Occupancy Monitoring using Passive RFID Technology for Efficient Building Lighting Control

Farhan Manzoor
University College Cork (UCC),
Cork, Ireland
f.manzoor@student.ucc.ie

David Linton
CSIT (ECIT), QUB
Belfast (NI), UK
d.linton@qub.ac.uk

Michael Loughlin
CSIT (ECIT), QUB
Belfast (NI), UK
m.loughlin@qub.ac.uk

***Abstract*—The control of artificial lighting is a key parameter to be considered in buildings towards energy and cost savings. Efficient, need-based control of building lighting through occupancy detection using Passive Infrared (PIR) sensors has become a reliable and well established approach. However, the use of only PIR sensors for occupancy monitoring does not offer much savings and depends upon a building's type and use, and its occupancy levels. Accuracy of occupancy monitoring greatly affects building lighting control strategy and hence, percentage savings. Besides considering lighting control based on occupancy detection using PIR sensors, this paper presents a data fusion approach of passive RFID based occupancy monitoring with PIR. The proposed methodology provides an estimated 13% of electrical energy savings in one open plan office of a University campus building. Practical implementation of RFID *gateways* provide real-world occupancy profiling data to be fused with PIR sensing towards analysis and improvement of building lighting usage.**

Keywords-component; energy efficiency; lighting control; occupancy monitoring; occupant density; PIR; RFID

I. Introduction

Within the Architectural, Engineering, and Construction (AEC) sector, Facilities Management (FM) is an important area that covers many different aspects of a building. According to the British Institute of Facilities Management (BIFM) and the European Standard [1], [2], *Facilities Management is the integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities*. At a corporate level, FM is broadly divided into; Strategic, Infrastructural, Operational, and Technical Facilities Management [3].

'Smart' or 'Intelligent' buildings have now evolved into a complete industry owing to the fact that they are intended to react 'intelligently' in unforeseen circumstances such as severe weather conditions, increased occupancy (and usage) expectations, and hazardous situations [4]. For contemporary *smart* buildings, the use of Information and Communication Technology (ICT) is essential for robust building operations. For robust day-to-day operations, technical facilities management needs to be highly efficient. This includes efficient support and maintenance of technical, mechanical, and electrical facilities within a building. These facilities mainly include the Heating, Ventilation, and Air-Conditioning module and the Building Management Systems (BMS).

From the Kyoto Protocol proposed in 1997 [5], the European Union is required to reduce emissions of greenhouse-gases by 8% [6], the UK government has set a minimum target of 60% Carbon Dioxide (CO_2) emissions by 2050 [4]. In order to achieve these goals, the FM industry is estimated to grow 2-3% by the year 2012 [7] with a current UK market worth of £106.3 billion. It has and will continue to adopt a number of modern ICT towards improved energy monitoring and operations. These ICT are typically implemented at a building's BMS or the Building Energy Management System (BEMS).

The most important parameter in buildings that should be considered towards energy needs and demands is the building occupancy. These considerations of needs and demands are desirable to efficiently control and monitor building energy in an attempt to reduce cost, while maintaining users' thermal and visual comfort. This is done through the application of efficiently operating building energy components through improved decision support from occupancy monitoring data analysis. This includes knowing *how* and *when* building zones are occupied by users and what the respective usage behaviour towards them is. Knowing building occupancy in real-time can aid in determining the required energy loads, moreover, the following tasks can be improved in their operation [8];

- Facility Programming/Facilities Management
- Space Planning and Staffing Requirements
- Security and Access Rights
- Analysis of Building Energy Usage
- Demand Controlled Ventilation
- Emergency Evacuation Strategies
- Development of life safety plans

However, due to the dynamic property (i.e. random and unpredictable) of any building's occupancy trend, it is very difficult if not impossible to collect accurate, real-time occupancy data [9]. Moreover, it is the type of technology or method that defines the level of granularity and properties of data collected towards occupancy monitoring. Figure 1, [10] shows the Spatio-Temporal properties of human-sensing that are considered for this study. For some technologies or methods of determining occupancy, it may be possible that only one or two of these properties can be reported but for detailed behavioural analysis, all five properties are required.

