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RFID-based Direction Finding Signage System (DFSS) for Healthcare Facilities

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1. Introduction

As RFID technology matures, it has huge potential for numerous applications in disparate fields of study. Due to the potential benefit and transformational technology that RFID promises, the United States Department of Defense (DoD) is dedicated to adopting passive RFID technology (United States Department of Defense suppliers' passive RFID Information guide version 10.0, 2008). RFID has potential benefits for supply chain, inventory management, asset tracking and improved labor management and productivity within an organization. Therefore, we can see top retailers like WAL-MART adopting the technology to harvest its full potential. Likewise, Technology giants such as HP, IBM, Intel and Sun have considerable efforts and plans ahead for adoption.

There have been many considerable efforts by the research community in adopting RFID in different fields of study. Healthcare applications using RFID are of primary interest as well. Although our application can be thought of as generic, we point out that we can improve healthcare quality by reducing patient wait-time and providing better patient care. Our research deals with an application based on RFID technology. We focus on designing a system using cost-effective devices so that mature applications can be built using the existing technology.

We propose an application titled "Direction Finding Signage System (DFSS)". A DFSS is a system that directs a person to a desired destination in an unfamiliar environment. The need for such a system arises when people need directions to locate a particular destination within a building. We further strengthen our idea by taking an example of a hospital environment, where emergency services are provided 24 hours a day and the volume of emergency patients is huge in number. Such a situation would result in a long waiting time for patients to discover their destinations of interest. We propose an efficient RFID application with RFID tags, readers and display devices that can visually help patients take the shortest route to their destinations. This would help them save their precious time and help them get the desired medication and care at the right time without wait-time hassles. Furthermore, the application can help a hospital's security team be destination-aware of the patients or users in case of an accident or an emergency.

This application is written in a .NET environment in C# for Windows platform. The choice of the software is solely on the basis of simplicity of the Application Programming Interface (API) provided.

The rest of the chapter presents important aspects of the application. Related studies on current signage solutions are described in Section 2. Section 3 describes the proposed system architecture and technology. Section 4 describes the hardware and software aspects of the implementation of the system by suggesting cost-effective hardware solutions and briefing the algorithm used. Section 5 describes our deployment scenario. Section 6 discusses potential future improvements and insights, and we conclude the chapter in Section 7.

2. Related studies & background

This section discusses the current major technologies from the literature and how they are used for navigation purposes.

An RFID tag is a compact tag that can be fixed at one place or can be carried by a person. The tags store information regarding an object, place or a person. RFID readers then read these tags to get the information stored. The authors in (Miller et al., 2006) have described the indoor localization attempt by using the RFID tags on fixed locations and using a moving reader to provide the location for tracking the person or object carrying the reader.

Global Positioning Systems (GPS) is a rapidly advancing technology with applications in aircraft, automotive and in-building navigation. However, there are a few problems related to GPS, such as inaccuracy and inefficient operability in dense urban environments or indoor locations. A navigation system using embedded wearable GPS devices and a system providing verbal guidance and environmental information via speech and Braille displays has been proposed (Loomis et al., 2000). There is yet another approach using Differential Global Positioning Systems (DGPS) for developing a navigation system for the visually impaired (Hashimoto et al., 2001).

Infrared transmission-based devices can also be used by people with sight disabilities as well as the elderly. Such a mechanism involves infrared transmitters that transmit directional information to handheld receivers. The basic principle in developing this device is that infrared transmission is directional. The direction in which the person receives the clearest message is the intended direction. This technology is otherwise referred to as the Talking Signs.

A Verbal Landmark (VL) (Bentzen & Mtchell, 1995) based system is an inductive-loop based radio-frequency system which, when brought under the desired range of the signal, transmits the speech message to the intended receiver. The receiver is a handy device that can be comfortably carried by the user. The transmitters are also compact and can be installed at desired locations. Messages transmitted are in different forms suitable to people who are visually impaired or unable to identify the signs or are unclear about the visual traffic directions. This technology, though cost-effective, is not very efficient in terms of reliability.

