RFID-Based System for Pilgrims Identification and Tracking

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***Abstract*—** This paper describes a prototype of a system developed using a *passive* RFID wristband tag for identification of pilgrims in the holy areas during Hajj. Upon presentation of the tag to a handheld reader all information related to the pilgrim holding the tag will be displayed on the screen of the reader. This way if a pilgrim gets sick, lost, or dies he can be easily identified through the tag on the spot. Officers around the holy area will have a light-weight handheld reader that can get all information from the tag without the need to burden the already overloaded communication network during the Hajj season. The developed prototype was tested on 1000 pilgrims from the country of Ivory Coast in collaboration with officials from Hajj Ministry and Development Commission of the Holy cities of Makkah and Madinah. The results of the experiment have convinced Hajj authorities to utilize this technology for all pilgrims in the future. Additionally, we have explored the possibility of tracking pilgrims using *active* RFID system. Due to the small number of working tags, experiment was performed only on 6 persons. Results of the latter experiment have shown that the system requires further development and needs to be validated with a larger number of tags.

***Index Terms*—** Identification, tracking, crowd control, RFID.

I. INTRODUCTION

Hajj (Pilgrimage) is undoubtedly the most crowded gathering of Muslims on earth. It has unique characteristics with regard to the people who attend it (pilgrims), the place they meet in, and the kind of rituals they perform. These characteristics result in a set of challenges to the authorities and organization departments in controlling the crowd, and identifying the personalities. It is strongly believed that RFID can be an ideal solution for crowd control and personal identification at Hajj season. In this paper a prototype system using a wristband RFID tag is developed for identification of pilgrims in the holy areas during Hajj.

RFID is an electronic tagging technology that allows an object, a place, or a person to be automatically identified at a distance using an electromagnetic charge/response exchange. Typical applications include labeling products for rapid checkout at a point-of-sale terminal, inventory tracking, animal tagging, timing marathon runners, secure automobile keys, and access control for secured facilities [1-2].

In the last few years RFID systems have experienced a surge of deployment (due to the drop in cost). Inventory tracking is now necessary on an unprecedented scale to support growing consumer markets at low operating costs. Furthermore, the components used to build the tags and tag readers have become more sophisticated as they provide greater functionality, longer reading range, and higher speed of data transfer. As a result, a number of influential organizations such as Wal-Mart, GE, U.S. Department of Immigration, and the U.S. Department of Defense, have recognized the capabilities of RFID to improve operational efficiencies [3]. Additionally, it has been used successfully during the 2008 Beijing Olympics, where 16 million RFID embedded tickets [4] were used for admission to the games.

II. CHALLENGES DURING HAJJ

While it is a great spiritual experience for all the pilgrims, at the same time it poses great challenges of all sorts for the authorities responsible for facilitating the Hajj. Despite all that is done to facilitate the Hajj, following are some of the common difficulties faced by the pilgrims and the authorities alike [5]:

- Identification of pilgrims (dead or injured)
- Medical emergencies
- Guiding lost pilgrims to their camps
- Loss of identity documents
- Crowd control

Muslims are obliged to perform Hajj once in their lifetime. Many of them love to perform it more than once. It is performed on specific days of the year (8^{th}- 13^{th} of the 12^{th} Hijri month) in designated boundaries (Makkah, Mina, Muzdalifa and Arafat). The whole crowd makes the same movements at the same times doing essentially the same thing.

The authorities for Hajj try their best to limit the crowd flooding to the area by assigning quotas for pilgrims from each country, and limiting the visits of people within the Kingdom to once every five years. Yet the number of pilgrims is in the range of 2-2.5 millions every year.

The following describes some of the unique characteristics about Hajj:

A. Large Number of Elderly Pilgrims

Many Muslims decide to perform Hajj when they are old. Moreover, many countries, in attempting to adhere to the quota, give preference to the elderly. Added to the crowd and exhaustion they face, a significant number of them are exposed to falling sick or even losing their lives.

B. Language Barrier

Pilgrims in Hajj season are, literally, coming from all countries on earth, with no exception. They speak different languages. It is a serious issue when it comes to helping the lost or treating the sick.

C. Dress Code

The dress of the pilgrim consists of two pieces of garments, one is rolled around the lower part of the body and the other is put on the shoulder. There are no pockets to carry the belongings. Although pilgrims are allowed to put on a belt with small pockets, most of them do not prefer to carry valuable documents because of the fear of losing them in the crowd.

