ASSESSMENT OF WSN AND RFID TECHNOLOGIES FOR REAL-TIME OCCUPANCY INFORMATION

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ABSTRACT: Real-time occupancy information is valuable to the building industry for a wide variety of applications such as on-site safety management, energy conservation, emergency response and so on. With the emergence of various technologies that can potentially be used for indoor location sensing (ILS), the building industry is in search for an ILS solution to provide accurate and cost efficient occupancy information. This study assesses two ILS systems that are built on two promising modalities: radio frequency identification (RFID) and wireless sensor networks (WSNs). Two algorithms were proposed and tested in a computer lab with an area of 235 m^2. Six occupants, who were attached with both RFID tags and WSN nodes, were tracked simultaneously. The occupants remained seated throughout the test, and the occupancy was monitored. The results show that the proposed systems were able to provide accurate room level occupancy information majority of the time, and that the choice of algorithm and technology affected the uniformity of the results.

Keywords: *Occupancy Detection, Indoor location Sensing (ILS), Radio Frequency Identification (RFID), Wireless Sensor Networks (WSNs), Sequence Based Localization, Nearest Neighbor Localization, Accuracy*

1. INTRODUCTION

Indoor location information is valuable to the building industry, and it lays the basis of a wide range of applications, such as locating building components [1], indoor navigation for the visually impaired [2,3], automated lighting and air conditioning control for building energy conservation [4,5], and emergency response support with space-specific information [6]. Various indoor location sensing (ILS) technologies have been compared in a recent study [7], and the viability of radio frequency identification (RFID) technology as an ILS technology for the built environment and its advantages over other competing ILS technologies have been illustrated. Wireless sensor network (WSN) is another emerging and promising technology, also used in ILS [8-10] due to its high sensing ability, robustness, ease and flexibility to deploy, and its low cost to scale, update and fix [11].

This study proposes and evaluates two different algorithms for tracking occupants that are built on two modalities,: RFID and WSN. The research provides room level location information instead of coordinate level location information, as the former is sufficient in certain real-life scenarios such as monitoring and maintaining assets on a room basis, or locating and rescuing a person from a specific room during an emergency. The remainder of the paper is organized as follows: section 2 provides an overview of RFID and WSN technologies and ILS research built on them, followed by section 3 that explains two algorithms used in this research. Section 4 presents test setup, and section 5 presents the results. Finally, findings are discussed in section 6, and section 7 concludes the paper.

2. BACKGROUND AND RELATED RESEARCH

2.1. Radio Frequency Identification (RFID) Technology

A typical RFID system consists of two components, a reader and a tag, and operates at a certain frequency. An antenna via radio frequency establishes communication between the tags and the reader. Tags can be either passive or active tags based on their power source. There are four types of frequencies available for RFID operations: low frequency, high frequency, ultra-high frequency and super-high frequency. As an effective automated field data collection technology, RFID technology has been extensively adopted by the building industry and applied to a wide range of applications including component prefabrication and delivery, on-site asset tracking, progress monitoring, accident prevention, quality assurance, and operation and management [12].

In relation to location sensing, a number of RFID-based algorithms have been developed and tested [13-15]. Most of these algorithms use one of the three location sensing methods: triangulation, proximity, and scene matching. Besides the algorithm design, previous research focused on examining the impact of and optimizing various deployment strategies for accuracy improvement, such as geometry of the sensing area [16], reference tag layout [17] and reader layout [18], target distribution [16], and number of nearest neighboring reference tag used in calculations [19]. Validation and evaluation of the algorithms and deployment strategies have been done through either simulations that use theoretical models to simulate signal propagation [14, 20], or in-building deployments that require field measurements of signal strength data in real environments [6,21]. Achieved accuracies vary between 0.3 m and 10 m [7].

2.2. Wireless Sensor Network (WSN) Technology

WSNs consist of nodes capable of sensing, computing and communicating, and they can sense changes in their surroundings such as varying occupancy, and communicate the information wirelessly to a server. WSNs are widely known for low power operation and their ease of deployment. The past decade has seen considerable research on the design and development of WSN systems --- consisting of large collections of embedded devices equipped with sensors, microprocessors and low-power radios [11]. WSNs are well suited for creating smart environments, where they can provide data network backbone of the entire environment along with the sensing capabilities. Deployment of a WSN system takes short time hence very large scale deployments can be achieved efficiently.

