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TRACKING AND AUTOMATING A LIBRARY SYSTEM USING RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

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Abstract- This paper discusses implementing a Location-Aware Library RFID service employing Radio Frequency Identification as a communication technology. Automating a library system with passive RFID tag infrastructure is proven to be feasible, and can be achieved with even distribution of RFID Antennas, well designed RFID network, an appropriate middleware, and a library application with an accurate error function that minimizes the error in the detected location to an acceptable distance, for instance, 35 cm. The paper first discusses the effect of using RFID on the upper application and System layers. A simulation of randomly distributed tags with spatially distributed antennas is shown. Simulation results are provided to prove the validity of the proposed approach, which proves that adding a localization feature to the system layer is feasible with an acceptable error range that does not exceed 1.1%.

Index terms: Radio Frequency Identification, RFID, Library Automation, Location-aware, Localization.

I. INTRODUCTION

With the rise of online resources and new technologies, the quality and quantity of the services that the library offers to the community are rapidly changing. Libraries interested in enhancing user services and providing independent access to library services and collections have begun to look at ways of automation in order to make the library services available online and integrated with the latest social services [1].

The library is one of the first areas that adopted implementing emerging information technologies (IT) to enhance the delivery of services to readers, and enhance the customer experience level [1-2]. Emerging IT can be defined as innovations that have the potential to create a new industry or to transform an existing one [3]. The implementation of emerging IT started with index cards, computerized databases for library materials, barcodes and now radio frequency identification (RFID) [1,4].

Radio Frequency Identification is the communication using electromagnetic field to transfer data between the tag and the RFID reader antenna. RFID tag is a small tag that contains pre-programmed information to link to database that contains identification information plus other details. Radio Frequency (RF) is the most commonly used communication protocol for connecting real-life objects in a network. RF is the electromagnetic spectrum associated to the radio wave that is a result of the propagation of the radio frequency signal, which is propagated as a result of an electric current passing through an antenna circuit [5].

Today, Radio Frequency Identification (RFID) is widely used in many different industries and sectors. It is more common and widely used when compared to other technologies, such as barcode technology, because of its contactless nature that enables simultaneous detection of multiple-item. In addition, the memory capability of RFID makes it more than just an identification technology, as it enables using the tag as data carrier that can update and transfer information momentarily [6].

Previously, many libraries had already installed barcode systems in order to simplify and automate the identification of items, where a barcode is placed on each book and the Library Management System (LMS) uniquely identifies the book by reading it, using a barcode scanner [7-8]. Since RFID system has a lot in common with the existing barcode system, RFID has been introduced in library systems starting from late 1990s [6], more and more library systems have adopted RFID technology to automate their systems.

Until recently, barcode technology was the most popular library system, because of its simplicity and low cost. It also has some important limitations, for instance, it requires line of sight for operation and also the data on a barcode is very limited in size, which cannot be modified or added. Modern application processes such as patient care or supply chain integration, and libraries, need more advanced capabilities, which a barcode system cannot achieve [9-10].

The use of RFID, for developing self-service applications in libraries, dates back to the late 1990's [6]. Since then, RFID has generated more and more interest among the libraries as a technology to enhance self-service for improving productivity and user satisfaction [6]. By 2003, more than 300 libraries in the United States had implemented RFID technology [11]. According to the 2004 library report in [11], the collections total nearly 1,000,000 monographs, 8500 serials subscriptions, 12,000 serial titles accessible through aggregated databases, over electronic indexes, databases or reference sources, and 27,000 media materials [11].

RFID technology provides a solution in managing, collecting, and distributing books effectively [12]. Moreover, RFID technology can bring significant savings in terms of staff costs, enhancing services, prevent book theft, provide a constant update of the library collections, and achieve real-time services [13-14].

A major paradigm shift in product traceability began with the transitioning to RFID technology from barcode. It has contributed to the ability of RFID technology to resolve tracking problems in more effective and faster way. This has resulted in significant economic, operational, technological and logistical impacts on supply chain infrastructures. The advantages of RFID technology over barcode and any other data collection technology, can be listed in: reading the tags in heavy moisture, noisy, or dirty environments; And greater flexibility in reading the tags with wide scanning area [10].

As shown in figure 1, operating and managing libraries, involves undertaking numerous repetitive tasks, such tasks include:

- Item tagging.
- Shelving and user-related borrow/return procedures.
- Alerting system for the late returns.
- Managing inventory and anti-theft protection.