D. Identification of Pilgrims (dead or injured)

Due to the crowd, age factor and sometimes unfortunate accidents, the death toll in Hajj season is on the high side. Many of the dead are on their own, carrying no documents. Every year at the end of Hajj season, authorities are confronted with tens of bodies of pilgrims that are never identified or claimed. This problem is not easy to solve as it is not known when and if any of these bodies will be claimed in the future.

Fig. 1. Pilgrims in Makkah during Hajj.

E. Knowing the Medical Record of Patients

Tens of thousands of pilgrims are brought to hospitals and clinics for emergency treatment. Knowing the medical record of patients, would facilitate efficient treatment and utilization of the limited resources available during this period. However, due to language barrier doctors may not be able to get basic information needed for more accurate diagnosis.

F. Guiding Lost Pilgrims to their Camps

Large numbers of pilgrims report on the hour to Help Kiosks to help them find their camps. It is not always easy to find a speaker of the lost pilgrim's native language. Without papers showing their location and contact numbers, and sometimes without a common language to communicate, it becomes almost impossible to help them. This puts a tremendous pressure on the security officers who are taking care of pilgrims.

G. Loss of Important Documents

With the special cloth of Ihram, it is highly likely that the pilgrim may lose some of his identification papers, like Passport, Residence Permit, and National ID in addition to money or

credit cards. This imposes additional burden not only on the pilgrims but also on the authorities.

H. Crowd Control

Crowd control has become a major problem with many pilgrims dying in accidents and stampedes in congested places during the Hajj. These accidents happen due to insufficient planning and management of available space as well as due to crowd behavior. The authorities have recently experimented with techniques to control the flow of the crowd to the most congested area of Al-Jamarat. The investigator is currently conducting some research on using RFID for this purpose, as well as controlling access of vehicles to the Hajj zones.

III. RFID TECHNOLOGY

An RFID system consists of the following three components as shown in Fig. 2:

- RFID tag or transponder
- RFID reader or transceiver with a scanning antenna
- Data processing subsystem that can be embedded in a handheld reader

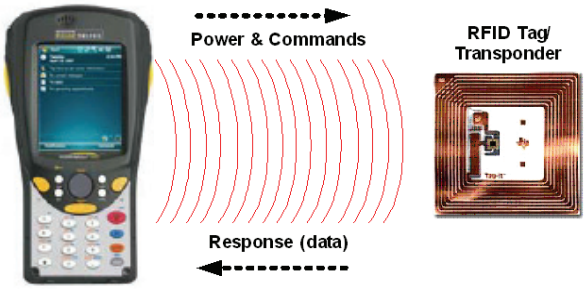

Fig. 2. A typical RFID system with handheld reader.

An RFID reader consists of an antenna, transceiver and decoder, which sends periodic signals to inquire about any tag in its vicinity. On receiving any signal from a tag it passes on that information to its embedded data processor. The scanning antenna puts out radio-frequency signals in a relatively short range. The RF radiation does two things: it provides a means of communication with the transponder tag (the RFID chip) and it provides the tag with the necessary energy to function (in the case of passive RFID tags). This is an absolutely key part of the technology; RFID tags do not need to contain batteries, and can therefore be made simple, cheap and remain usable for very long periods of time. The scanning antennas can be permanently affixed to a surface; handheld antennas are also available. They can take whatever shape needed.

When an RFID tag passes through the field of the scanning antenna, it detects the activation signal from the antenna. That "wakes up" the RFID chip, and it transmits the information on its microchip to be picked up by the scanning antenna.

The RFID tag is composed of an antenna, a wireless transducer and an encapsulating material. These tags can be either active or passive. While the active tags have on-chip power, passive tags use the power induced by the magnetic field of the RFID reader. Thus, passive tags are cheaper but with lower range (<10m) and more sensitive to regulatory and environmental constraints, as compared to active tags. They do not have a transmitter; they simply reflect back energy (radio waves) coming from the reader antenna. Thus they do not require batteries, and can be much smaller and have a virtually unlimited life span.

Active tags have their own transmitter and power source. They broadcast a signal to transmit the information stored on the microchip.

Operating frequency is the determining factor for the type of application an RFID system is best suited for. These include high frequency (850-950 MHz and 2.4-5 GHz), intermediate frequency (10-15 MHz) and low frequency (100-500 kHz).