A navigation system for the blind comprises a cane equipped with a color sensor, light emitting diode, a control unit and a vibrator. This has been developed and implemented in Japan (Magatani et al., 2001). The methodology involves optical beacon systems attached to the ceiling in the building that continuously send out infrared signals which are picked up by the respective receivers held by the user within the range of the beam. Some hospitals paint colored paths and the feedback from the color sensor vibrates the cane for navigation.

The System for Wearable Audio Navigation (SWAN) (Walker & Lindsay, 2006), designed at the Georgia Institute of Technology, includes a small, light-weight laptop or even a handheld device, a pedometer and tracking devices such as RFID tags, RF sensors, and

inertial sensors. The sensors help evaluate the direction the user is currently facing and also the direction of the actual destination. After the direction is determined, an audio interface provides the user with a speech message indicating the directions along the path. This system also allows the user to learn about the surrounding environment, and thus transmits sounds indicating obstacles on the path.

Dead Reckoning (Roston & Krotkov, 1992) is another technique on which indoor navigation can be based. It refers to estimating the current position of a user based on past courses navigated and speeds from a known past position. The future position can be analyzed from the current position and past data. For this purpose, a DR graph is plotted and constantly updated with changes in the surrounding environment and user walking traits. This process only provides a rough estimation, and thus inaccurate.

Although there are many different technologies associated with various navigation systems, we believe that there is tremendous potential in RFID-based systems.

3. The proposed system

3.1 Radio frequency identification system

RFID works on radio waves, and operates in different frequency ranges. It has been widely used in inventory tracking, supply chain management, manufacturing, asset tracking and health care. A typical RFID system consists of a reader, an antenna and a tag. Generally, the reader is called the interrogator and the tag is called the transponder. The transponder is a microchip attached to the antenna. An interrogator (reader) typically consists of a transmitter and a receiver module and an antenna.

RFID operates on Low frequency (125/134 KHz), High frequency (13.56 MHz) and Ultra-high frequency (850 MHz to 950 MHz & 2.4 GHz to 2.5 GHz) modes according to the type of antenna used. The operating frequency is chosen according to the data rate and the range required for the application.

RFID tags can be further classified as active tags and passive tags. An active tag is a battery powered tag, which consumes energy from the battery to power up its circuitry and broadcasts the signal to the reader. Since it has the source of power within itself, it can transmit over a longer distance. A passive tag instead powers up its circuitry with the help of the radio signal emitted from the reader. At the same time, the data exchange takes place. Hence, it transmits over shorter distances than active tags. The semi-passive tag utilizes the functionalities of both active and passive tags. It has its own battery to power up its microchip as an active tag, but the RF signal is reflected back to the reader like a passive tag. Furthermore, the tags are also classified on the ability of the reader to read or write on the tags as "read-only" and "read-write" tags.

Although RFID has enormous capabilities, its use has been criticized because of security issues. When two or more readers overlap, the tag may not be able to respond to multiple queries at the same time. This is called reader collision. Also, when an area contains many tags, the reader may not be able to read a particular tag. This is called tag collision. Although there are plenty of techniques that address reader collision and tag collision, behavior plays a significant role in the adoption of RFID in any applications.