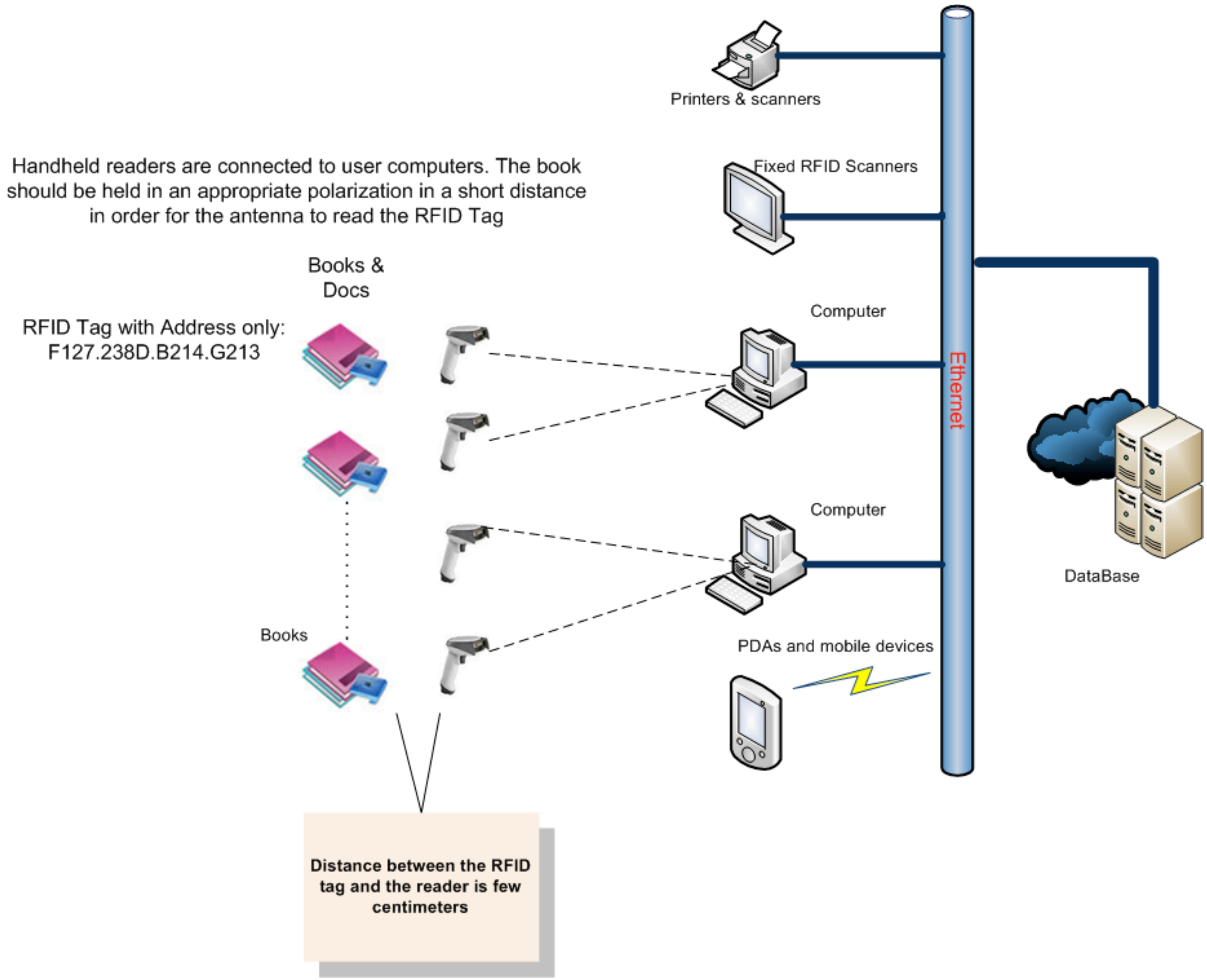


Figure 1. Traditional Library System

These tasks are not only repetitive, but are meticulous involving considerable amount of labour, effort and time. Manual operations of such tasks demand high levels of resources in terms of number of people required, and the amount of time and budget required, which are all likely of introducing human errors, thus affecting both, the efficiency and effectiveness of a library operation system. With hopes of increasing efficiency and effectiveness, many libraries are adopting the automation [15] of the tasks outlined above. In doing so, radio frequency identification (RFID) technology is being deployed to play a vital role of efficient management in library automation [16-17]. RFID technology has revolutionized the item identification and tracking system.

Automating a library system can achieve the following:

(1) Reduce the human error to the minimum by automating the library return procedure using categorization of the library sections. This will be explained in details in the System Architecture section.
(2) Speed up and automate borrow and return process by automating the administration process in borrow, return, and the automated arrear book alarms.
(3) Reduce the maintenance work in the library by categorizing books in the library according to the subject, and alarming the administrator of any misplaced book.
(4) Maintain the library items efficiently by tracking objects in the library, and alarm the administrator in case of any unauthorized object removal upon leaving the library gates.

The current system in a public library employs the smart tag to extract what a book keeper and a library owner would be interested in. What this research would add to the system that would benefit the librarian, library users, and the library owner, is a location-aware library system that can be easily injected and integrated with the existing system without affecting the running modules and the smart entities. This involves redesigning the system to automate the library business processes, taking advantage of the capabilities of the passive RFID reader antennas, and relying on a smart middleware application to handle the calculations to locate library objects at runtime. The core service layer will be supplied with a location-aware tracking service, without affecting the services running on the system, which will enable the upper application layer to track and locate the smart entities in the hardware layer, refer to figure 2. The existing tag readers must remain operational after adding the new service, which is essential to any library system. The main challenges in reusing the existing UHF RFID infrastructure are as follows:

* The solution must be compatible with the existing commercial passive UHF tags, which requires designing the library system based on antennas compatible with the existing RFID tag specifications.
* The reader antenna must be simple enough for very low-cost mass production, and easy integration into different shapes and sizes of store structures (shelves, tables, security gateway), inclusive of existing structures.
* The reader antenna must be able to activate and read at least 20 books per second (This will be explained in Section III).

The proposed library system automates the following processes:

* The borrow and return processes can be automated, the system will use main reader antennas on the library gates to automatically scan in/out the books the reader take in/out the library.
* Accurately locating books inside the library on request (accurate to 35 cm). The librarian must be able to use an interface to request the location of a specific book.
* Based on the library book categories, the librarian must be warned if there is a book that has been returned to wrong shelf (If the book belong to a different subject category, the system should be able to retrieve this category from the database and warn the librarian about the location of the book and where it belongs).
* The communication between the RFID antennas and the main computer(s) should be secure.

This paper purposes a solution for tracking and automating a library system. Section II covers the system architecture of a traditional library system; the business processes in a traditional library system will be explained briefly. In the next section, the middleware architecture will be described for a best performance. A high-level prototypical implementation of the application layer will be presented in section III.

II. TRADITIONAL LIBRARY SYSTEM ARCHITECTURE

An RFID tag may contain only a unique identification number (barcode or accession number), which identifies that book. It is the only piece of data that can be communicated between the RFID system and the LMS system; this has made the interoperation easier and more efficient. The required data are held in the LMS, which can be accessed using this key identifier [18].

However, utilizing an RFID tag to hold more information about the book may not be achievable using the existing library RFID tag infrastructure. Examples about some of the information to be stored in a tag, bibliographic information, the shelf that the book is held on, its previous lending history, supplier information etc. This information will have to be obtained from in the LMS, i.e. the interface between the two sets of hardware (RFID and LMS) must be able to exchange this information. As RFID suppliers are now developing applications which utilize this type of data they need to be working closely with LMS suppliers and follow the latest RFID International Organization of Standardization (ISO) to standardize the set of data being exchanged [18]. A high-level system architecture diagram is shown in figure 1 in the previous page, the figure describes the traditional service model of a library system.

RFID system offers contactless identification, automatic retrieval of data, and wireless data storage. Data reading using RFID enhances performance and productivity by increasing the accuracy and speed of information communication. The tags, readers, and back-end servers are the three basic components in a basic library RFID system. The tag and the reader must work at the same specified frequency and conform to the same protocol to guarantee the compatibility of the communication system [19]. Moreover, the tag and the reader antenna must be aligned to achieve the required polarization for the antenna to read the tag. The distance between the antenna and the tag must not exceed the maximum distance that a reader antenna can read [12].

The handheld reader antennas are connected to the librarian computers. The librarian computer is connected to the library network, which is connected to the backend server with a LAN network. The backend server uses middleware to filter and store all information for each specific RFID tag, see figure 1.

Currently, the majority of libraries are equipped with high frequency (HF) RFID tags and readers operating internationally at a frequency of 13.56 MHz [13]. The main advantage of using frequency 13.56 MHz, is that it is available in most countries. This frequency has been reserved for industrial, scientific and medical applications. However, the UHF RFID system surpasses the efficiency by increasing the reading range and providing multi-reading capacity compared to the HF RFID system in the library automation system [13,20].

According to ISO standard 28560-1; The exchanged information in a typical modern library system contains information set of data elements suitable for library implementation, to meet the needs for secure and efficient library system [21]:

(1) Circulation of library items.
(2) Acquisition of library items.
(3) Inter-library loan processes.
(4) Data requirements of publishers, printers and other suppliers of library items.
(5) Inventory and stock checking of items.

The importance of the ISO standard is to provide the framework to ensure interoperability between libraries in exchange of library items with RFID tags, and enhance the possibility of the library to acquire or renew equipment or library items from different software or vendors [18].

When the existing library systems were investigated, the problem found was that most of these systems do not comply with the ISO standard, in fact; most of them just use the RFID tag for identification purposes only, storing all the other related information in the library system database, and the system retrieves this information when the tag is scanned. The design takes this case into consideration, as most of the existing tags are not re-programmable, the system should keep track of these tags in the database and exchange only the identification information.

The RFID tags that are found in the library of Auckland University of Technology are only used in anti-theft system, while the existing barcode tag is used to identify the library object in general and track the borrow-return process [18].

Librarians in Takapuna public library in Auckland, New Zealand confirmed that the library system is built to utilize the RFID system. All the library objects are tagged with pre-programmed passive RFID tags, which has a unique identifier and no other information is stored on the RFID tag, which makes the system non-ISO 28560-1 compliant. The librarians have their hand-held RFID scanners connected to their computers, which they use to scan books at the time of borrow and return. This process has some drawbacks such as, the distance between the tag scanner and the tag cannot exceed 10 centimetres in the best cases. The alignment of the tag and scanner to reach a specific polarization of the reader antenna can be time consuming to the librarian sometimes. There is also an auto restore shelve that the borrower can return books to which contains a fixed wide antenna that covers a wide area, which auto-detect books when they are placed on top of it.

