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TRACKING OCCUPANTS AND INVENTORY ITEMS IN BUILDINGS USING RFID TECHNOLOGY

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In order to make control decisions, Smart Buildings need to collect data from multiple sources and bring it to a central location, such as the Building Management System (BMS). This needs to be done in a timely and automated fashion. Besides data being gathered from different energy using elements, information of occupant behaviour is also important for a building's requirement analysis. In this paper, the parameter of Occupant Density was considered to help find behaviour of occupants towards a building space. Through this parameter, support for building energy consumption and requirements based on occupant need and demands was provided. The demonstrator presented provides information on the number of people present in a particular building space at any time, giving the space density. Such collections of density data made over a certain period of time represents occupant behaviour towards the building space, giving its usage patterns. Similarly, inventory items were tracked and monitored for moving out or being brought into a particular read zone. For both, people and inventory items, this was achieved using small, low-cost, passive Ultra-High Frequency (UHF) Radio Frequency Identification (RFID) tags. Occupants were given the tags in a form factor of a credit card to be possessed at all times. A central database was built where occupant and inventory information for a particular building space was maintained for monitoring and providing a central data access.

1 INTRODUCTION

Despite the fact that modern smart buildings have state-of-the-art Heating, Ventilation, and Air-Conditioning (HVAC) systems, thermal comfort and indoor air quality are still not satisfactory [1]. According to the Sustainable Energy Ireland (SEI) report of 2008 [2], the average Irish household (in the residential sector) is responsible for emitting 4.8 tonnes of CO_2 from direct fuel use. Public and commercial buildings in the service industry consume the equivalent of 1.5 million tones of oil every year; this represents 15% of the total primary energy consumption in Ireland [3]. These figures strongly suggest that there is need of methods to monitor, analyse, and reduce excessive energy consumption, to reduce high energy cost. It has been found out through research [4] that a large part of excessive energy usage is accounted due to occupants and their energy usage behaviour. Besides designing air-tight and insulated buildings, there is also a need to determine the occupant or user behaviour. This would be helpful to know how occupants react to the available energy resources, and hence, their energy consumption requirements. Based on this, energy consumption requirements depending upon the number of occupants can be calculated. There is yet no standard method to determine occupant behaviour towards buildings, different buildings use different methods depending on their size, type, and usage. Some of these methods include fix and preset supply of energy, whereas others perform requirement analysis based on occupant requests. Problem with the latter solution is the unexpected user demands and delay in carrying out these demands. While determining behaviour of occupants towards a building facility, it would be also important if their information of localisation and also of inventory items is available. Based on prior physical location knowledge of occupants and items, effective management of personnel and items in fire or emergency situations can be carried out.

In this paper, we present a prototypical demonstrator for occupant and inventory monitoring system implementation based on Radio Frequency Identification (RFID). This system tracks, reports, updates, and identifies occupants and inventory items entering into a building space. Based on the number of personnel present and moving in and out of a building facility at any time and also over a certain period of time, their behaviour towards the facility is determined. The results of occupant behaviour are envisaged to be made available to the central Building Management System (BMS) for further processing. The building space used and presented for this study is an office room of the Department of Civil and Environmental Engineering at University College Cork (UCC), Ireland.

The paper is structured to discuss, in the first section, different use cases to present the need for occupant monitoring. It includes topics of occupant density, occupant patterns, thermal comfort, inventory management, and fire/emergency evacuation. The second section discusses the demonstrator’s implementation methodology with sub-sections covering topics of RFID Technology, Experimental Setup, and System Architecture. Finally, topics such as results, conclusions and future work are presented.

2 USE CASES

To highlight the importance and application of knowing occupant behaviour towards buildings, this section discusses some use cases. These use cases represent the conditions when the requirement of tracking and identification information becomes vital and how these can be drawbacks in different aspects when occupant information is not known.

