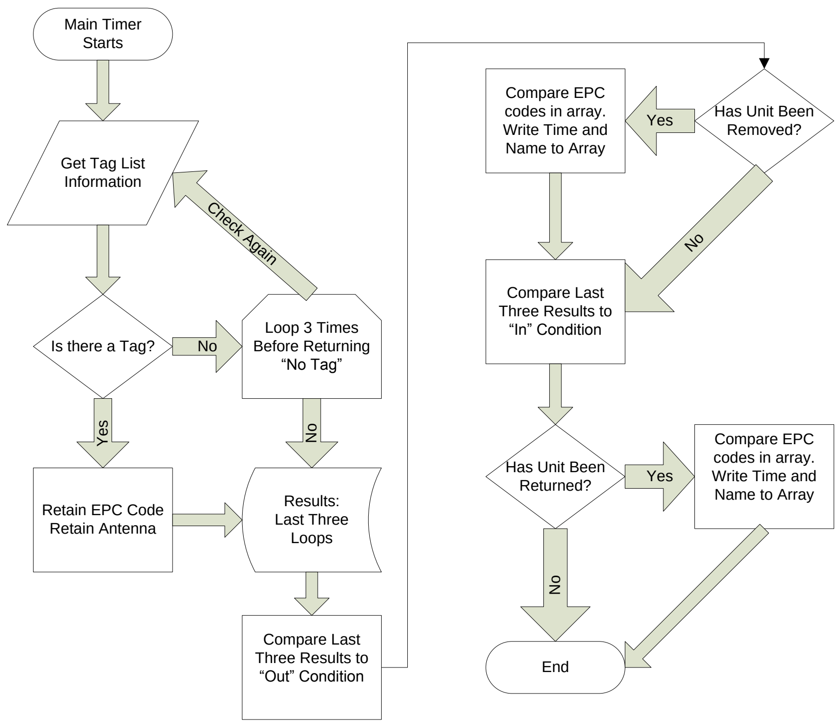


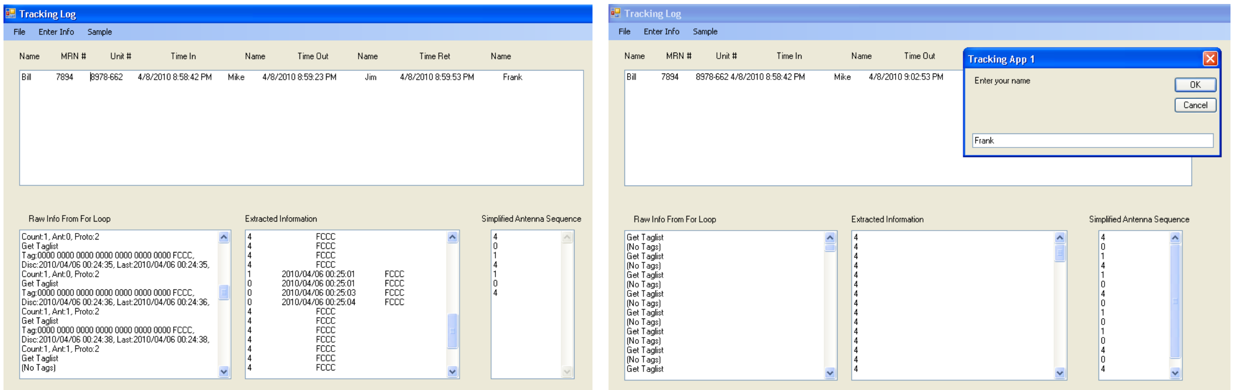
Figure 9, Main Timer Tick Event Flow Chart

System Evaluation

The complete prototype system integrating the experimental set-up, the selected tags, and the VB control and monitoring software was then tested to evaluate its the overall performance. An evaluation procedure was developed using the preferred tags (the Omni and the all modified ALN9640 tags) using empty and the saline filled BU. The BU was placed in the cabinet and the program was started, the BU was then removed from the cabinet and transferred through the two antenna zones down the "hallway" and then returned. This was done ten times for each BU/tag configuration. Each time the results were assessed based on the following scale:

- A "0" would be assigned if the program did not detect the tag at all.
- A "0.5" would be assigned if the tag was detected on the out OR return trip, and
- A "1" would be assigned if the tag was detected on the out AND return trip.

The results were then averaged and a score assigned for each trial as a percentage. The VB user interface is shown in figure 10.