AUT library system is still utilizing both RFID, and the barcode system. The existing barcode system used to regulate the borrow/return process, and identify books in the library management software. The RFID system is used only in the anti-theft system.

a) RFID Tag Description

RFID tags can be passive, retrieving the necessary energy either from the interrogating wave or from a constant signal that some antennas transmit to power up the tag. The second type of tags is the active tag, which includes a battery as a power source, to enhance the reading range. Passive tags are the cheapest to manufacture, do not require maintenance, and are more compact and lighter [22]. World-assigned RFID frequency bands range from high frequency (HF) up to microwaves [23], refer to Table 1. The allocated band at ultra-high frequency (UHF) ranges from 860 MHz to 930 MHz, divided into three sub-bands corresponding to the three world regions. In general, UHF passive RFID tags present the lowest unit cost, which makes UHF RFID the preferred choice for mass applications. This type of RFID tags are the most commonly used in library systems. Table 1 below explains briefly the frequency bands and how the spectrum divided between them [24].

Table 1: Operating frequencies and performance characteristics [24]

	Low frequency (LF)	**High frequency (HF)**	**Ultra high frequency (UHF)**	**Microwave frequency (MF)**
Frequency range	125-134kHz	13.56MHz	860-930MHz	2.45GHz
Read range(passive)	< 0.5 m	1.0m	3.0m	10m
Tag cost	High	Lower than LF tags	Lowest	High
Typical application	Tracking, Cardkey	Lower than LF tags Airline baggage handling, library book tracking, electronic article surveillance	Supply chain tracking, warehouse management	Electronic toll collection, Railroad monitoring

Frequency allocation is managed through regulation by governments. Which makes the frequency ranges specified in Table 1 vulnerable for change between different countries. In Europe, the frequency range for UHF band is: 902 MHz to 921 MHz, while the range for this band in New Zealand is narrower, from 915 MHz to 921 MHz, which limits the range for the allowed frequency range for RFID applications. The transmission frequency plays a sensitive role in the covered area that the RFID system can operate on. Almost, all RFID systems operate on one of four frequency bands: low frequency (LF), high frequency (HF), ultra high frequency (UHF) and microwave (MF) [8].

The data capacity for the RFID tag depends on the manufacturers' specifications. Some tags have capacity to store up to 2,048 bits of information [25], most existing Library tags typically have space for 128-bits of information, which is adequate for current system demands, but trying to adhere with the minimum limit of 128-bit when designing a library system, does not meet the ISO 28560-1 standard. This kind of problems can be overcome by programming the tag to hold the identification number only, and the rest of the functionalities must be maintained in the middleware.

b) Middleware Architecture

The middleware is a repository software or device that connect RFID readers and the collected data with a unified data "*Repository*", providing the necessary Application Programming Interface (APIs) and interfaces to integrate the library network components with each other on one side and with the repository on the other side [26].

The lowest layer in the hierarchy is the Hardware layer, which consists of the distributed physical RFID tags, hand-held reader antennas, librarian computers and all other library hardware. One layer above is the Entity Read/Write (ERW) service. It defines a generic and unifying interface to the underlying physical passive RFID tag infrastructure, which uses RFID as a standard communication protocol. The Core Service layer consists of generic services that operate with individual Smart Entities to achieve specific purposes they are designed for. The higher-level service layer is represented by a collection of specialized services that rely on the core services to provide service to the application layer on top in a robust, and fault-tolerant manner. Finally, the Application layer contains the applications and services that are designed to serve the end-user and the library system in a consistent, interactive and fault-tolerant way. The application architecture is explained in figure 2 below [26].

The middleware architecture is extensible, facilitating the integration of additional services using pluggable modules that can be injected and integrated with the adjacent modules, the lower and upper layers. For a fault-tolerance reliable operation of the middleware application, the redundancy resulting from the super-distribution of the smart entities is exploited by the middleware services. For instance, the core middleware services support the integration of additional tags that are distributed at a later point in time, without a noticeable service interruption, i.e. dynamic-integration of tags [27]. Furthermore, the services provided by core service and high level service layers mask the complexities of applied fault-tolerance, self-organization, and self-calibration mechanisms as well as hardware-specific details from higher-level services and applications [27-29].

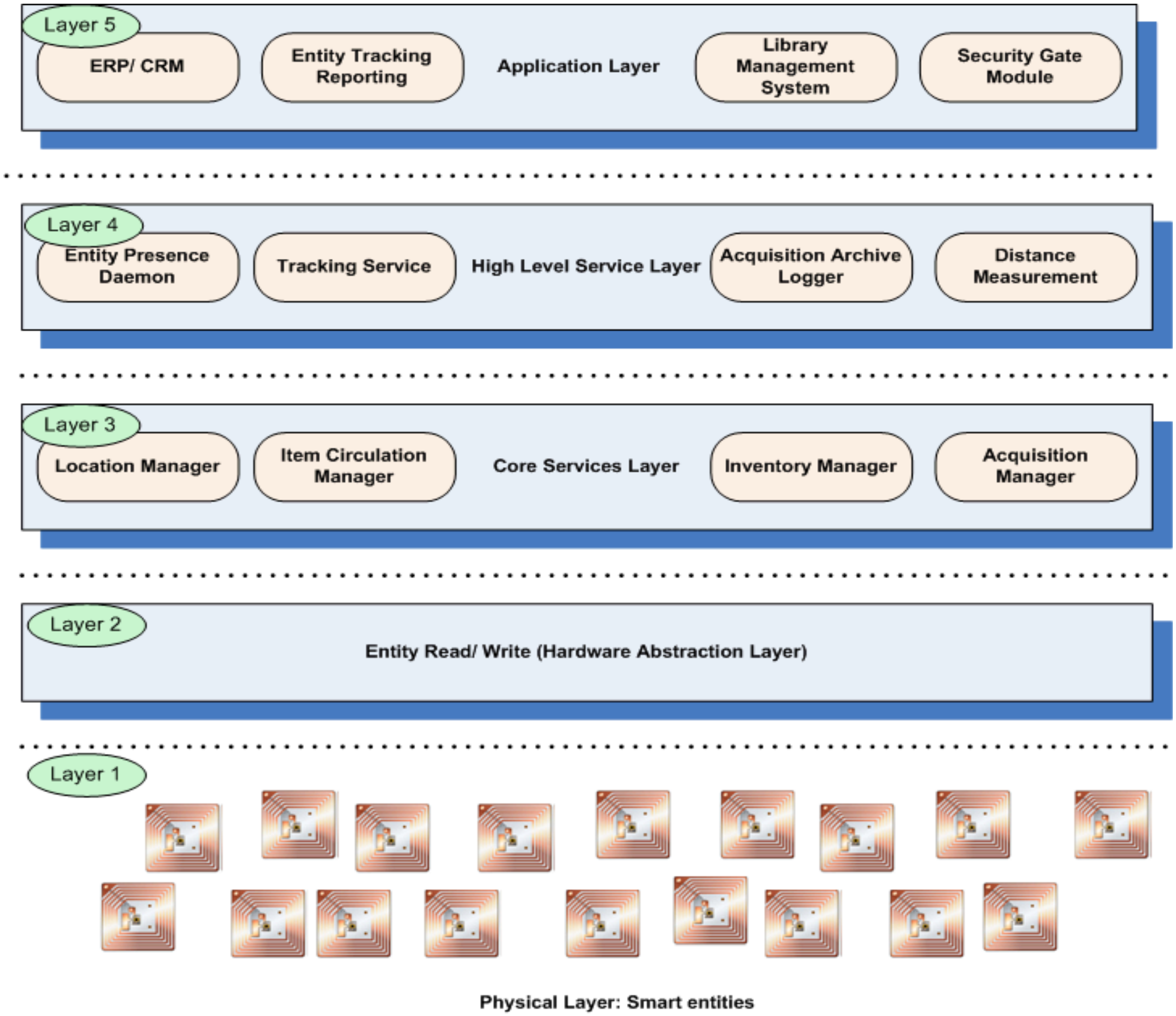


Figure 2. Library System Application Layer Architecture [30]

The change applied to the library system starts from layer 2, the entity read/write functionality is revised and automated, this part will be explained in details in section III. A new service will be introduced to the three upper layers in the middleware stack.