2.1 Occupant Density

Occupant density is referred to as the number of people present in a building space at a particular time. A building facility's density can be calculated through continuous monitoring of in and out activities by occupants. The estimation of occupant density contributes to the information of occupant behaviour towards a building space and to the overall cost of managing a specific building facility based on personnel usage. Generally, the total occupancy cost, which is the overall cost to maintain occupants in a building, includes [5];

- Property occupation costs
- Adaptation and equipment costs
- Building operation costs
- Business support costs
- Management costs

A reliable and efficient method of calculating occupant density is important to reduce a building's energy cost requirements. Knowing the occupant density allows optimization of building energy management and can influence building operation. On the other hand, a lack of this information can lead to increased total occupant management costs because of not knowing the energy consumption requirements [6]. The occupancy data is also important to continuously monitor a building's capacity limitations.

2.2 Occupant Patterns

Occupant patterns represent the use of a building space over a specific period of time. It can be referred to as the collection of occupant density information over a certain period of time. It provides a perspective as to how much a particular building space is used for that time period and also its peak and off-peak timings of population density. This then adds on to the information of determining occupant behaviour. Based on these patterns, and hence, personnel density environmental requirements, control of a building's different systems and elements can be improved. For example, in an account of a heavily densed area for a longer duration, temperature requirements can be decreased due to high collective heat released from bodies. Occupants require and need an indoor environment of a temperature that poses no health-risks [1] and offers proper levels of humidity and ventilation.

2.3 Thermal Comfort

When speaking of thermal comfort of occupants in a building, many parameters such as air temperature/velocity/quality, humidity, heating/cooling, and ventilation to name a few are considered. Maintenance of thermal comfort desires and requirements is one of the most important and challenging goals of a building's facility management team. Occupant patterns are valuable in making thermal comfort control decisions as they can provide peak and off-peak usage timings of a building space. For example, knowing for a certain time of the day to have peak occupant density, a building's heating supply can be decreased relative to the body heat output of the number of occupants. Similarly with less people, the heating can be accordingly increased for adjustments.

As another example, many computer systems present in single room of a computer lab in Universities generate an excessive amount of heat. This generation of heat from multiple computers and other electrical appliances leads to an increased temperature of the room beyond normal. Therefore, the buildings' central heating system needs to be lowered in heat supply for that particular lab room. The same would be required to apply for improved air ventilation and in decreasing CO2 emissions. A building's ventilation needs to be accordingly adjusted, as respiratory diseases can spread and infect occupants in lack of proper ventilation [7].

2.4 Inventory Management

In large building projects, there are a numbers of components, suppliers, inventory, and complicated design details that require monitoring, maintenance, repair, and replacement. This paper partially focuses on the application of Decentralized Information Management (DIM) by placing RFID tags on inventories [8]. Technical specifications and progress monitoring of inventory maintenance activities is written into a tag memory and the tag is attached to building elements. In this way different element and component related information is distributed throughout the building. On each maintenance visit, this information is efficiently collected using RFID. Any maintenance or replacement done can be stored in the tag as an update for the following visit. The benefit of using DIM is the storage and retrieval of technical documentation from a central database and of the performance data allowing engineering and maintenance staff to make timely decisions.

The data parameters written into the tag of an inventory item are as under;

- Tag ID
- Product General Information
- Product Manufacturer
- Product Specification
- Optional Sensor readings
- Last Maintained
- Person responsible
- Contact person
- Comments

As one of the applications to inventory item management, an active RFID tag equipped with a temperature sensor was attached to a radiator in the same office room at UCC. The heater is supplied with hot water from the building's central heating system. Figure 1 shows the temperature readings for the month of April, 2009 with reading samples made after every hour. It can be inferred from the figure that there has been a continuous supply of heat from the radiator and it has been working fine. On the contrary, if there had been a break in the continuous graph, it could be concluded that an equipment fault has occurred. Because this information would be available in real-time to the BMS, facility managers would be notified and would carry out a rectification solution. Furthermore, the peak temperature was recorded to be 33.2 C^o and the lowest to be 14.5 C^o.