Due to its advantages, there has been considerable work on the design of radio-based localization algorithms and applications [8,11,22-30]. In addition, many researchers focused on in-building sensor network deployments. Sensorscope [31] was one of the earliest long-running in-building sensor network, used for collecting raw sensor data for lighting and temperature. Ceriotti et al. described the development and deployment of a WSN system to monitor climate and structural changes in a heritage building [32]. Agarwal et al. reported the design of a novel occupancy sensor and showed how the deployment of such sensors can translate to energy savings through simulations [33]. Lam et al. [34] described the deployment of a heterogeneous wired/wireless sensor network, which combined gas detection and ambient sensing, including light, temperature and sound, and used various classification algorithms to estimate occupancy at a coarse granularity. Halgamuge et al. [35] showed how to improve the robustness of link quality for a wireless sensor network deployment in a multi-storey building with concrete floors by using an external hub. Gezer et al. [36] described a hypothetical deployment of IEEE 802.15.4 based sensors for monitoring the energy consumption of appliances in an apartment. Spinaret al. [37] reported on an IP-based wireless sensor network for measuring ambient climate and energy consumption in buildings.

3. ALGORITHM DESIGN

In this study, two different algorithms are used to estimate the locations of occupants. The first algorithm, sequence based localization (SBL), divides the complete 2D localization space into distinct regions by the perpendicular bisectors of the lines, joining a pair of reference nodes/antennae. Perpendicular bisectors are drawn for all pairs of reference nodes/antennae. These regions can be of three different types: vertices, edges, and faces, as shown in Figure 1. Each region can be identified by a distinct localization sequence. These sequences are the rank vectors of distances to any reference node/antennae from that region.

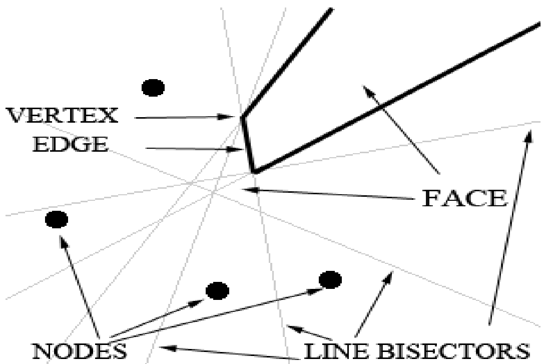

Figure 1.Illustration of sequence based localization regions

Recorded signal strength index (RSSI) is a measure of the distance between a transmitter and a receiver. In order to evaluate the localization sequence at the location of an unknown node/ tag, RSSI values can be used instead of distance. Therefore, evaluated localization sequence of unknown node/ tag is compared against all the possible localization sequences, any match gives the corresponding region and the location is evaluated as the region's centroid. Signal interference can significantly affect the RSSI values hence the evaluated localization sequences. Due to which, they may not match to any of the possible localization sequences. This imposes a need to find the nearest possible sequence rather than finding an exact match. To accomplish this step, hamming distances between the evaluated and stored localization sequences is determined and the nearest possible sequences are used to evaluate the position of the unknown node tag.

The second algorithm, nearest neighbor localization (NNL), estimates the location of the unknown node/tag by the position of reference nodes/tags with highest signal strength. If there are more than one reference nodes/tags which have highest signal strength then the location of unknown node is determined by the centroid of these reference node positions.

4. TEST DESCRIPTION

The tests were carried out at the 4th floor of an educational building at USC. This floor was selected as it has typical obstructions such as walls, metallic objects, and furniture. A computer lab (235 m^2) on this floor was used to conduct tests (Figure 2).

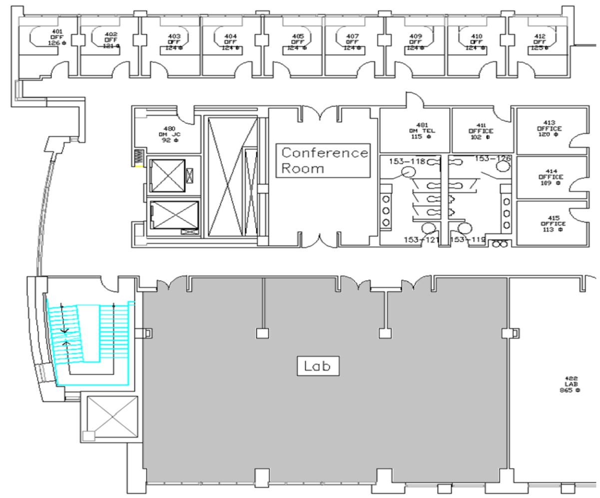

Figure 2. Test bed layout

Two modalities tested were an off-the-shelf UHF (915 MHz) active RFID and WSN nodes operating at 2.4 GHz. Reference tags for RFID and reference nodes for WSN were deployed in and outside the computer lab. Each RFID reader supported two antennae, which were attached to the reader via data cables. Powered by an AA battery, each tag emitted a non-directional signal every 1.5 seconds. A middleware was used to communicate with the readers and extract real-time data, including tag IDs, tag model, battery life, RSSI readings, last contact time, and contact count.