Figure, 10 VB user interface

Results and Analysis

The bar chart shown in figure 11 summarizes the system performance test results which correlate very well with the tag analysis results. The best system performance using saline filled BU was achieved using the Eraser, followed by the Omni flex and the max tags. The worse system performance was when using the silicone work-around. When using the developed Eraser tag configuration the system performance outperformed all others, and with its very low cost it was definitely the tag of choice.

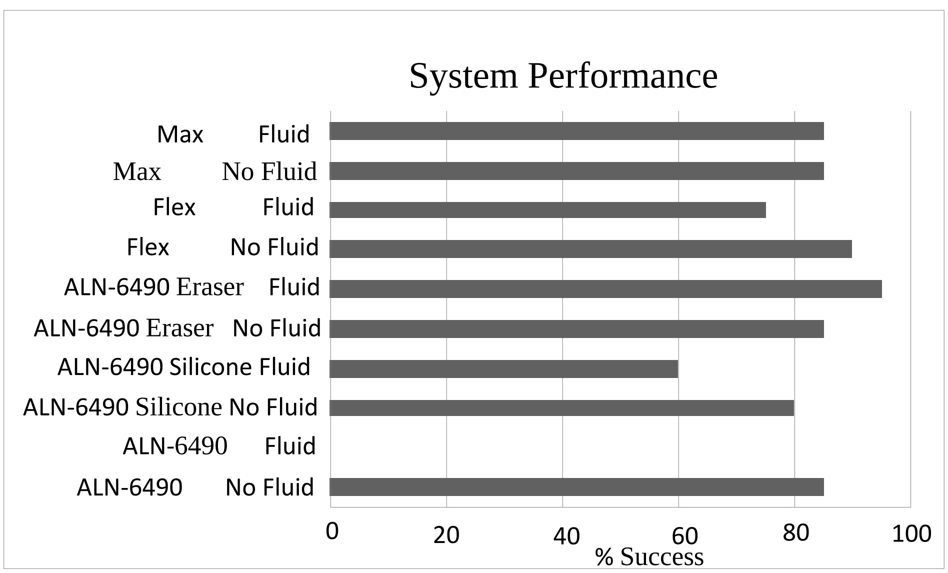


Figure 11, Experimental model performance analysis

Performance Evaluation

Student performance evaluation was based on two interim reports and a final report.

- Following the student's visits to the medical center he presented his first report. He presented an analysis of the logistics and the proposed solution. This included a clear explanation of how the medical center envisioned the blood unit transportation logistics.
- The second report presented the analysis of the individual tags performances under the conditions imposed by the logistics processes and the development of a work-around tag.
- The final report was comprehensive; the student presented the final integrated prototype system test results that justified the proof of concept.

Educational Outcome

The involvement of students in undergraduate research is of utmost importance. It provides an excellent venue for the students to integrate the theoretical and practical knowledge gained during their educational period to analyze and solve real world problems. In this project:

- The student utilized an evolving state of the art technology to develop and implement an automated solution for a critical industrial logistic problem.
- He was confronted with the practical complexity of RF signal propagation, and used his knowledge to provide a successful solution.
- He learned the theory of RFID system, gained hands-on experience with its practical applications, and realized how a seemingly simple operational configuration can have considerable effects on the reliability of the system.
- Learning the theory of UHF RFID tags and how they operate, he innovated a simple effective solution using a low cost tag that parallels the efficiency of an industrial relatively high cost tags.
- Involvement in research made the student think like an engineering technologist. He not only learned how a sophisticated system operated but also learned how to analyze the problems associated with RF systems operations, signals, and their effects.
- Using his industrial level computer programming and mathematical background, he developed an effective VB application program, which not only acquired and analyzed the data but also controlled the process and provided vital information through a simple informative user interface.
- He developed a decision based method and provided a simple effective reliability analysis method to justify the outcome.
- He attended a number of meetings with medical center managers and professionals to discuss the project requirements. The meetings refined his communication skills as an engineer and emphasized the importance of understanding the underlying process prior to the implementation of any project.

Conclusion

Using basic RFID equipment together with moderate programming experience and creative thinking, an innovative solution was implemented to produce a tag configuration that can rival expensive tags available in the market. The prototype system proved to be a viable solution for the blood unit waste management problem and provided the background for further research. Further development is necessary for the system to be acceptable for real world implementation in the healthcare industry. Most importantly the undergraduate research provided the opportunity for the student to gain considerable theoretical and real world practical experience beyond what he has learned during the normal class periods.

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