2.5 Fire/Emergency Evacuation

Despite many buildings having adequate fire alarm systems, behaviour and response of occupants in practical situations is nearly unpredictable. It is observed in a study that occupants tend to ignore the sound of fire alarms in large public buildings [9]. Panic and haphazardness can lead to improper evacuation and can be fatal. Therefore, it is not wise to solely trust on people themselves to efficiently evacuate a building in case of emergencies. There are needs of other methods to efficiently and safely evacuate people from buildings. Many buildings are designed of emergency exists with false expectations and assumptions regarding human behaviour when in panic. On the contrary, it would greatly be advantageous if the number of people in each facility of a building is known beforehand. The demonstrator presented calculates the occupant density; this would allow fire fighters and rescue teams to properly plan evacuation strategies and to prioritize a building space for necessary operation.

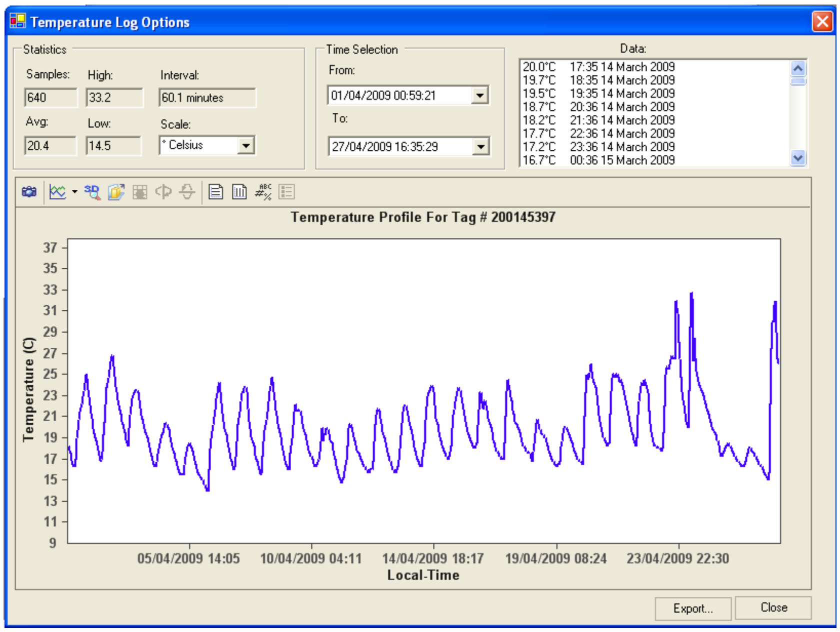

Figure 1: Temperature monitoring through active RFID

The BMS, located inside a building, may not be accessible in case of a fire, therefore; continuous and real-time data uploading to a remote location should be practiced. Based on this, fire rescue services can effectively access the data from an online central location using a laptop, PDA, or a handheld device. Even if the BMS and/or the tracking infrastructure is destroyed or not functional, evacuation teams can rely on the last available data of occupants. Here, the information of occupant density in particular building spaces would be useful to find out how many people are still left in the building. Identification would be important to know if there are any disabled/elderly people in the building for priority based evacuation. Similarly, based on the information of inventory items, it can be determined what items are dangerous or expensive to be destroyed in fire. This information is beneficial for biological or chemical labs in Universities which contain chemicals, explosives, hazardous liquids, and capital-intensive devices. It is also an important solution in case of fire for hospitals, healthcare, and pharma industries, where both the occupants (doctors, nurses and patients) and even possibly inventory items (expensive medical equipment) are important.

RFID technology is an efficient and reliable means of collecting data and relating it to another pre-set or pre-defined data objects. The problems and situations of the use cases discussed above are likely to be solved through RFID effectively. To the complete whole BMS, RFID system integration can provide runtime data update for building control management.

3 IMPLEMENTATION METHODOLOGY

In this section, a brief introduction of RFID technology, experimental setup, and architecture of the demonstrator are explained, followed by the results achieved. This accounts for the complete implementation of the demonstrator. The use cases discussed above have a strong link and requirement to occupant density information, which the demonstrator provides.