- ***High-frequency*** RFID systems are suitable for applications requiring a longer read range such as supply chain, inventory, assembly lines, toll-collection systems and railroad car and container tracking.
- ***Intermediate-frequency*** RFID systems are just now beginning to emerge in the financial transaction processing areas of smart card use.
- ***Low-frequency*** systems have short reading ranges and lower system costs. They are most commonly used in security access, asset tracking, and animal identification applications.

As you move up in frequency, tag and reader costs move up as well. Tags at 125 kHz operating frequency have ICs costing tens of cents as compared to 2.4 GHz ICs costing several dollars.

Applications of RFID systems fall into two principal categories: firstly, short range applications where the reader and the tag must be

in close proximity (such as in access control) and secondly, medium to long range applications, where the distance may be greater (such as reading across a distribution centre dock door). A sample of RFID applications includes:

- Security, ticketing and access control
- Supply chain logistics & retail
- Asset tracking and traceability
- Lifetime item identification
- Medical applications
- Animal and specimen identification
- Airline baggage handling
- Vehicle access control

IV. RFID SOLUTION FOR HAJJ

RFID offers an effective, convenient and economical solution to the Hajj problems described above. A wristband RFID tag that can be worn at all times can be provided to each pilgrim. When the tag is presented to an RFID reader the information stored in the tag can be retrieved and displayed on a handheld portable unit. The following is some of the information that can be stored in a tag:

- Personal details - like name, address, blood type, nationality, etc.
- Medical condition
- Contact information of the pilgrim's Hajj group
- E-purse that can be loaded with optional amount of money

RFID may help in crowd control by allowing the authorities to estimate the number of people at specific locations where there is a risk of accidents taking place. Combined with the efforts of the security personnel it may be possible to ease the flow of pilgrims at key points resulting in proper utilization of space. RFID readers can be installed at key entry and exit points to ping wristband RFID tags and thus get a fairly accurate estimate of people passing those points. This will help the security personnel in controlling the entry of pilgrims in high risk areas.

The utilization of the wristband can allow the pilgrims to leave their documents on safe places like hotels safe deposit boxes. Moreover, if an ID is lost, it is possible to retrieve the information needed to produce a replacement of the lost ID with the presence of wristband tag. Information stored in the tag on the medical condition of the pilgrim can be very useful in case of a medical emergency. Having access to the medical condition of the patient in the emergency room from the tag he holds on his wrist may help save the life of the patient and improve efficiency of the medical team. The tags will also help in guiding the pilgrims who get lost - besides helping in the immediate identification of pilgrims who die during Hajj.

With the new rules that each local or external pilgrim should obtain permission to perform Hajj, the permission certificate can be the wristband itself. The presence of the tag can be detected at a distance and does not require visual reading by the security officers. For example, the officer can read tags from a distance and find out if all passengers of a car have permission to perform Hajj. This is because RFID tags do not require line of sight or contact with the reader for the information to be transferred. This would increase efficiency and deter violators in a way to achieve the objectives of Hajj authorities to control the number of pilgrims every year and make it easier for authorized pilgrims to perform their once in a life time Hajj.

Some types of RFID wristbands can't be unlocked once fixed and requires cutting the band. This will guarantee that the wristband will not get lost or disposed. There is a possibility to collect the wristbands upon finishing Hajj activities. The collected RFID tags could be re-programmed and installed in new wristbands to be used for upcoming Hajj seasons.

The wristband tag can be a real working watch; this should remove the fear and sensitivity of pilgrims and their reluctance to wear such tags. Other paper wristbands did not find the full cooperation from pilgrims in the past.

V. DEVELOPMENT OF THE PROTOTYPE SYSTEM

The developed prototype system consists of the following:

A. WorkAbout Pro S Hand-Held Computer

The WorkAbout Pro [6] is a flexible, programmable and expandable portable data collection terminal, designed for a range of data collection needs. It is available with either Windows Mobile 2003 SE or Windows CE .NET configurations. The WorkAbout Pro delivers the

performance, ruggedness and durability required for mobile data collection in an ergonomic package. The device used in the prototype has Windows Mobile 2003 as the operating system and a built-in RFID reader that supports worldwide RFID Standards in LF (125 - 134.2 KHz) or HF (13.56MHz) technologies. Based on industry standard Microsoft and Intel XScale architecture, the WorkAbout Pro ensures seamless application development and integration capabilities. Compact Flash and SD/MMC memory expansion slots combined with USB, and a 100-pin high speed expansion interface, to provide flexible radio and peripheral connectivity.