3.2 DFSS system architecture

The proposed system architecture is shown in Figure 1. The user scans the RFID tag at the information desk. This information is then sent over the network to the server and, in return,
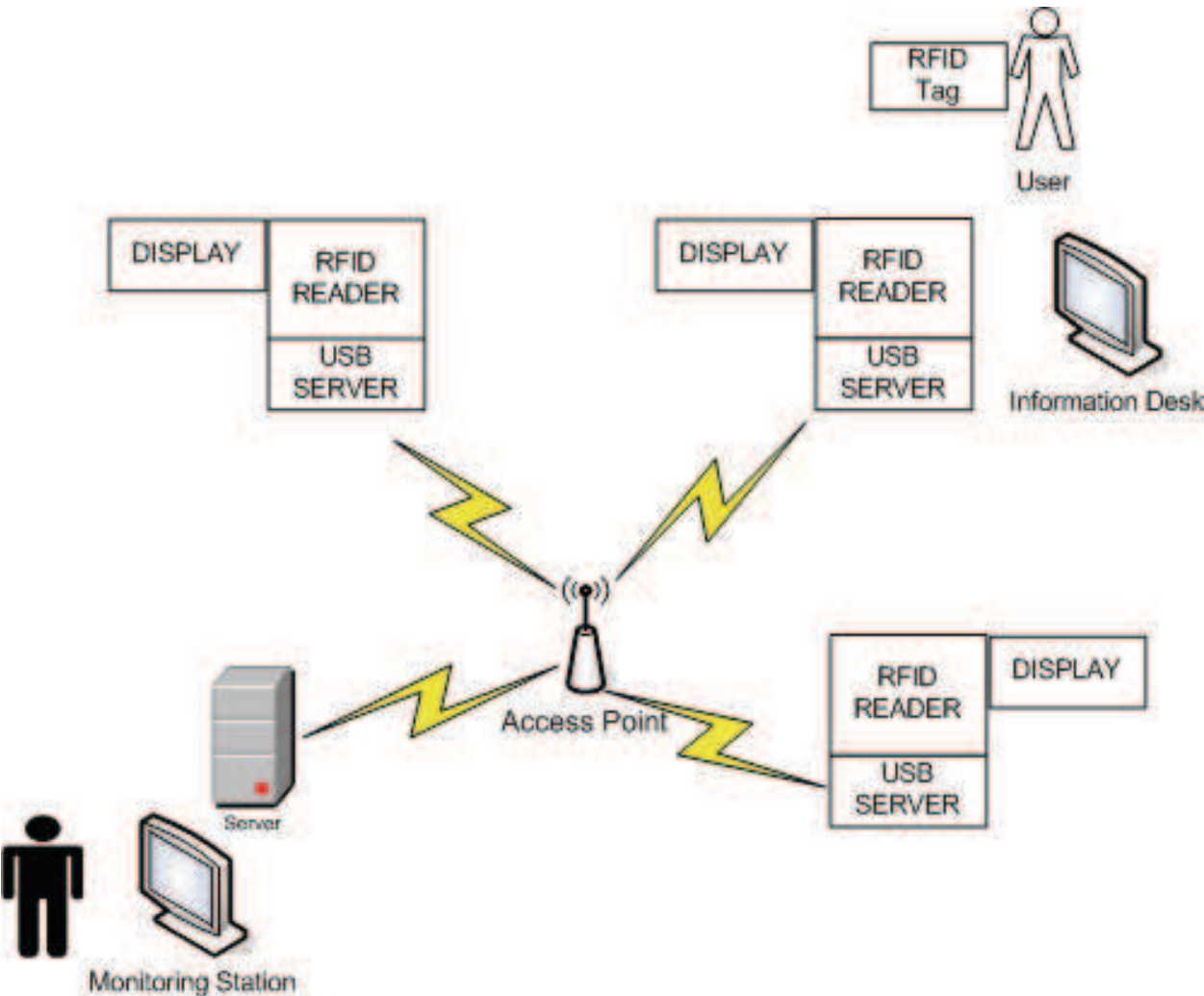
Fig. 1. DFSS System Architecture

the server sends back the direction information to the display device associated with the reader that scanned the tag. The system aims to guide the patient to a particular destination. The monitoring station also helps locate the troubled patient so that immediate assistance can be provided without wait-time hassles. The system proposes low cost hardware and has no cabling costs by using wireless communications for the infrastructure. The system is scalable and can be easily integrated into an existing wireless network setup.