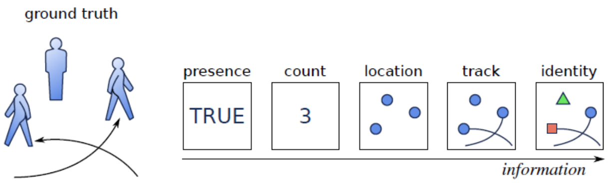

Figure 1. Different Spatio-Temporal properties of human-sensing [10]

Incomplete or inaccurate monitoring of building occupancy can result into improper space and energy management, leading to increased total costs [11]. This can further pose a serious implication in case occupant identification information is required for security purposes. While a number of methods and techniques have been researched and implemented towards efficient occupancy monitoring and data collection in buildings [12], they are building specific and are not generally applicable. The reason is again that of each building's occupancy being specific that depends on use and type of the building.

In this paper, we evaluate a methodological approach that uses occupancy monitoring data to influence building lighting control in particular facilities or zones. The main goal is to provide real-time occupancy monitoring data to facilities manager/s that can take predictive control decisions for efficient energy use based on this data. It is envisaged that in this manner, building energy will be optimally used while saving the associated cost. For this purpose, passive Radio Frequency Identification (RFID) technology is used as proximity-based sensing 'gateways'. There are two parameters of occupancy monitoring that define building profiling (identity and timing of occupant behaviour with a building facility) including *a) Occupant Density* which reports the number of people present in a zone at any given time, and *b) Occupancy Pattern* that is a collection of occupant density data over a period of time.

For this study, an attempt is made to demonstrate how buildings typically account for occupancy information using only *presence* (figure 1) information through Passive Infrared (PIR) Sensors. Based only on this information, building energy components are operated which can be an inefficient method leading to energy waste. A RFID-based demonstrator is deployed which determines all of the five properties from figure 1. With the use of passive RFID, small, light, and cheap tags are handed out to users or occupants of a specific building facility. With Unique IDentification (UID) numbers, each time an occupant makes an 'event' (entrance/exit), the RFID system *counts* and *identifies* occupants in real-time with reliable accuracy. The location of occupants detected is classified as IN/OUT at particular timestamps as the 'RFID gateway' is deployed at an entrance/exit point of the building facility.

This paper is divided into sections such that, section II provides a brief state-of-the-art in the related work. Section III discusses the real-world implementation of an RFID-based occupancy monitoring demonstrator including its working methodology and architecture. An observational analysis is performed in order to find out advantages and feasibility of the proposed method in section IV. Calculations for effective energy and cost savings from the proposed methodology are made in section V. Section VI provides overall return on investment (ROI), followed by a conclusion of the paper in section VII.

II. Related Work

According to the International Total Occupancy Cost Codes [13], generally, the overall costs to maintain occupants in a building include; Property Occupation, Adaptation and Equipment, Building Operation, Business Support, and Overall Management. The report suggests that a reliable and efficient method of calculating building occupancy is vital to estimate these costs. A lack of this method can result in increased total occupant management costs [11]. While highlighting the importance of automatic occupant detection on a continuous and real-time basis, occupancy evaluation through user feedback is also an effective method to determine needs and requirements. This is commonly termed as Post-Occupancy Evaluation (POE) and dates back to the early building lifecycle strategies from the British, European, as well as American standards [14]. In order to add value to both, building assessments and its clients, POE aims to answer four broad questions [14]; *1)* How is this building working?, *2)* How is it intended to work?, *3)* How can it be improved?, and *4)* How can future buildings be improved?

The Rensselaer Lighting Research Centre was amongst the first to consider use patterns of occupants to predict potential energy savings in buildings [15] As effective lighting control in a building is a function of and depends upon the lighting-based activities carried out by occupants, the research work in [16] monitor user activities and aims to improve lighting control.