Every second, each WSN reference node transmitted a beacon, which contained the reference node ID and reference node local timestamp. On the reception of every beacon by the moving node, RSSI value was measured and stored along with the reference node ID, and local timestamps of transmitter and receiver. All WSN nodes were powered by two AA batteries.

There were 6 occupants seated and they remained in the computer lab throughout the tests, which is taken as the ground truth in the occupant detection rate calculations. Each occupant carried an active RFID tag and a WSN node. A total of 9 data sets were collected with RFID. Data was collected in every second with WSN; however, in order to compare the results which were obtained from both modalities, 9 corresponding data sets were selected for evaluation. Synchronization was made to sure that data the chosen data sets from WSN modality were collected at the same time as those from RFID modality. Based on the

RSSI readings received from the occupants' tags and nodes, locations of the occupants were estimated.

5. FINDINGS

An important indicator to evaluate the performance of the two modalities is the detection rate, which is defined as the percentage of estimated locations of all targets in all data sets that are within the boundaries of the computer lab. The detection rates for both modalities with both algorithms are summarized in Table 1.

	RFID		WSN	
	SBL (%)	NNL (%)	SBL (%)	NNL (%)
Occupant 1	100	100	100	100
Occupant 2	0	0	100	100
Occupant 3	77.8	100	100	100
Occupant 4	100	100	100	88.9
Occupant 5	100	100	100	100
Occupant 6	11.1	100	100	100
Average	**64.8**	**83.3**	**100**	**98.2**

Table 1: Occupancy detection rates for both modalities and algorithms

As seen from Table 1, the WSN yielded better detection rates with both algorithms. The WSN generated 100% detection accuracy with SBL; however, the same detection rate was not achieved with NNL, where only one isolated case of misdetection was observed. The NNL yielded better results for RFID with an average detection rate of 83.3%. Although most of the occupants were detected correctly with RFID, the modality was unable to detect one of occupants in any of the cases.

In order to assess the consistency of the estimated locations, the authors assessed how the locations were scattered. Table 2 shows the average distance of each occupant's estimated location from its corresponding centroid. Figure 3 and 4 show the estimated locations per occupant with SBL and NNL, respectively.

	RFID		WSN	
	SBL(m)	NNL(m)	SBL(m)	NNL(m)
Occupant 1	0.16	0	1.18	2.52
Occupant 2	0.49	0	1.68	2.00
Occupant 3	0.85	0	2.07	5.31
Occupant 4	2.42	0	1.35	1.07
Occupant 5	0.91	0	1.62	3.95
Occupant 6	0.72	0	2.57	3.61
Average	**0.92**	**0**	**1.74**	**3.08**

Table 2. Average distances from corresponding centroids for both modalities and algorithms

As can be seen from Table 2, estimated locations obtained by WSN (an average distance of 2.41 m) were more scattered than the ones obtained by RFID (an average distance of 0.46 m) with both SBL and NNL. The farthest distance from the centroid was calculated as 5.31 m with WSN and was observed with the third occupant with NNL (Figure 4c). RFID yielded zero value with NNL for all occupants because there was only one RFID antenna which was located inside the computer lab. On the other hand, estimated locations of WSN with NNL were more scattered because there were multiple reference nodes inside the computer lab. These results are associated with the number of reference nodes deployed in the closed proximity of unknown nodes (computer lab) because the NNL algorithm localization output is nearest reference node location based on the RSSI value.

Overall, WSN system tended to yield more scattered points than RFID system which may be attributed to higher power antennae being used by the RFID system making it sensitive to any minor changes in the surroundings. Whereas the WSN system used weaker transmitters and receivers so changes in the environment may have been more likely to be reflected in the output, resulting in more jitter.

6. DISCUSSION

The test results show that both RFID and WSN systems were able to provide accurate occupancy information in a room majority of the time. Therefore, they bare the potential to be implemented, where room level occupancy information is needed, such as detecting whether a room is occupied or not for automated ventilation control. The WSN system yielded better results with SBL while RFID yielded better results with NNL. This demonstrates different algorithms and modalities differ in terms of sensitivity to changes in the environment and that the choice of algorithm and modality should be scenario-specific. For example, when detecting occupants in a zone, SBL algorithm and WSN technology are preferred, as they better capture minor changes in occupants' locations in time. In other scenarios, where more uniform results are needed to avoid confusion, NNL algorithm and RFID technology can be used.