4. Implementation

4.1 Hardware

We explored some interesting devices that could be used to design the system. As the tags would be scanned from just few inches away from the reader, we decided to use a low frequency, cost-effective RFID reader. We chose the Phidget RFID readers, which are designed to be used with any tag designed for EM4102 protocol. We chose passive read-only tags for our purpose. The Phidget comes with tags of different shapes and sizes. The orientation of the reader and tag in respect to each other affects the distance over which the tag is usable. For smaller tags, it must be closer to the reader to be read. The effective range for the credit-card size tag that we use is 5 inches.

Fig. 2. Phidget RFID reader, EM4102 tags, USB servers, 20X2 PhidgetTextLCD

The device used in this system has a few limitations. Multiple RFID readers within 1-2 meters distance could interfere with each other, which could be mitigated by enabling and disabling the antenna of the readers. Also, the Phidget RFID has no collision detection or avoidance capability. Hence, a reader would not be able to read two tags that are within close proximity. We believe these issues will not affect our system as we have low range for the read field, and there is a very low probability of two users trying to use the reader simultaneously. The Phidget RFID reader comes with an on-board LED; however, we decided to integrate yet another device for efficient display of the results. The device, PhidgetTextLCD, allows us to display messages on a 2 x 20 LCD screen. The PhidgetTextLCD has a 2 x 20 LCD (2 lines high, 20 characters per line) with each character having an arrangement of 40 pixels (8 pixels high by 5 pixels wide). The LCD display has support for both standard ASCII library and unicode characters. The onboard interface kit could also be used to integrate various sensors into the display device and open doors for pervasive computing.

Device Specifications

Antenna Output Power (max, far field)	< 10 µW
Antenna Resonant Frequency	125kHz - 140kHz
Communication Protocol	EM4102
Read Update Rate	30 updates / second
External +5V Supply Voltage	5VDC
External +5V Supply Current Limit	400mA
External LED Supply Voltage	5VDC
External LED Supply Current Limit	16mA
External LED Output Resistance	250 Ohms
Recommended Terminal Wire Size	16 - 26 AWG
Terminal Wire Strip Length	5 - 6mm (0.196" - 0.236")
USB-Power Current Specification	500mA max
Device Quiescent Current Consumption	16mA
Device Active Current Consumption	100mA max
Typical Read Distance - Credit Card Tag	11cm (5")
Typical Read Distance - Disk Tag	6cm (3")
Typical Read Distance - Key Fob Tag	7cm (3.5")

Table 1. Phidget RFID reader Device specification (PhidgetRFID Product Manual, 2007)

The Phidget Devices use a Universal Serial Bus (USB) to communicate with the computer, thus providing developers with an easy to use and robust API. The Phidget libraries are available for many languages such as: Java, C, C++, .NET(C#) and Delphi. We chose C# for our development.

These devices were sparsely deployed at many locations and were allowed to communicate to a central station using an existing Ethernet or Wi-Fi network. We focused on using wireless communications for the system to reduce cabling costs. We found two USB servers for this purpose. The KeySpan USB server has 4 USB ports, an RJ45 Ethernet connector and an embedded USB host controller with software drivers that would make the device appear as an additional USB host controller on the station. We used a wireless bridge to connect to an access point in our network. This requires two different power sources to each of the devices. Since we aimed at reducing power costs, we sought for yet another device with an integrated 802.11 support. The other USB server we used was the Silex hi-speed USB 802.11 wireless device server. This device server provided connectivity through an integrated wireless antenna, therefore for reducing the need for a bridge or any interim device. The Silex USB server required virtual link software to be installed on the station for connectivity with the USB devices.

4.2 Software

We chose to use .NET libraries provided by Phidgets to interface the readers and LCD kits. We maintain a software association between readers and the destinations of interest and also between readers and their respective display devices. This helped us to identify the display device to send the destination information to once we scanned a tag on the reader. We found the shortest path between locations using the Floyd-Warshall shortest path algorithm, as it computes the shortest path between all pairs of vertices in the system. The system requires weighted graphs of the map of setup building, and also the directionid (north, south, east, and west) between each pair of vertices.