Similar to the work presented in this paper, it is useful to consider methods of monitoring and collecting real-word occupancy data; nevertheless, probabilistic models and predictions have also been used by research studies to predict occupancy trends, such as in [17], [18]. Also, Yu et al. in [19] proposed a decision tree method for building energy demand modelling based on user occupancy. A stochastic occupancy model towards control of building components is presented in [20]. Binomial and Poisson distributions, and Markov Chain processes were used to model building occupancy from multiple sensors in [21] and [22], respectively. Despite these and other literature studies, this paper emphasizes that collection of real-world occupancy data using RFID technology is more accurate and feasible; especially towards validation of a the proposed methodology working.

III. Demonstrator Implementation

According to [23], besides using and relying only on occupancy sensors (PIR), the most common and successful strategy is to combine their use with other occupant sensing and monitoring information. In this paper, we present an approach to combine the already implemented PIR lighting control with occupancy information collected through passive RFID technology. Occupancy detection infrastructure is implemented in an open plan office of a University campus building, figure 2.

Open plan office 2.12 of the Western Gateway Building at University College, Cork is considered as the deployment facility for the occupancy monitoring demonstrator. Office 2.12 is a 22.94 × 8.9 m building facility containing an open plan area for meetings, semi-private cubical desks for 8 research staff members, an open area classroom that on average accommodates 10-15 students, and 6 private offices (3 single and 3 double occupant offices). In total, a maximum of 27-32 occupants use the office facility and are used to provide IN/OUT logs towards occupancy monitoring as they move about to/from the office. Each user is provided with off-the-shelf passive UHF tags which are EPC Class 1, Generation 2 standard [23] compliant. These are the TIE, *ALN-9634* passive tags manufactured by Alien Technology [24]. The RFID readers used is the Alien Technology's ALR-8800 passive RFID reader [25] at the European UHF frequency of 865.6 – 867.6 MHz. The reader supports a maximum of four antennas. The antennas used are the Alien Technology's ALR-8611-C mono-static, circularly polarized patch antennas [26]. Since they are mono-static, each antenna can either transmit or receive at a time but not both. Therefore, as from figure 2, a pair of antennas needs to be mounted in such a way that they are horizontally parallel to each other. While facing each other, they constitute the read-zone for any tag to be detected in. Appropriate read-zone and range of readers can be determined through a site survey which involves testing the tag for readings at different location points and angles (a passive tag needs to be in parallel with the reader antenna/s in order for backscattering [27] to take place and the tag IC to derive power).

Figure 2. RFID based Occupancy Monitoring System Deployment

The overall system's deployment architecture is shown in figure 2. A central data warehouse stores raw (directly from RFID hardware) data (in table 1) and custom (self-entered) data parameters (in table 2) that are combined for each office occupant or user based on unique tag IDs. The end application is the use of occupancy monitoring data, which for this work is a listing of occupancy that details their respective IN/OUT for profiling and behavioural analysis. Additionally, the demonstrator reports .CSV files that can be used towards system validation (section 3.2).

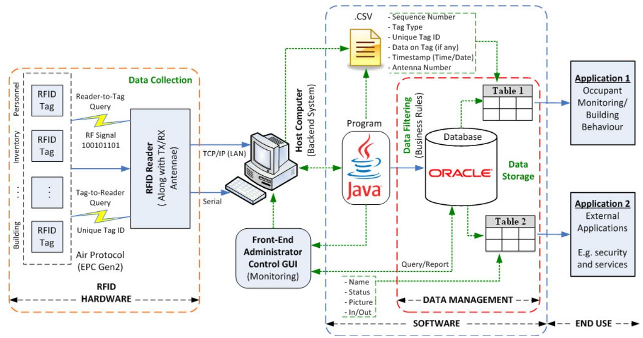

Figure 3. Occupancy Monitoring System Architecture

3.1 Occupancy Calculations

To collect occupancy data as users move about office 2.12, the RFID gateway system switches ON/OFF on a daily basis. The main reason for this is that in order to know whether an individual has entered (IN) or exited (OUT) of the office, the system's algorithm depends on individual *flag* statuses. Initially all flag values assigned to each tag are set to zero. Every tag-read with an *odd* flag status is considered as an IN while every *even* value as an OUT.