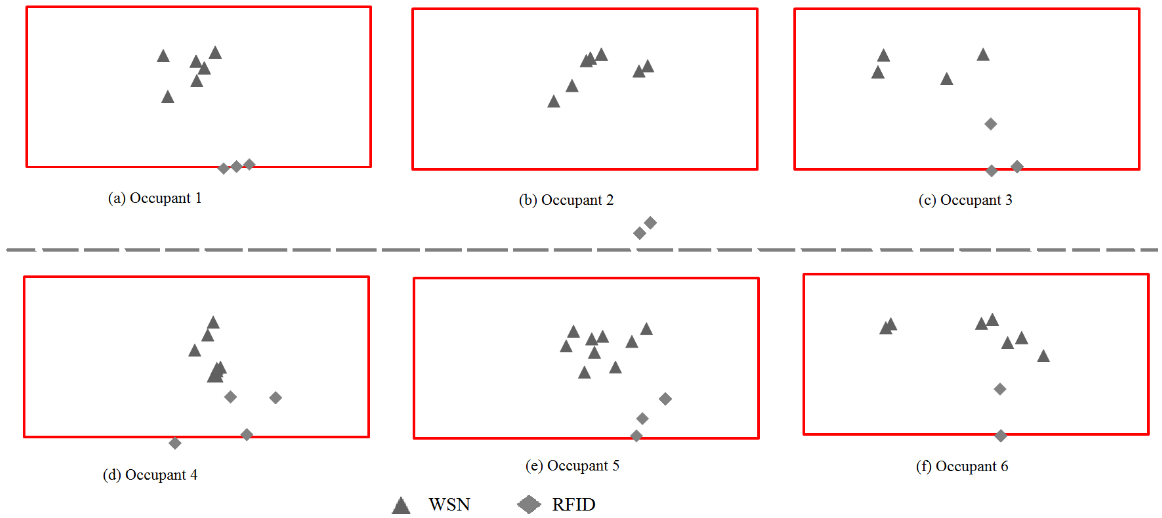

Figure 3. Estimated locations with sequence based localization algorithm (red lines: the boundaries of the computer lab)

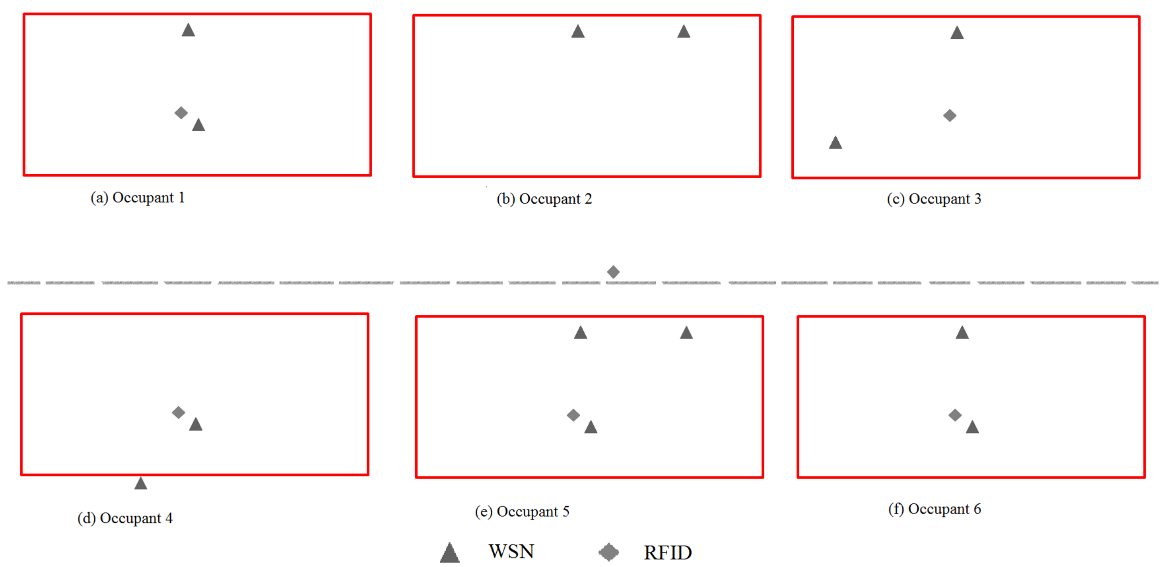

Figure 4. Estimated locations with nearest neighbor localization algorithm (red lines: the boundaries of the computer lab)

7. CONCLUSION

Room level occupancy detection is important to various applications such as asset maintenance and rescue tasks. This research built two ILS systems based on RFID and WSN modalities, developed two ILS algorithms, and tested both systems with both algorithms in a computer lab with an area of 235 m^2. Results show that both systems were able to provide accurate occupancy information majority of the time. Although WSN technology tended to yield more scattered results it generated better occupant detection rates. While WSN yielded better results with the SBL algorithm, the NNL algorithm was more effective with RFID technology. With the validation of the modalities and algorithms, future research will be done on improving the detection rate through better network design and deployment, and applying the systems for detecting occupants moving around in multiple rooms at different speeds.

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