The algorithm developed is as follows:

1. For the first time when a reader reads a unique tag, it provides the user with an interface (as shown in Figure 3) to input the destination of interest. Then it adds the (tagID, dest) tuple to the run-time hash scan table.
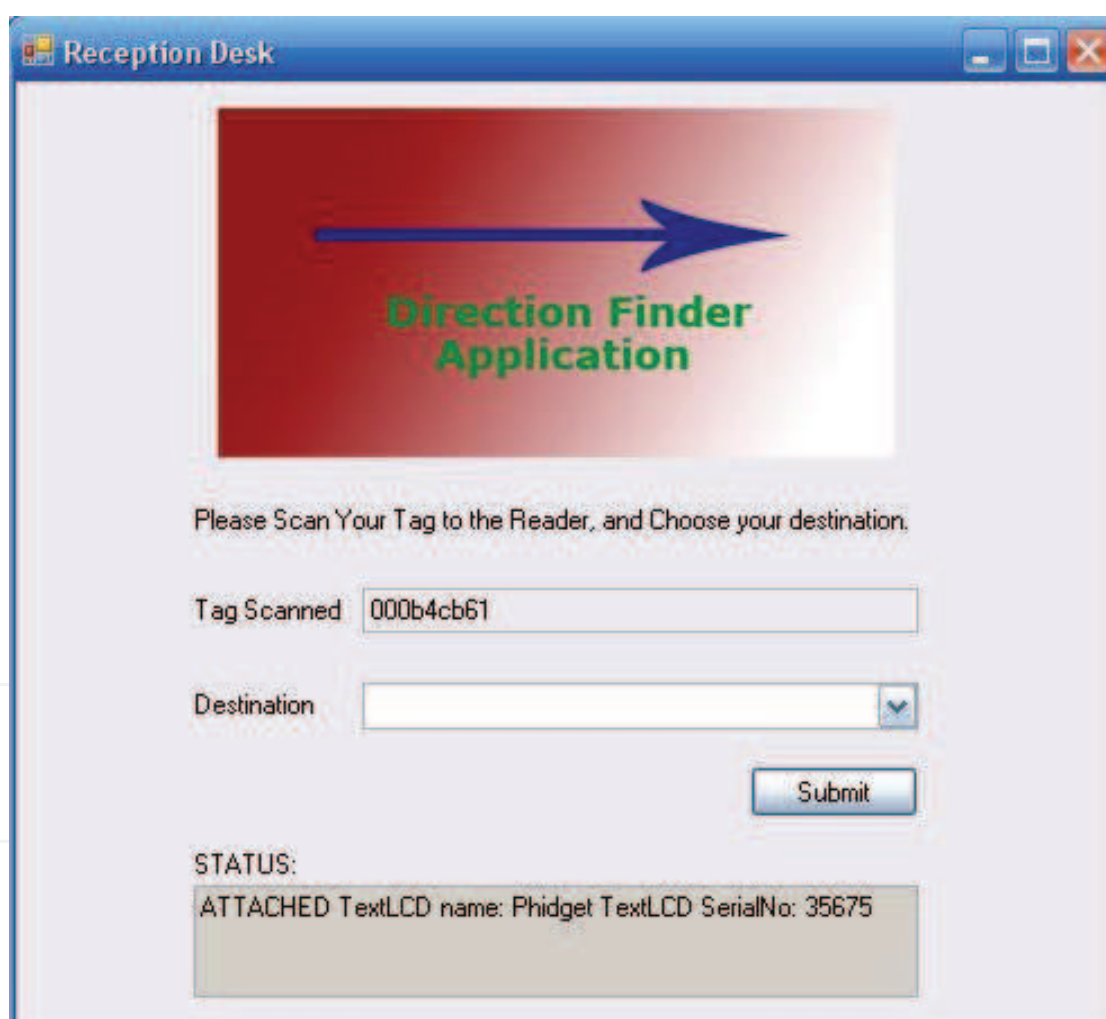