Due to the unreliability in signal propagation that comes with passive RFID technology, an obvious disadvantage of this simple approach arises when a tag is not read or is 'missed'. In this case, after a miss-read, the next read flag will be assigned an odd value instead of even and the occupant will be registered as IN instead of OUT (or vice versa). To account for this, we try to validate the system for its accuracy in data collection of user's IN/OUT.

3.2 System Validation

In order to determine the accuracy of the RFID-based occupancy monitoring demonstrator, a system validation test is important. A detailed description of the system validation is described in [28]. A comparison for system accuracy in reading passive RFID tags is performed against actual events (IN/OUT movements of occupants) with those collected by the passive RFID gateway/system. For this purpose, all users were asked to fill in 'timesheets' every time they enter or exit the office area. Occupants were explained the purpose of this with assurance of data privacy, security, and integrity and were requested to fill in the timesheets as accurately as possible.

One mode of the ALR-880 RFID reader allows each tag reading (or event) to be stored as a separate text file (XML formatted) with its respective timestamp (date and time) and source ID (reader name and antenna number). This allowed easy comparison of the individual entry log by the RFID gateway with the actual events manually recorded by users. After collecting one week's actual occupancy result, the data for one day of occupant density is shown in figure 5.

Based on one day's data collection and comparison, it was determined that the overall system accuracy of 91.43% was achieved. This was found to be a high and reliable accuracy for the system's data collection. Any miss-reads encountered towards IN/OUT events are replaced by a respectively complimenting IN/OUT timestamp.

IV. Observational Analysis

The occupancy data collected for one working day to build user behavioural analysis for interaction with building facility in order to predict energy usage (building lighting), is discussed. This analysis is envisaged to provide a case study for the methodology of combining RFID-based occupant monitoring with PIR sensing towards potential building energy savings. Similar analysis can be performed on data spanning over longer periods. As previously mentioned, occupancy profiling information consists of both, occupant density and occupancy pattern data. Occupant profiling provides an estimation of the time duration for which building users stay in the office and is considered to be the time at which they utilize building energy (electrical energy from building lighting). Figure 4 shows individual profiling of office 2.12 users over one day from actual data. The plot's y-axis represents users with their naming initials vs. time of occupancy on the x-axis. The flat line on the plot shows users that are absent for the specific day of data collection. On the other hand, figure 5 gives the total density or number of occupants as they interact (enter and exit) the office throughout the day. It shows occupant density data for one day over an hourly distribution.

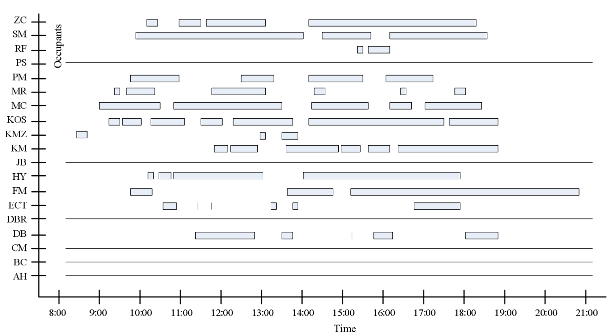

Figure 4. Office Occupant Pattern over one day [28]

4.1 Lighting Layout and Working Methodology

Office 2.12 has 36 light sets, each of 2×28 watts with the three open areas having 8, 6, and 8 lights, respectively. Two of the 6 private offices have 3 lights while the remaining four have 2 lights each. The control and operation of these lights for ON/OFF switching is essentially managed based on presence sensors (PIR). The PIR sensors are set at a time delay, TD (time set for lights to remain switched ON once PIR sensors are triggered) of 30 minutes. Any change in this sensors' TD would have to be approved by the building's facilities managers and the University's Buildings and Estates Department; this led to the main problem of practical testing as no change was allowed in the building physics or its PIR timing operation towards lighting control. Also, note that these lights are not dimmable and therefore, for this study, the preference of luminance levels was not considered.