III. PROPOSED SOLUTION

The automation of tasks in a library is achievable based on concepts such as, data gathering, warehouse management, tagging, reporting or custom application processes. The library items will be tagged in order to be activated and interrogated at any time, regardless of the orientation of the object or the location of the RFID tag. The main computer must be able to identify and locate tags, based on a location abstraction depending on the individual tags for each resource in a fault-tolerant manner.

This research presents the feasibility, and applicability of adding location-aware services to the core layer (without affecting the running services). In order to enable the upper application layer to track and locate the smart entities. The existing tag readers must remain operational after adding the new service; this is essential to any library system. The main challenges in reusing the existing UHF RFID infrastructure are as follows:

* The solution must be compatible with the existing commercial passive UHF tags, which requires designing the library system based on antennas compatible with the existing RFID tag specifications.
* The reader antenna must be simple enough for very low-cost mass production, easy integration into different shapes and sizes of store structures, i.e. shelves, tables, security gateway, inclusive of existing structures.
* The reader antenna must be able to activate and read at least 20 books per second.

Using radio frequency operated smart 'tags' allows real-life objects to become 'smart objects' that will actively communicate with computer applications connected to the network. The information 'sensed' about their identities is exchanged while reacting to the 'physical world'. This information is driven by robust middleware applications that activate the tags in the required areas and securely process tag information [31].

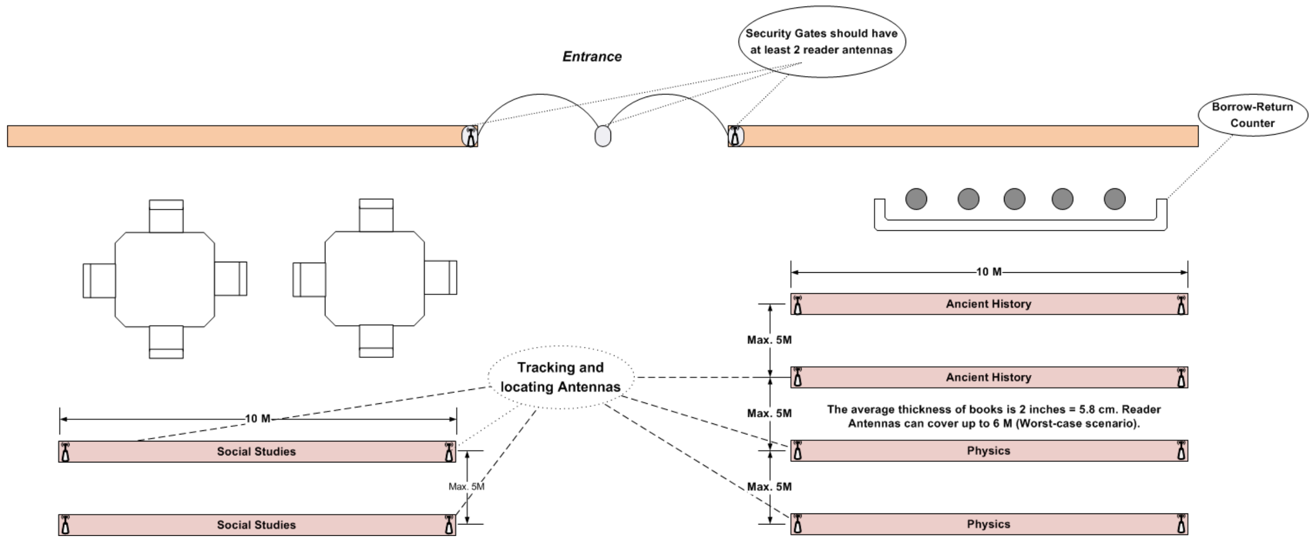


Figure 3: Conceptual Library Design

The library system will be designed accurately to evenly distribute the antennas between shelves to guarantee the coverage of the tags from three antennas in order to accurately estimate the tag coordinates in the 3 dimensional space. Figure 3 shows a simplified diagram of the aisles of a conceptual library.

As shown in figure 2, the ***Hardware Layer***, is the lowest layer, which contains the passive RFID tags, readers, and antennas. it has been investigated to get the tag operating frequency. This will be used to decide whether the tag infrastructure will need to be renewed if the operating frequency of the tags is in the HF range. The readers and antennas will interrogate all the passive tags in the required area to get the required ID, and interrogate the tags multiple times from multiple antennas in order to get the location, more information about the localization algorithms in the next paragraph.

The ***Hardware Abstraction Layer*** is one layer above the hardware layer, which is where the communication with the entities takes place, represented in the middleware, the engine that operates the application and integrates with the antennas processes signals from the tags.

The third layer is **Core Services Layer**, which contains the Location Manager Module, which will be responsible of locating the objects via a strong error-minimization function based on the received antenna reading datasets from the layers below, and pass the tag coordinates to the services that use it in the upper layers.

All the layers op top are services and applications that rely on the mentioned layers on the bottom. The LMS system will be built to track, locate and manage the library objects. It will utilize all the services in the layers below to track the library items and display the items' information to the librarian or the library user in graphical and useful format.

RFID based positioning methods have been researched extensively, the existing tag locating techniques can be summarized into two main categories [32]: (a) RSSI-based methods (Received Signal Strength Indicator) [32-35] and (b) Phase-based methods [32-35].

RSSI-based localization [36] has attracted considerable attention due to its simplicity and low cost [32]. RSSI utilizes the power loss value received from the passive RFID tag, as explained in the next section, a single reader antenna may be able to determine the range of a tag based on the RSSI indicator, which is proven by the simulation model built in section IV [36-37].

The proposed real-time locating and tracking technique is based on the power loss value utilizing multiple spatially diverse reader antennas. Each antenna provides an RSSI value that depends on the distance that separates the tag from the antenna. Multiple antennas interrogating the same tag from different vantage points provide an RSSI dataset from which the tag location may be estimated [32]. The dataset detected by each reader antenna will be inserted into a mean-square error testing function. The error function is minimized at each test point in the interrogation zone to find the point with the minimum mean-square error [32,37].

Referring to figure 3, the antennas must be distributed around the shelves depending on the maximum distance an antenna can cover, which depends heavily on the antenna specifications. SkyRFID Antenna model number SKYA902LPH106 will be used in this research, which can cover an area of 20 to 21 metres, taking into consideration, for this solution to work, each tag in the library must be covered by at least three antennas. According to the manufacturer specifications, this antenna is capable of reading 400 tags per second simultaneously [38].