Fig. 3. GUI snapshot at information desk

2. Once the reader re-reads the tag which it finds on a run-time hash scan table, it reads the current reader's ID that scanned the tag and destination reader's ID from the scan table, and feeds the (currfid, destrfid) tuple to a function that returns the next-hop RFID reader. The function does so by sending the (currfid, destrfid) tuple to the Floyd-

Warshall algorithm, which returns the distance to be traversed to reach the destination and the next-hop reader ID along the shortest path.

3. With the next-hop reader ID, the system queries the hash for the (currfid, nxthoprfid) tuple to get the directionid, which is sent to the display device associated with the currfid for display purposes.

Thus the user can navigate to the direction of the next hop reader and repeat the scan process unless he reaches the destination of interest. The display device also shows how far the user is from the destination.

5. Deployment

For deployment, we chose the third floor of the PKI (Peter Kiewit Institute) building at UNO (University of Nebraska at Omaha). The RFID readers and LCD displays were located at different points and marked on the map. Then we generated the test scenarios to verify the shortest path to the destination. We believe our map of critical interest is similar to a maze-like hospital building.

We identified four locations on the floor as our primary points of interest. There is an information desk that would require the patients to scan their tags, and express their point of interest. The information desk can be attended by a staff member or remain unattended at the cost of the user submitting their destination of interest from a scroll on a PC. This information is required by the central server for computation of the shortest path and the next destination. On computation, the server sends the direction information to the display device and the user follows the direction.
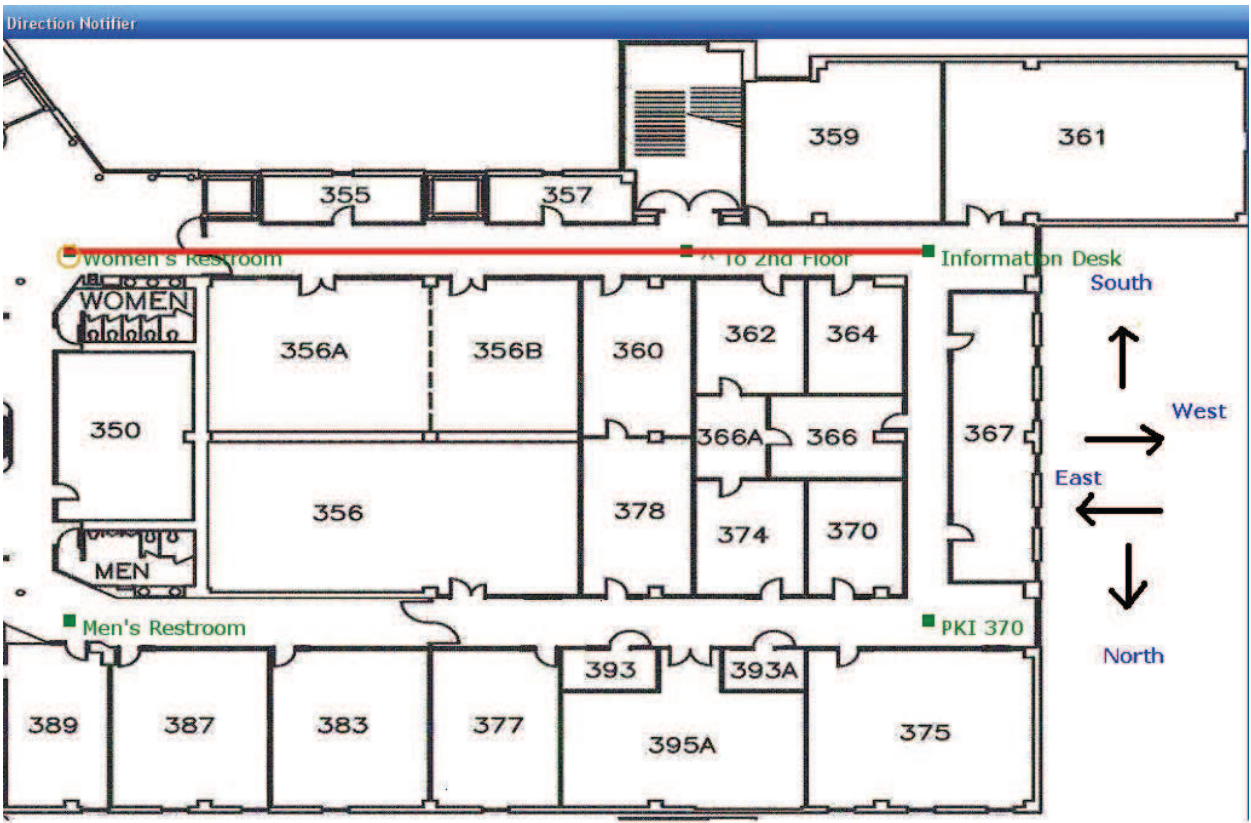