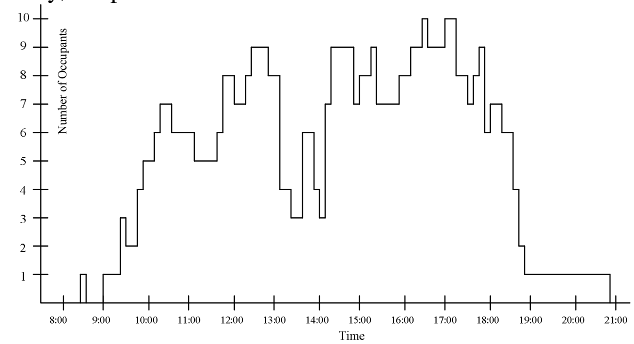

Figure 5. Office Occupant Density trend over one day [28]

4.2 Proposed Methodology

The currently deployed and used, PIR-based lighting control methodology in the WGB building is so called the *PIR-Only*; while the proposed method making use of RFID-based occupancy monitoring data is so called the *PIR+RFID* method for this study. Disadvantages of the *PIR-Only* method include;

- A 30 minutes TD allows lights to remain switched ON for 30 minutes which is a long time period. Lights remain ON when not in use causing energy waste.
- Limitations of PIR visibility causes *false OFFs* and body movements need to switch lights ON.
- One PIR sensor controls a number of lights (2-8) via the same LCM which allows them all to switch ON even upon one movement detection.

Considering these limitations and drawbacks of the *PIR-Only* method, in *PIR+RFID*, we propose to take advantage of occupant density (IN/OUT) information (from figure 5), occupancy profiling data (from figure 4), information of lighting layout, and seating placement of each occupant. Occupant density and profiling data is continuously provided by the RFID *gateway* in real-time on a daily basis. It is proposed to utilize these data parameters and have only respective overhead lights switched ON for the relevant user at specific times when required (IN). This can be done as it is now known *who* occupies what desks at what times. Furthermore, the TD is proposed to be reduced from 30 minutes to say 10 minutes (this was discussed with the facilities manager to be reasonable). This will ensure obvious savings in energy usage and hence, the associated cost. The proposed method is a system towards data fusion between that collected through PIR sensors and from RFID system.

In order to compare the lighting strategy or ON duration by the two methods (*PIR-Only* and *PIR+RFID*), one criterion considered is the time duration for which any *N* number of lights remain switched ON, T_N. Similarly, the second criterion considered is the time duration at which maximum number (at one time duration) of lights remain switched ON, T_{max}.

4.3 Lighting use from the PIR-Only Method

It was observed for the specific day that a maximum number of 34 (out of 36) lights switched ON for different time durations throughout the day, hence, L_{max} = 34. The maximum number of lights (34) remain ON for a total time duration of 5 hours and 25 minutes, hence, T_{max_PIR} = 325 minutes. Also, the minimum number of lights that remain ON throughout the day is L_{min_PIR} = 10.

4.4 Lighting use from the PIR+RFID Method

After an observational analysis for the proposed *PIR+RFID* method, similar output variables for maximum time duration and minimum lighting were calculated. To recall, the two propositions of the *PIR+RFID* method proposed were, *1)* to consider only respective lights for relevant users to switch ON through the information of individual tag IDs (figure 4 and 5) and assigned an IN status after a read or 'event' and *2)* the TD for PIR is reduced from 30 minutes to 10 minutes. For the case of *PIR+RFID*, T_{max_RFID} occurs at three different intervals for a total of T_{max_RFID}=295 minutes (4 hours, 55 minutes) for the maximum number of 34 lights. Also, the number of minimum lights switched ON through this method is L_{min_RFID}=6 which is less than through the *PIR-Only* method.

V. Effective Energy and Cost Savings

Firstly, an advantage of the *PIR+RFID* method over *PIR-Only* is obvious in terms of the time duration for which the maximum number of lights switched ON (at the same time), i.e. T_{max_RFID} for *PIR+RFID* is 30 minutes less than T_{max_PIR} for *PIR-Only* (325-295=30 minutes). Secondly, the time duration for the minimum number of lights switched ON for the *PIR+RFID* method is longer than *PIR-Only* with even less number of lights, which is desired. With *PIR-Only*, a minimum of 10 lights remain ON for a total duration of 1 hour, 30 minutes throughout the day. On the other hand, with *PIR+RFID*, only 6 lights remain ON for 2 hours. This estimation of overall short T_{max} and small L_{min} for lights being switched ON through the *PIR+RFID* method directly translates into efficient energy utilizations and cost savings.