The average thickness of a library book is 2 inches [39], which is equivalent to 5.08 cm. The worst-case scenario, each antenna can cover an area of 20 × 20 metres, 400 metres in total. If this number is divided by 5cm, which is approximately the average thickness of a book, the result is 80 books, multiply this number with 5, the number of shelves in AUT city campus library, the result is 400 books.

While a single reader antenna may be able to roughly determine the range of a tag based on the above model, it requires multiple spatially diverse reader antennas to estimate the coordinates of a tag unambiguously [32]. In order to guarantee that each book is covered by at least three antennas, the 20m distance must be divided into half, taking into consideration that the maximum distance between two aisles is 5 metres, refer to figure 3.

1. Mean Square Error

Mean square error is the most common technique to forecast the accuracy depending on a data set of observations. It is the average squares of the difference between the actual previous actual observations and the predicted. The measure of the centre of distribution is associated with the value of error. Supposing that we are measuring the quality of t, as a measure of the centre of distribution, the mean square error is given in equation (1) [40]:

$$MSE(t) = \frac{1}{n}\sum_{i-1}^{k} f_i (x_i - t)^2 = \sum_{i=1}^{k} p_i (x_i - t)^2 \quad (1)$$

where x is a vector of i predictions, p is the power loss value, t is the assumed good measure of the centre (In our case; t can be the first estimated distance value).

The Mean Square error value based on RSSI value can be calculated from every antenna at each test point n. Then the mean-square error (MSE) function is calculated using the formula [32]:

$$MSE(n) = |P_1 - S_1(n)|^2 + |P_2 - S_2(n)|^2 + |P_3 - S_3(n)|^2 + |P_4 - S_4(n)|^2 \qquad (2)$$

where P_1 to P_4 are the measured RSSI values from antennas 1 to 4, and S_1 (n) to S_4 (n) are the modeled RSSI values for antennas 1 to 4 at point n. As mentioned earlier, the RSSI from each antenna is averaged over all frequencies because our basic signal model does not depend on frequency. The tag is estimated to be located at the point n_{mmse} with the minimum MSE (MMSE) [32].

IV. SOFTWARE SIMULATION

Applications in general need to achieve a high degree of realism and simulation capability, this requires the use of the simulation models need to include a physical description of the environment where the network will be deployed. As well as a definition of the physical features and operational parameters for the hardware components that the researcher has chosen to implement in their final design concept [41].

RFID networks in particular are hard to simulate using the existing simulation tools for two main reasons:

1. The first is that RFID system is a short distance identification technology, that replaced the bar code to identify library objects, which required a reading distance of no more than few centimetres; hence the requirement to simulate such a network, is either does not exist or insignificant, as the main components of the existing library infrastructure, is the middleware computer, and the RFID reader.
2. The second reason is the variety of the operating frequencies, and the dropping price of the RFID components has made it easy for a researcher to implement a hardware prototype to prove the concept and test the design.

Wireless Sensor Network Simulator was used initially to build the simulation. WSN is designed for localization of sensor nodes in a simulation task that requires a network of sensors and sinks. The program implements eight localization algorithms, while more can be implemented when required, since it is an open source. Numerous parameters that define network topology include: network size, locators deployment strategy and antenna type, as well as the path loss and node mobility can be configured using this tool, see Figure 4, the Graphical User Interface (GUI) for the WSN [36,42].

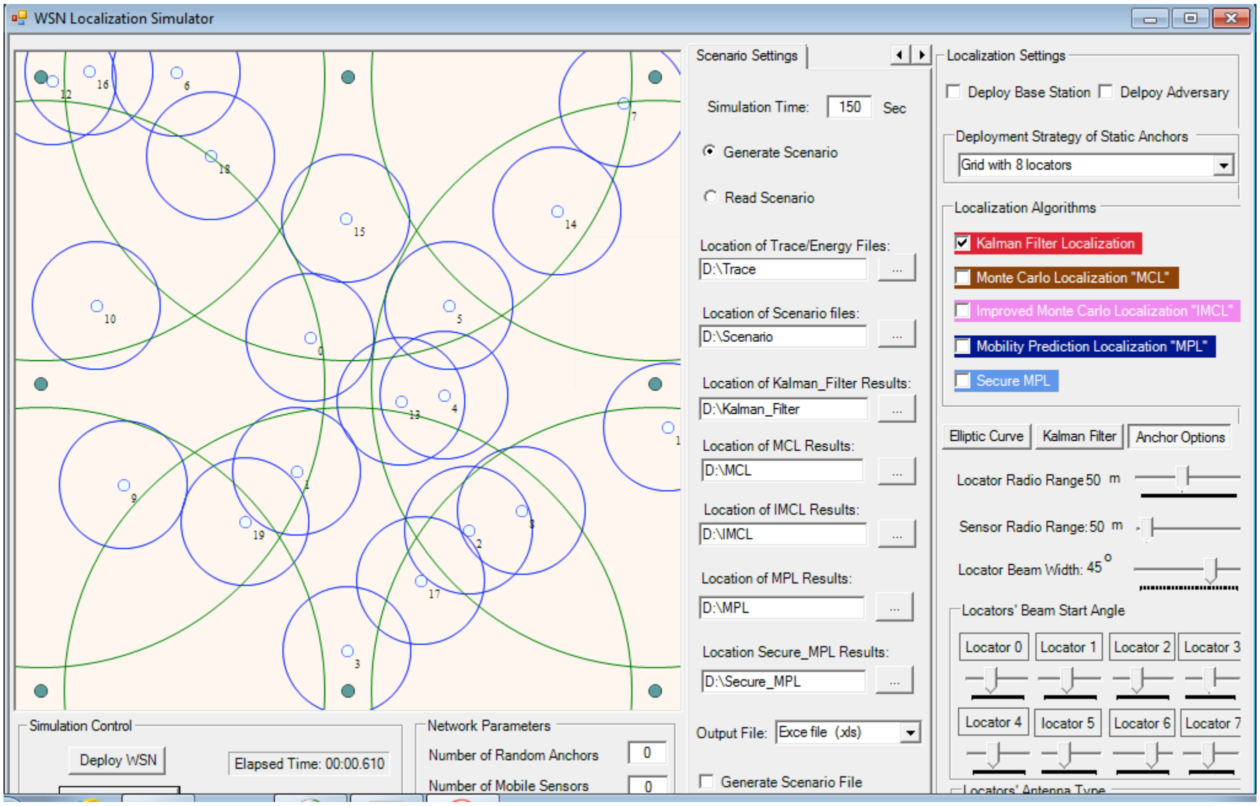


Figure 4. A simulation for 24 tags arranged in rows and columns

Since WSN is customizable to a certain extent, the code for WSN has been revised to arrange the RFID tags in rows and columns to mimic a real-life library scenario and to estimate the distance between the antenna and the tag based on the power loss value that is calculated from the residual energy value, see figure 5.

As seen in figure 5 and 6, for each time slot or iteration, the simulation application measures the residual energy for each tag. However, there is no indication of which antenna detected the tag and the number of missed or detected tags in the system by each antenna. As this is an important limitation to the simulation system, which may negatively affect the results. In addition, two more challenges were faced in this simulation, which can be summarized as follows:

1. The software does not identify the sensors detected by every antenna. The sample text file, the result files show that all tags have been identified per iteration, which implies that the simulation tool does not categorize the tags detected by the deployed antennas.