Fig. 4. PKI third floor map for deployment.

As the users follow the direction specified and reach intermediate readers, the central station will be able to monitor and track the users as shown on the screen snapshot in Figure 4. This could help the staff monitor and track the patients. We believe this will be extremely useful in a medical environment as it helps nurses/staff to provide care and assistance to patients/users walking along the hallway, if needed.

In this chapter we have presented the accomplishment of our idea and are highly optimistic about the benefits provided by the prototype for tracking in medical environments where patient care is of utmost importance. We tested our setup with three tags, each with different destinations, and achieved our expected results.

6. Discussion and further work

The system has many benefits as compared to previous approaches in direction signage systems. We prove that our system is robust, cost-effective, scalable, and easy- to-integrate.

We show that we can support multiple tags with multiple destinations in the system with minimal concerns about tag and reader collisions. This proves the robustness of the system. The system is capable of supporting multiple patients/users from a single setup infrastructure. This proves the scalability of the design. Each patient would have a tag with their destination of interest on the system, and the direction information would only be sent on-demand, i.e., only when the patient scans the tag on a reader. Hence, the setup would not create much traffic in the air. Again, because the communication medium between the reader and the central station is Wi-Fi, it can easily integrate into any building with existing wireless network infrastructure. The choice of implementing low cost devices and relying on wireless media for communication to the central station in order to reduce cabling costs proves that our system is more cost-effective than other solutions previously proposed.

Furthermore, as every reader event can be observed from the central station, the system allows staff to track visitors and/or patients within the building and can provide alerts for staff to assist if needed. We can even expand the system to let the system administrator override the path computed and redirect a patient to a less congested route. We believe that our simple proof-of-concept can lead to many more exciting future developments and research into direction signage systems.

7. Conclusion

We have presented a cost-effective direction signage system that can be used in environments where waiting times in a maze-like building, such as a hospital, is of primary concern and of utmost interest. Our study focuses on using RFID technology to reduce such wait-times as minimally as possible. Therefore we proposed a DFSS that can help people in such environments find their destination with the best possible care and attention without having to change much of the existing infrastructure in setting up the system.

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Sustainable Radio Frequency Identification Solutions

Edited by Cristina Turcu

Radio frequency identification (RFID) is a fascinating, fast developing and multidisciplinary domain with emerging technologies and applications. It is characterized by a variety of research topics, analytical methods, models, protocols, design principles and processing software. With a relatively large range of applications, RFID enjoys extensive investor confidence and is poised for growth. A number of RFID applications proposed or already used in technical and scientific fields are described in this book. Sustainable Radio Frequency Identification Solutions comprises 19 chapters written by RFID experts from all over the world. In investigating RFID solutions experts reveal some of the real-life issues and challenges in implementing RFID.

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