3.1 RFID Technology

Radio Frequency Identification (RFID) is an automatic, efficient, and a reliable identification and data collection technology. An RFID tag can be attached to a product, person, vehicle, or animal for the purpose of tracking and identification using radio waves. The main components of RFID systems are a reader, tag or transponder, and a backend system (host computer). The reader sends radio waves to a tag upon which the tag sends back its unique ID [10]. The ID is received by the backend system via the reader where it is translated and combined with a set of pre-stored data parameters. The use of data captured or collected using RFID for a particular application depends on a set of rules governing the application scenario. RFID systems can be active or passive depending upon the tags used as having a battery or not, respectively. Different frequencies, such as; Low (LF: 125-135 kHz), High (HF: 13.56 MHz), Ultra-High (UHF: 433 and 860-960 MHz), and Microwave (μW: 2.4 and 5.8 GHz) [11] are used for RFID system implementations, again depending upon the application requirements and scenario, the choice of frequency selection would be affected.

Depending upon its variations and capabilities, RFID is used for many applications in industries of defense, energy, automotive, aviation, health, pharma, manufacturing, and retail and distribution [12]. In many of these industries, one use of RFID is for real-time localisation/positioning and identification of objects and components. This localisation information is required for people, animals, and item based components. For example, throughout the Supply Chain Management, from manufacturing to the end-consumer, RFID is used to track, locate, and identify inventory on an item level for timely status update [13].

We use RFID firstly, for tracking and identifying personnel in and out of an office to analyse their behaviour towards it and secondly for monitoring selected inventory items and components within the office. The demonstrator's experimental setup is explained in sub-section 3.2 followed by the system architecture explanation in 3.3. The only and major distinction between different RFID system implementations is the data translation, relation, and its understanding. Also, based on the data, making decision/action rules depending on the application requirements is different.

3.2 Experimental Setup

For our demonstrator, the behaviour of occupants and inventories is monitored through a doorway portal frame. The door frame at the office entrance accompanies three (maximum four) RFID reader antennas (figure 2) arranged in positions so as to cover the maximum appropriate read zone, which is the full door coverage area. Figure 2 shows the ideal propagation of each antenna along with propagation back lobes created (shown in red colour). The actual propagation is not symmetric but is distorted substantially, creating areas of greater and lesser radio propagation. The occupants or users of the office are given passive UHF, EPC (Electronic Product Code) Class 1 Gen 2 RFID tags packaged in a form factor of a credit card. The frequency used is UHF at EU 865.7-867.5 MHz. Inventory items have the same tags (without packaging) attached to them at an appropriate position.

With passive RFID technology, because the orientation of tags with respect to the reader antennas is important for efficient reads, therefore, placement and direction of antennas is very critical [14]. The tags need to be parallel and not perpendicular to the antennas for an effective read. This is necessary for the tag antenna in order to get enough power off the reader emitted waves to wake up the tag IC through the process of backscattering [15]. Upon receiving energy from the radio waves and the tag IC being active, the tags respond back using the EPC air-interface protocol with a standard data packet format and modulation schemes [16]. The requirement of tags being strictly parallel to the antennas is important when the antennas used are linearly polarized. For our demonstrator, the antennas used are circularly polarized. With these types of antennas, the direction of propagation can be controlled and the tags are not strictly required to be parallel to the antennas, as the not well oriented tags can still be read effectively. But because there would be less control over the orientation of tags as people can place them in any pocket, wallet, or purse; the antennas need to be placed at optimal positions and directions. These positions and directions can be found only through making different practical test cases to see appropriate read-ranges and tag reading within those ranges. Figure 2 shows the coverage area and read distances of the antennas.

Figure 2: Demonstrator doorway portal

3.3 System Architecture

Like any most technological architectures, middleware is an important part of a RFID system. It is an interface between the front-end RFID hardware components and the backend application usage, the enterprise business applications (figure 3). An RFID middleware is mainly responsible for dealing and managing readers and their communications with business applications [17]. Broadly categorizing, RFID architectures would have a three layered structure involving, data collection, data translation, and the application use.