As mentioned, each light is 56 watts (0.056 kW), the number of lights say, *n* and time duration, *t* (in hours) for which the lights remain ON would give the total energy consumption for time duration, *t* in kilowatt hours (kWh). To calculate the cost of electrical energy, per unit price is considered at a flat rate of €0.1144 (~$0.154).

After calculations, results show that electrical energy consumed in office 2.12 (via lighting) in one day through the *PIR-Only* method was [28];

E_{PIR} = 20.0737 kWh at a cost of €2.2964 (~$3.0915)

On the other hand, the electricity consumption via the *PIR+RFID* method was [28];

E_{RFID} = 17.4627 kWh at a cost of €1.9978 (~$2.6886)

From these results, it is evident that the proposed *PIR+RFID* method saves 2.611 kWh of energy and €0.2986 (~$0.4029). In terms of percentage savings;

$$\frac{20.0737-17.4627}{20.0737}\times 100\% = \frac{2.611}{20.0737}\times 100\% = 13\%$$

VI. Return On Investment

Although these energy and cost savings results are only from one office after one day, similar system deployments throughout the WGB would result in greater savings after an annual analysis. Besides this, the availability of real-time occupancy monitoring data to facility managers is a step towards efficient building operations and security measures. This enhancement of facilities management tasks should also be considered while calculating Return-On-Investment from the business case of deployment for RFID-based occupancy monitoring systems throughout a building. Moreover, the cost of installing RFID readers is high, that too depending upon the type of technology used, calculating Return on Investment (ROI) only for cost is not feasible. For this reason, other intangible outcomes should be considered as overall 'return'. From section I, the application scenario of this research is to provide facilities managers with better availability and view of real-time data. This is envisaged to provide occupants' behavioural patterns in a facility towards better space management. Besides lighting control, the real-time occupancy monitoring data can be used to determine other building energy parameters such as, thermal and visual comfort and CO_2 emissions for regulatory standards and health and safety. This can further be used to estimate building energy demand and requirement and cost of a building facility.

The 13% energy saving and absolute figures of electricity and cost from section V are for one day (13 hours). Similar estimations can be made for a yearlong savings for the whole WGB building. Based on the Irish academic calendar of 2010, 215 working days are considered with full occupancy loads as per figure 5. Since daily electrical energy savings are estimated at 2.611 kWh, for 251 days, this can be approximated to 655.36 kWh with almost €75 (~$101) savings. The whole WGB building comprises of three floors all with 14 office spaces with almost the same number of people and occupancy. Based on this assumption of similar occupancy trend, a total of 27525.162 kWh ≈ 3000 kWh of energy can be saved for the whole WGB building with more than €3000 of cost savings.

VII. Conclusion

In this paper, we presented a new approach for improved building lighting control for an open plan office, the so called *PIR+RFID* method. The method proposes fusion of occupancy data with that of PIR (Passive Infrared) sensors used to control a building's indoor artificial lighting. System validation results show that an accuracy of 91.43% was achieved from the rest being miss-reads. This percentage was good enough for the intended use and application scenario.

Exploiting occupancy profiling information, only respective lights are switched ON when needed for individual users based on individual ID received from RFID tags.

Observational and empirical analysis results show that 2.611 kWh or 13% of electrical energy can be saved in one day (13 hours) from only one office area with 27-32 regular office occupants or users. In absolute figures, this translates to a total of 655.36 kWh of annual energy and €75 (~$101) cost savings from this office only. Although a 13% energy savings is less based on the required cost of deploying Passive RFID-based systems, it is important to consider the methodology use. With this methodology of combining RFID for occupancy monitoring in building facilities, facilities managers are provided with reliable real-time information of occupancy trends that can be used to monitor building energy, use, and security.

The *PIR+RFID* method shows improvement of building lighting control in comparison to the *PIR-Only* method which relies only on PIR sensors. However, a fully practical implementation of the proposed approach in the respective building requires changes in building physics and operation which requires prior approval and consent of various stakeholders including facilities and services managers, building owners, and the space users.

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