2. The result files show that all tags are identified, which implies that there is no tag miss. WSN assumes that the antennas are spatially distributed in the simulation window, the tags are completely covered by the deployed antennas.

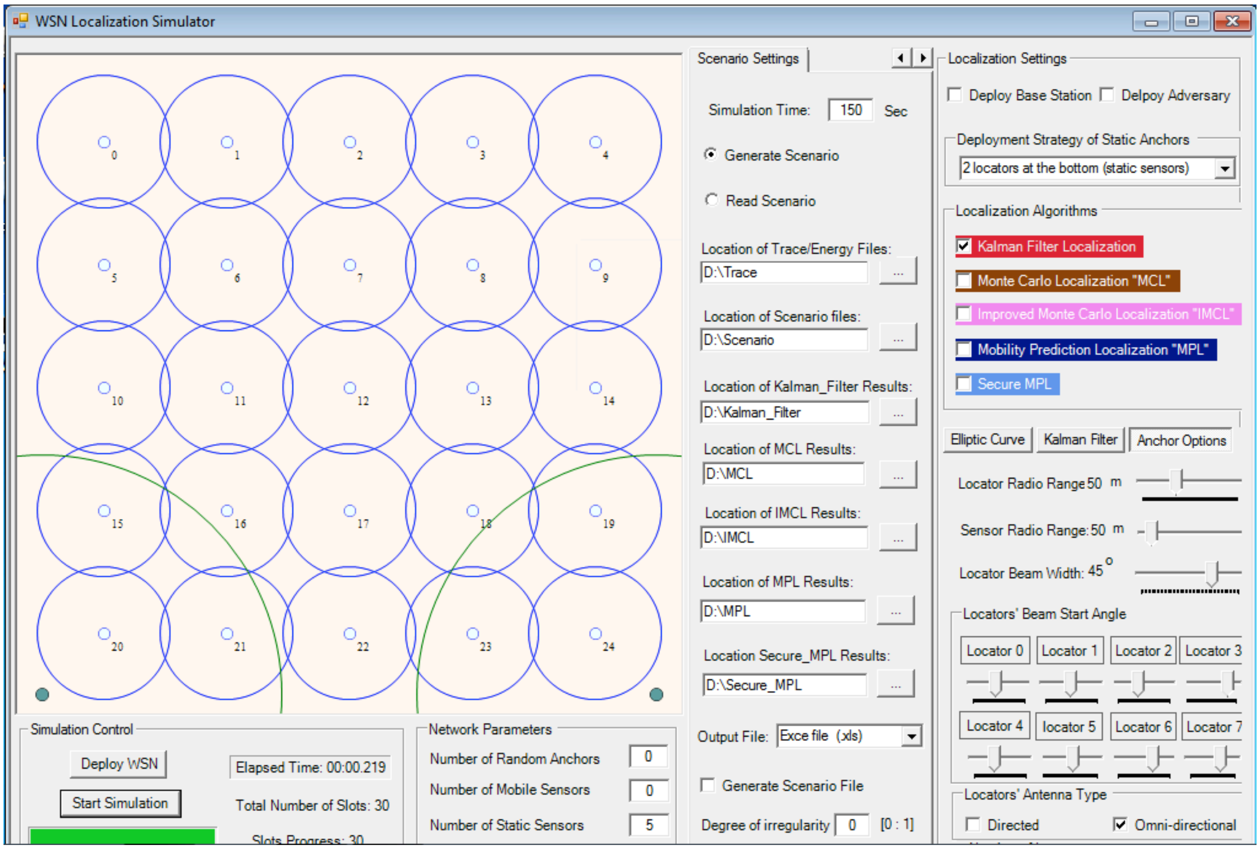


Figure 5. WSN simulation window-Post-Code modifications to locate tags in columns

In order to overcome the above limitations, a new simulation application has been developed to simulate the RFID system using a specific set of hardware specifications, like frequency, antenna gain, and so on, which was built on Java.

According to Chhimwal et al.[43], the following components need to be considered when building a WSN system:

- Nodes: each node is a physical device monitoring a set of physical variables. Nodes communicate with each other via a common radio channel.
- Environment: the main difference between classic and WSN models are the additional 'environment' component. This component models the generation and propagation of events that are sensed by the nodes, and also triggers sensor actions, i.e. communication

among nodes in the network. The events of interest are generally a physical magnitude as sound or seismic waves or temperature.

- Radio channel: it characterizes the propagation of radio signals among the nodes in the network. Very detailed models use a 'terrain' component, connected to the environment and radio channel components. The terrain component is taken into consideration to compute the propagation as part of the radio channel, and also influences the physical magnitude.
- Sink nodes: these are special nodes that, if present, receive data from the sensors, and process it. They may interrogate sensors about an event of interest. The use of sinks depends on the application and the tests performed by the simulator.
- Agents: the agent may cause a variation in a physical magnitude, which propagates through the environment and stimulates the sensor. This component is useful when its behaviour can be implemented independently from the environment, e.g., a mobile vehicle. Otherwise, the environment itself can generate events.

The new software must achieve the following:

1. The simulation window must distinctively draw antennas, and sensors. In addition, all items on the window must be uniquely numbered.
2. The coverage area of each antenna's radio wave must be outlined and coloured distinguishably from sensor areas.
3. The simulation tool must generate at least two types of files: (a) A list of RFID tags and antennas with the actual distance between sensors. This list will be used to validate the simulation results. (b) A list contains the estimated distance measured by each antenna for each detected sensor. This list contains the estimated distance in pixels, in metres, and the power loss values.