A typical RFID system's middleware comprises of all ALE (Application Level Event) and EPCIS (EPC Information Service) programs and softwares in the backend system [18, 19]. ALE softwares are the ones that are collecting data from the front end (tags) and passing it further down the architecture. They may also include initial data filtering and aggregation. EPCIS are the softwares which from the local database, access data and pass it further to the RFID information processing part of the architecture. This involves data translation, relation, understanding, and manipulation. An RFID middleware includes all softwares except on-device (reader) and business application softwares. Also depending upon the application needs, there may be two or more application level programs that translate data differently. After giving a brief overview of a general RFID system architecture, the complete architecture used for our demonstrator is given in figure 4.

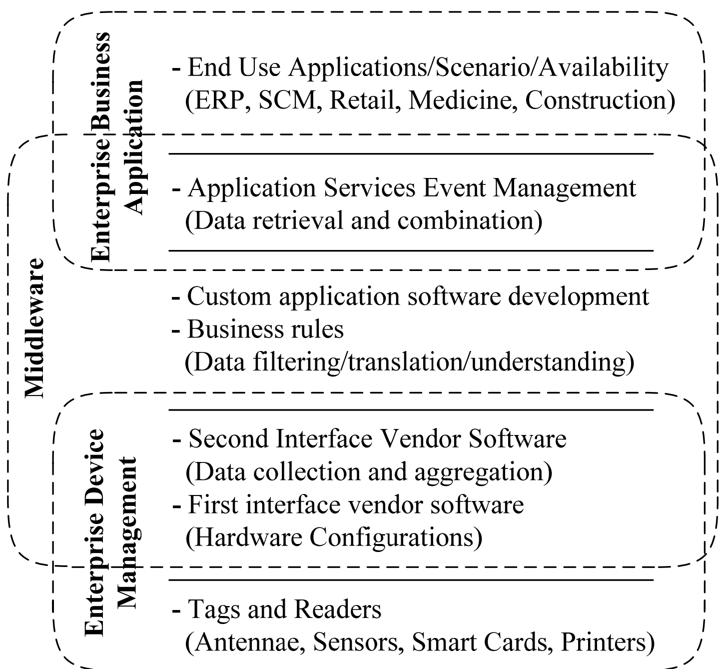

Figure 3: General architecture of an RFID System deployment

The three RFID reader antennas are time synchronized in a round-robin fashion in order to have only one antenna active at a time. In this way, the RF controller of the reader only has to process one input at a time, instead of multiples. This enables the reading and hence, data collection process faster. According to the reader's adjustable time slicing, each antenna gets to be active after every three milliseconds. This is realistically enough time allowing at least one antenna to read a tag while passing through the doorway portal, which was evident from some practical test-reads with people and inventory items. Different orientations and angles for tag placements were also tested. At each tag read (an event), the reader program stores all tag related information to a CSV (comma separated values) file.

Each tag read contains the following information parameters which constitute table 1 in figure 4;

- Sequence number
- Tag type (EPC Gen 2 in our case)
- Unique Tag ID
- Data on tag (parameters other than tag ID)
- Timestamp (time and date), and
- Antenna number through which read (1 to 3)

An example of the CSV file contents are shown as a table in table 1. The table contains data for three different tags with unique IDs, respective timestamps upon which the read occurred, and the antenna number which read the tag. Reads by different antennas can occur because of different tag positions and orientations. All the tags did not include any extra data written into memory and all are of the same type 'EPC Gen 2', therefore, there are no columns shown for these two parameters.