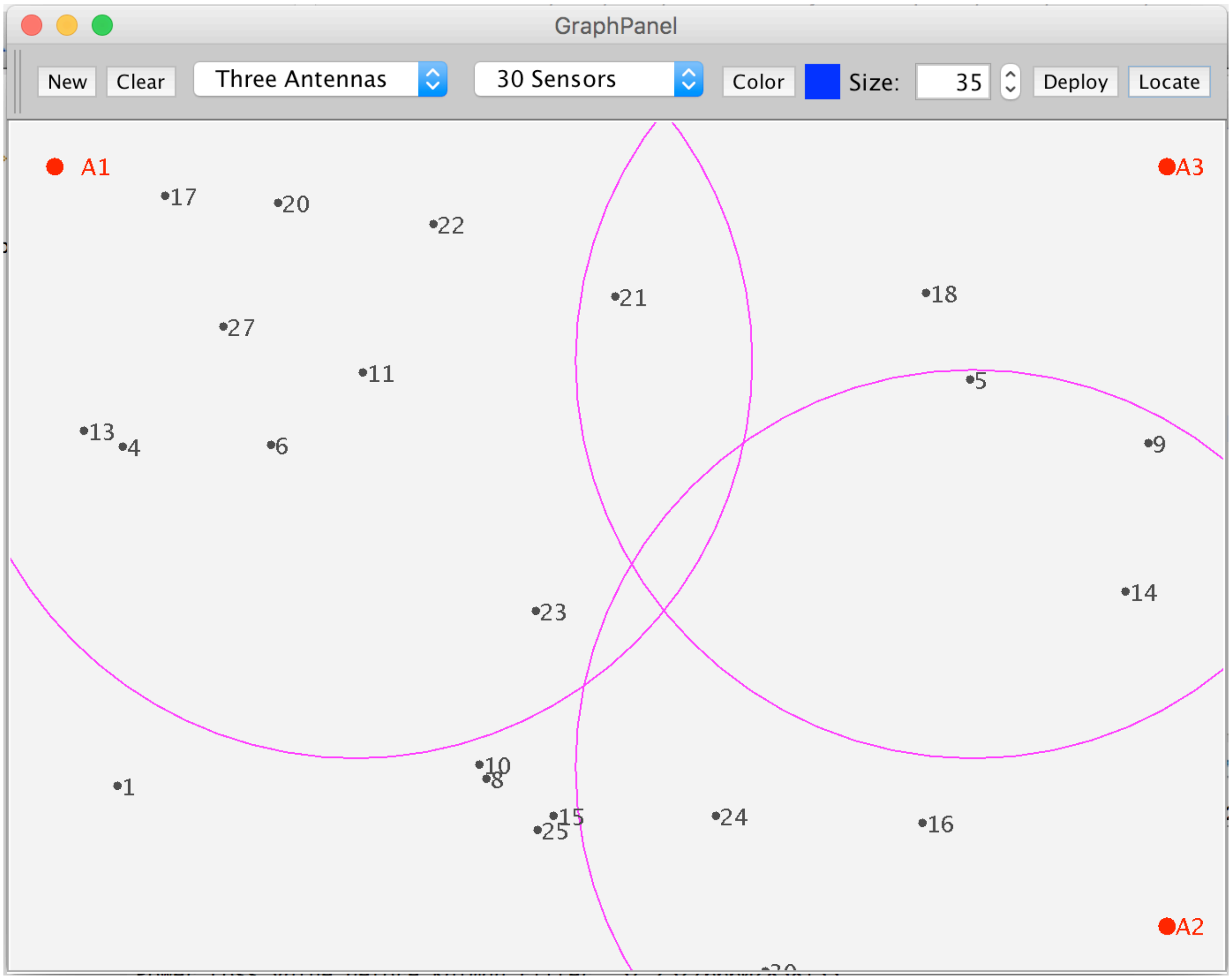


Figure 5. RFIDSim Simulation of three antennas and 30 tags

The developed system comprises a number of different java methods related to painting corners, nodes, sensors, circles and so on, as well as many other methods that are called internally within the other methods to deploy the simulation and generate the result files. The chosen programming language is Java, the reason for choosing Java over the other programming languages is explained next.

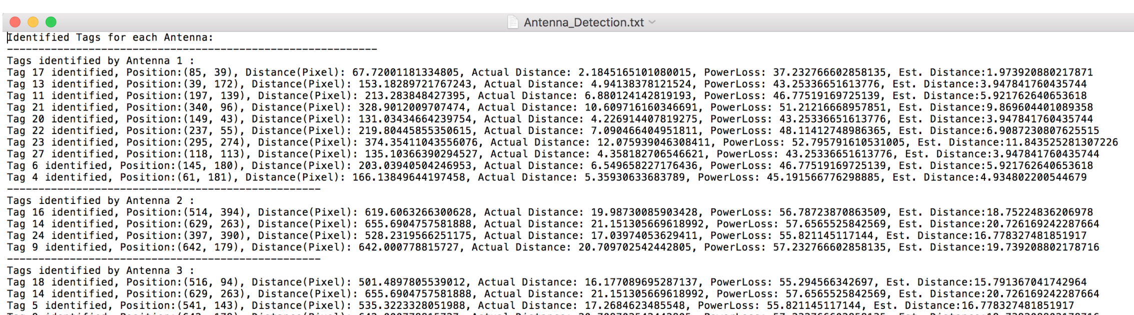
Java is designed to enable development of portable, high-performance applications for a wide range of computing platforms possible. By making applications available across heterogeneous environments, can provide more services and enhance end-user productivity, and dramatically reduce the cost of ownership of both enterprise and consumer applications. Java has become invaluable to developers by enabling them to [44]:

- Write software on one platform and run it on virtually any other platform.

- Create programs that can run within a web browser and access available web services.
- Develop server-side applications for online forums, stores, polls, Hyper Text Markup Language (HTML) forms processing.
- Combine applications or services using the Java language to create highly customized applications or services.
- Powerful and efficient applications for wireless modules, sensors, gateways, consumer products, and practically any other electronic device [44].

Depending on the solution design, the basic simulation of RFID system requires covering the radio frequency signals transmitted by at least two main RFID components, RFID reader antenna, and the tag. Which must be clearly represented in the simulation window. The results of the simulations are dependent on few factors, which can be listed in the following:

- The assumption that the programmer makes usually to describe the physical layer objects in the simulation application, which may deviate from the actual description of the hardware in real life which may cause a variance in behaviour between the object in simulation and real life [43]. This must be fixed by the programmer at the early steps of building the simulator, the programmer needs to describe the hardware based on the manufacturer documented specifications, this should be as accurate as possible.
- The noise introduced to the RFID signal in real-life must be taken in consideration, which is an important factor for the programmer to get accurate results that are close to real hardware test. This can be solved by introducing a Kalman Filter to the simulation results.
- Polarization is another important consideration that every researcher needs to take into consideration when simulating RFID reader antennas and tags. To maximize the tag range, antenna polarization of the tag must match that of the reader antenna, both must be described in the simulation.


Antenna_Detection.txt

```
Identified Tags for each Antenna:
----------------------------------------------------------
Tags identified by Antenna 1 :
Tag 17 identified, Position:(85, 39), Distance(Pixel): 67.72001181334805, Actual Distance: 2.1845165101080015, PowerLoss: 37.232766602858135, Est. Distance:1.973920880217871
Tag 13 identified, Position:(39, 172), Distance(Pixel): 153.18289721767243, Actual Distance: 4.94138378121524, PowerLoss: 43.25336651613776, Est. Distance:3.947841760435744
Tag 11 identified, Position:(197, 139), Distance(Pixel): 213.283848427395, Actual Distance: 6.880124142819193, PowerLoss: 46.77519169725139, Est. Distance:5.921762640653618
Tag 21 identified, Position:(340, 96), Distance(Pixel): 328.9012009707474, Actual Distance: 10.609716160346691, PowerLoss: 51.21216668957851, Est. Distance:9.869604401089358
Tag 20 identified, Position:(149, 43), Distance(Pixel): 131.03434664239754, Actual Distance: 4.226914407819275, PowerLoss: 43.25336651613776, Est. Distance:3.947841760435744
Tag 22 identified, Position:(237, 55), Distance(Pixel): 219.80445855350615, Actual Distance: 7.090466404951811, PowerLoss: 48.11412748986365, Est. Distance:6.908723080762515
Tag 23 identified, Position:(295, 274), Distance(Pixel): 374.35411043556076, Actual Distance: 12.075939046308411, PowerLoss: 52.795791610531005, Est. Distance:11.843525281307226
Tag 27 identified, Position:(118, 113), Distance(Pixel): 135.10366390294527, Actual Distance: 4.358182706546621, PowerLoss: 43.25336651613776, Est. Distance:3.947841760435744
Tag 6 identified, Position:(145, 180), Distance(Pixel): 203.03940504246953, Actual Distance: 6.549658227176436, PowerLoss: 46.77519169725139, Est. Distance:5.921762640653618
Tag 4 identified, Position:(61, 181), Distance(Pixel): 166.13849644197458, Actual Distance: 5.35930633683789, PowerLoss: 45.191566776298885, Est. Distance:4.934802200544679
--------------------------------------------------
Tags identified by Antenna 2 :
Tag 16 identified, Position:(514, 394), Distance(Pixel): 619.6063266300628, Actual Distance: 19.98730085903428, PowerLoss: 56.78723870863509, Est. Distance:18.75224836206978
Tag 14 identified, Position:(629, 263), Distance(Pixel): 655.6904757581888, Actual Distance: 21.151305669618992, PowerLoss: 57.6565525842569, Est. Distance:20.726169242287664
Tag 24 identified, Position:(397, 390), Distance(Pixel): 528.2319566251175, Actual Distance: 17.03974053629411, PowerLoss: 55.821145117144, Est. Distance:16.778327481851917
Tag 9 identified, Position:(642, 179), Distance(Pixel): 642.000778815727, Actual Distance: 20.709702542442805, PowerLoss: 57.232766602858135, Est. Distance:19.739208802178716
--------------------------------------------------
Tags identified by Antenna 3 :
Tag 18 identified, Position:(516, 94), Distance(Pixel): 501.4897805539012, Actual Distance: 16.177089695287137, PowerLoss: 55.294566342697, Est. Distance:15.791367041742964
Tag 14 identified, Position:(629, 263), Distance(Pixel): 655.6904757581888, Actual Distance: 21.151305669618992, PowerLoss: 57.6565525842569, Est. Distance:20.726169242287664
Tag 5 identified, Position:(541, 143), Distance(Pixel): 535.3223328051988, Actual Distance: 17.2684623485548, PowerLoss: 55.821145117144, Est. Distance:16.778327481851917
Tag 9 identified, Position:(642, 179), Distance(Pixel): 642.000778815727, Actual Distance: 20.709702542442805, PowerLoss: 57.232766602858135, Est. Distance:19.739208802178716
```