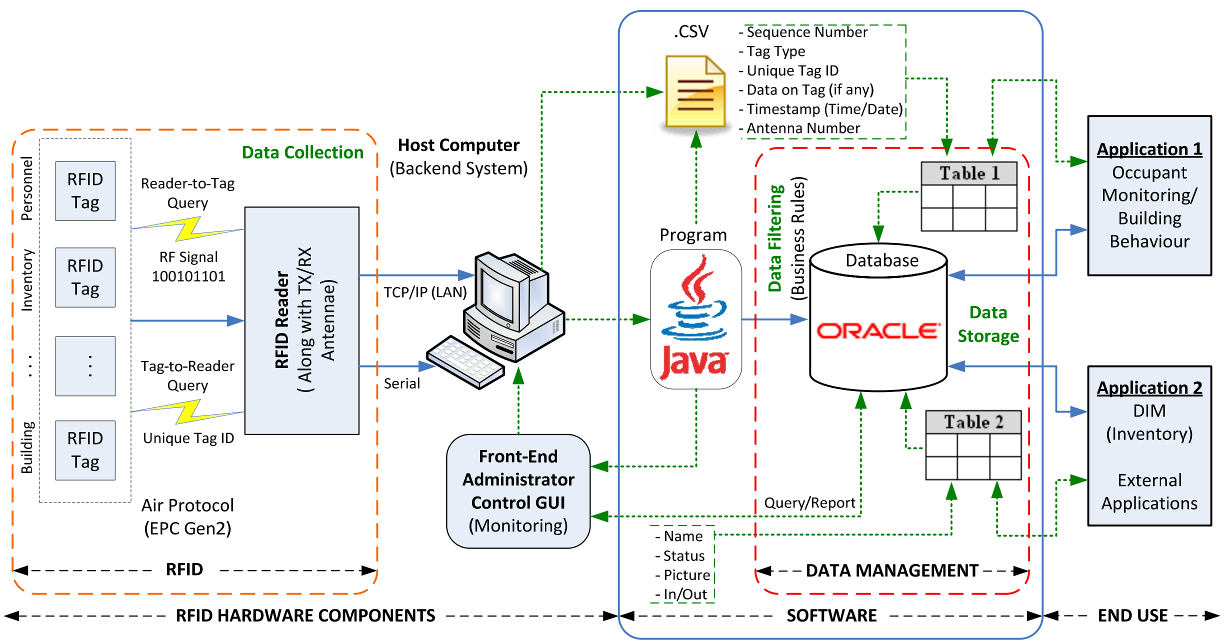

Figure 4: Demonstrator architecture used for Occupant and Inventory tracking

A Java-based program running on the same (host) computer system reads the .CSV file for each tag's parametric values and writes them into an Oracle database. As a simple business rule, if a tag ID has made an entry (read event) for the first time (not previously stored), it is concluded that the respective person or inventory item is now IN the building space. On the other hand, if an entry is made the second time, it is concluded that the tag is now OUT of the office. This is presented as an algorithmic flow chart in figure 6. More generally, a specific tag read at an odd number means the tag is IN the office, likewise, an even number of read recording accounts for the tag now being OUT of the office. But for this concept to work, it is assumed that there are no miss-reads, if so, the IN/OUT status sequence is lost.

Seq. Num	Tag ID	Time	Date	Antenna Number
1	001234ABCD4321DCBA	18:55:19.250	04/09/2009	1
2	004567ABCDE00EDCBA0987	18:55:19.250	04/09/2009	1
3	00ABCD1234DCBA4321	18:57:19.250	04/09/2009	2
4	00ABCD1234DCBA4321	18:58:27.120	04/09/2009	2
5	001234ABCD4321DCBA	18:58:27.650	04/09/2009	1
6	004567ABCDE00EDCBA0987	19:01:28.445	04/09/2009	3
7	00ABCD1234DCBA4321	19:05:40.485	04/09/2009	3
8	001234ABCD4321DCBA	19:05:40.950	04/09/2009	1
9	004567ABCDE00EDCBA0987	19:08:42.100	04/09/2009	2
10	001234ABCD4321DCBA	19:10:59.160	04/09/2009	1

Table 1: CSV file data values for RFID tags read

From the database, an application can access the data and process it further. In our case, the data is accessed and displayed on a GUI interface showing a compact profile of the person or inventory item to which the tag is associated with. This profile consists of custom parametric data values such as the name, occupancy, status, picture, and IN/OUT status (table 2 in figure 4) for people defined in the database (and parameters for inventory items mentioned in section 1.3) and also the ones received from the RFID, i.e. tag ID and timestamp, etc.