Figure 6. RFIDSim Simulation of three antennas and 30 tags

The result is a raw file that contains the power loss value, the actual and estimated distance in pixels and metres, and the actual coordinates of the RFID tags in order to be used for validation purposes. See figure 6.

The suitable simulation window is (670 × 480 pixels). The first antenna is placed on the exact coordinates (20 × 20 pixels), which represents point (0, 0) in reality, which is the reference point that will be used to locate objects from, for objects localized from antenna 1. The second antenna is located on the opposite corner of antenna 1, which has the coordinates of (650, 450), which means that the detectable simulation window size is (650 – 20 = 630 pixels), that means that sensors lie within that area are detectable from the nearest antenna(s). The simulation distance in pixels is 630 pixel, which represent 20 metres in real life; i.e. 1 metre in real life is equal to 31.5 pixel in our simulation.

According to the manufacturer of SkyRFID, the minimum detection range of antenna SKYA902RHP9 is 10 metres in a worst case scenario. So, the simulation space is divided so all the sectors in the simulation space is detectable by at least 3 antennas.

The power loss was calculated based on the ideal situation [45]:

$$P_{Loss} = 20.\,\mathrm{Log}\,(4\pi.\mathrm{d}\,/\lambda) \quad (3)$$

The distance is calculated using the power loss values, the antenna frequency (which has been assumed to be fixed at the beginning of the simulation based on the chosen hardware). The distance can be measured using the power loss equation 3 [45]:

$$P_{Loss} = 20.\log\frac{4\pi.d}{\lambda} \quad (4)$$

where λ is the wavelength, d is the distance, P is the power loss.

From equation 4, the estimated distance can be calculated if the other variables in the equation can be determined, the distance formula is shown in equation (5):

$$d = \frac{\lambda.e^{\frac{P_{Loss}}{20}}}{4.\pi} \quad (5)$$

If the sensor location lies within the radio wave range of the antenna, the actual distance is calculated and generated using Equation (6):

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \quad (6)$$

where X1, Y1, and X2, Y2 are the coordinates of the sensor and the antenna. The above equation has been converted into a java method in order to be called by all classes/methods that need it.

In summary, a network model was built for an RFID system to simulate the antenna, tag distribution in reality, and the radio frequency signal flow between these components. For a randomly chosen simulated model, the maximum distance detected between an antenna and an RFID tag, was '11.843525281', while the actual distance was '12.36094349'. The percentage of the error to the total distance is (12.36094349/11.843525281) × 100%, the total is 1.043 %, which can be considered an acceptable error range considering that this will be entered in a mean square error minimization function that will also gather more readings from the all the antennas that can reach the negotiated tag including that antenna that was used in the original reading.

Simulation results prove that implementing a location-aware service employing Radio Frequency Identification as a communication technology automating a library system with passive RFID tag infrastructure is feasible and can be achieved with even distribution of RFID antennas, well-designed RFID network, the appropriate middleware, and a library application with an accurate error function that minimizes the detected location error to 35 cm.

V. DISCUSSION AND CONCLUSION

Sensors have become part of our daily life activities, and several useful applications are being developed everyday [46]. This paper addresses the problem of design and implementation of a smart library sensing system. The work considered several aspects, ranging from librarian interviews, contacting radio frequency hardware manufacturers, and software development. Every stage contributes strengths and flaws in its own specific parameters, which may be carried through to the next stage.

At the beginning of the research, the librarians in Takapuna public library in Auckland, North Shore, and Auckland University of Technology (AUT) university library, in New Zealand were interviewed to get a general understanding about the used library management system software and the nature of the business processes followed normally in the borrow/return, book shelving, book tracking, and anti-theft system.

In summary, this paper investigated aspects involved in automating a library system using RFID technology as a communication protocol for the underlying RFID infrastructure. The library middleware application is a smart location-aware service that is used to identify and track library objects automatically and dynamically at runtime.

The simulation framework can be used for the design and testing of automated RFID based library systems. The simulation application has proven that this research produced satisfactory results. Hence, the methodology developed is potentially promising and can be used as a basis of practice for future work in implementing the library system automation solution.

The simulation results also show that the RSSI is proportional to the received power, which is also proportional to the transmitted power and the gains of the reader and tag antennas. In addition, it is inversely proportional to the distance-squared between the reader antenna and the tag. It is also a function of the polarization alignment between the reader and tag antennas.

As a future work, it is intended to enhance the framework by adopting efficient smart tracking method as presented in [47] and [48]. In addition, the integration of this RFID based framework into a library requires the following:

- RFID Antenna and Tags: more investigation can be carried out focusing on different hardware manufacturers, who are residing in New Zealand, and have the ability to provide hardware compliant with NZ Frequency spectrum.
- RFID Simulation Application include:
  - An RFID Simulation framework that can be used to simulate the operation of similar wireless networks. More dynamic features can be added to the framework in order to enhance the application.
  - The simulation software can be extended by building a signal model based on one directional distance relationship. The RSSI value is proportional to the inverse of the squared distance value.
  - Developing an extension program for integration with third party middleware applications to minimize or eliminate error when it is manually done, and provide better simulation results.
- Hardware Implementation include:
  - Build a prototype for a small implementation of a library system to prove the theoretical part of this research.

– Conduct a heavy search for a New Zealand RFID hardware provider who can reprogram the required hardware to comply with the requirements specified by NZ Spectrum Management.

Finally, passive RFID have contributed positively to enhance the existing library solutions, and helped automating manual library processes. However, the functionalities offered by passive RFID technology are mainly limited by the short distance that the radio signal can cover. Since this is the age of IoT domination, smart solutions are expected to replace the existing manual processes. The proposed framework can be extended, in order to support existing systems and provide smart solutions, such as using smart mobile phones, and WSNs in order to enable librarians to identify, search, locate, and track items inside libraries [49].

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