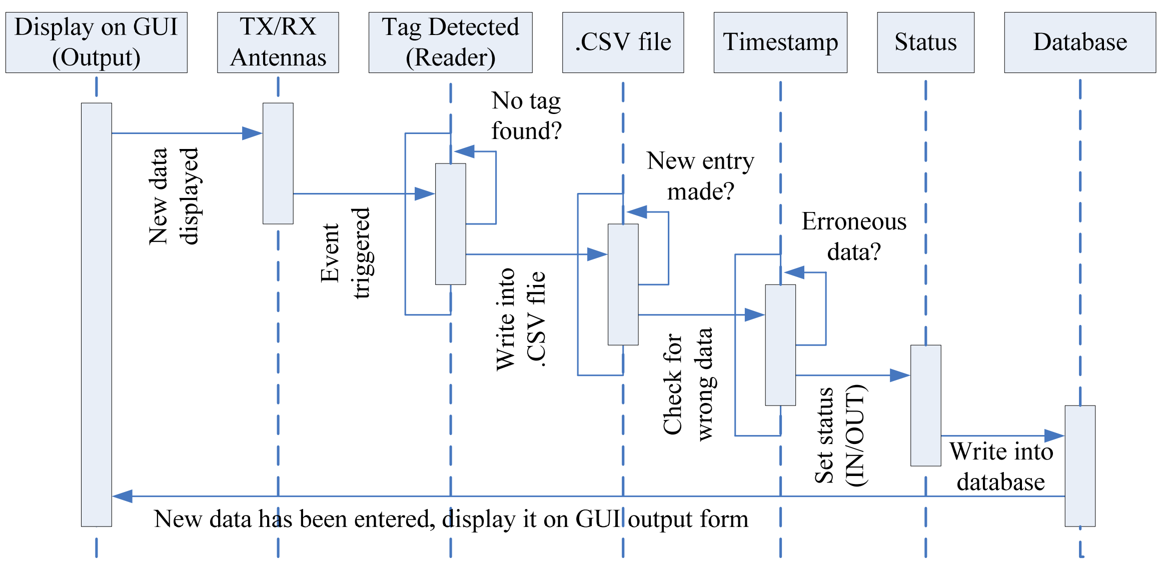

Figure 5: UML Sequence diagram from event to database

Figure 7 shows a GUI form displayed after a tag read event that belongs to an occupant or user of the office space. The display is made available in nearly real-time on the screen and the data is kept stored in the database to maintain a log. In this way, the occupant density and hence, behaviour of the building space is monitored by counting and identifying people and inventory items in and out of the space by maintaining a log. The sequences of operations starting from an event occurrence up to writing into the database are summed up in a UML sequence diagram in figure 5 as a summary.

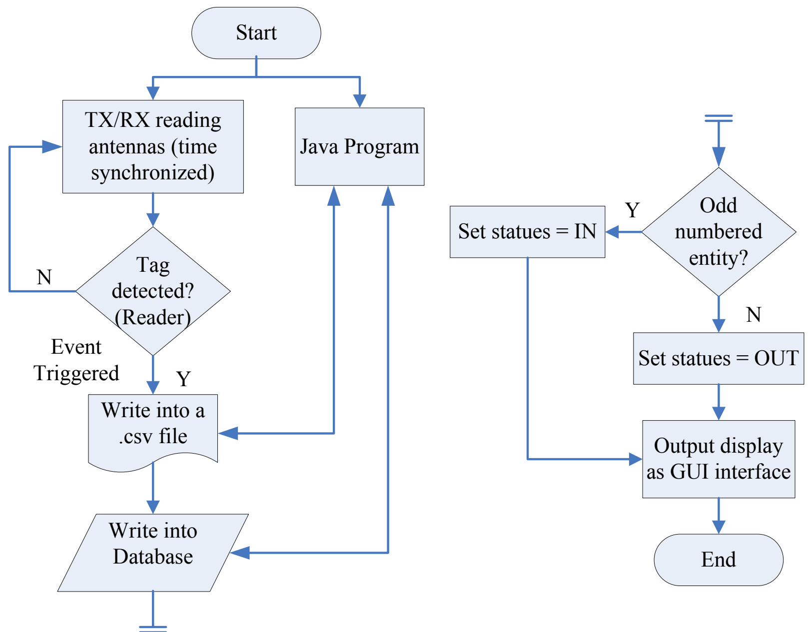

Figure 6: Algorithmic flow chart to determine IN/OUT status of a tag read

4 RESULTS

As soon as a tag-read event occurs, the tag ID and all related parameters are recorded in the database. Figure 7 shows one particular tag related occupant profile from the database as a Java-based GUI form. Currently, there is some delay from the time of occurrence of an event (tag read) to the displaying of GUI form an average of about 5 seconds. This delay accounts first from the RFID reader buffer to writing into the CSV file (2-3 seconds), then from CSV file to the database (1 second), and finally from the database to the GUI form display as it involves searching for parameters from the database (1-2 seconds).

5 CONCLUSION AND FUTURE WORK

The demonstrator of occupant and inventory tracking was successfully deployed as an initial prototypical scenario representation in an office environment. Occupants and inventory items were tracked and identified for a fixed number of hours each day to monitor the IN/OUT activity, this accounting for the office density at different times. In explanation of each use case scenario, it becomes evident how important this information is, determining occupant patterns, managing inventory items, and planning fire/emergency evacuation procedures in buildings. The problems associated to the use cases were suggested and reported to be solved through the integration of RFID technology within buildings.

As a future work, the delays in event of a tag read to the display of GUI form needs to be decreased to make it a real-time application. The RFID data needs to be linked and uploaded to the BMS in real-time to help in making building energy control and usage optimization decisions. Any miss-reads leading to incorrect IN/OUT status calculation need to be accounted for through optimized placements and directions of the RFID reader antennas.

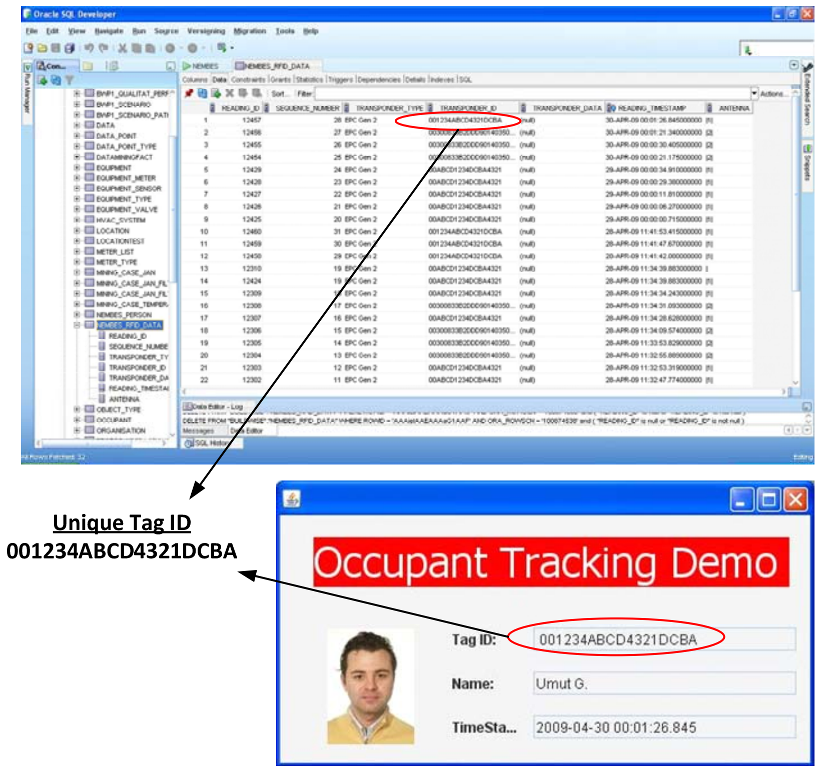

Figure 7: Database and GUI form for an occupant

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