B. Psion Teklogix Mobile Devices SDK

The Psion Teklogix Mobile Devices SDK [7] for Windows Mobile 2003 SE, provides support for programming in .NET Compact Framework, C/C++ and Java. Developers are able to write flexible mobile applications to take advantage of a variety of scanners and drivers, all from the single platform. Once developed, an application can be deployed, without modification, on any Psion Teklogix mobile computer.

The Mobile Devices SDK provides a consistent set of APIs for all the Psion Teklogix Windows CE and Windows Mobile based computers. Applications built using this release of the Mobile Devices SDK are expected to be fully compliant with future software releases for the Psion Teklogix handheld computers.

C. Development Tools

- ***Microsoft Visual Studio 2005***

Microsoft Visual Studio [8] is the main Integrated Development Environment (IDE) from Microsoft. It can be used to develop console and GUI applications along with Windows Forms applications, web sites, web applications, and web services in both native code as well as managed code for all platforms supported by Microsoft Windows, Windows Mobile, .NET Framework, and .NET Compact Framework [8].

- ***SQL Compact Edition***

SQL Server Compact [9] is a free and easy-to-use embedded database engine that lets developers build robust mobile applications that run on all Windows platforms including Windows XP, Vista, Pocket PC, and Smartphone.

- ***Mughamrat Windows Mobile Arabic Layer***

In the Middle East market, the Arabic language support is mandatory. Hence, building Arabic C# .NET applications, running on a Pocket PC or on Windows CE is a challenging task due to the many problems related to the Arabic language specifications that developers have to cope with. To avoid these problems, Mughamrat has developed WAL (WinCE Arabic Layer) [10], which is a software development kit for developing application with an Arabic interface for mobile devices.

D. Pilgrim Information System

This software is designed to read and write pilgrims information from the data source using passive RFID tags. The purpose of the software requirement specification is to describe all the functional requirements, constraints, dependencies and the way the requirements be fulfilled. Through the use of this software the user will be able to save user information to data source, read user information using hand held device, and assign RFID tags to users. The following sections provide details about the application architecture and usage.

- ***User Info Writer***

The application allows the user to input pilgrim information and assign them a tag ID. The application has been developed using C# and .NET framework. There is only one Class in this application that takes care of the required functionality. The userInfo class provides all the functions needed to store the pilgrim's info on the data source which is a SQL compact edition database. The class diagram is shown in Figure 3.

- ***User Interface Screens***

Figure 4 shows the main screen of the application. It allows the user to input all the required information for the pilgrim. User can search for the required photo by clicking the Browse button. Once all the information is filled in, the user clicks the **Save** button and all the information along with the image and RFID tag number are saved to the database.

Fig. 3. UserInfo class diagram.

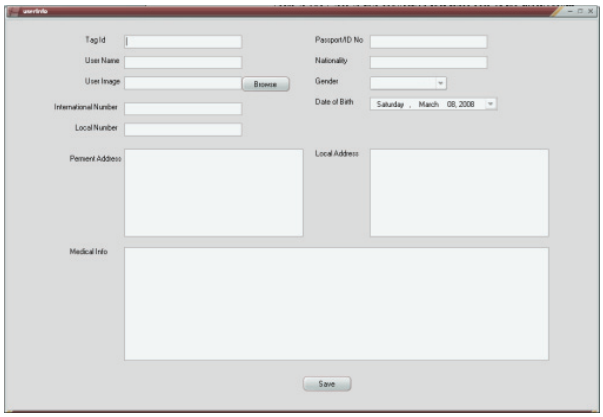

Fig. 4. Main screen of the application.

- ***Software for the Tag Reader***

This application has been developed to be deployed on a Psion Teklogix Workabout Pro S that has a built in RFID reader and Windows Mobile 2003 as the Operating System. The application will allow the user to scan any RFID tag to get the tag number and then retrieve the information related to the tag from the data source that is deployed along with the software. There is only one Class in this application that takes care of the required functionality. The class diagram is shown in Fig. 5.

- ***Database Design***

There is only one database table so that the size remains small and the database doesn't have to store any relation information. tag_id is the primary key and is the tag number of the RFID. The fields used in the database are given in Table 1.

- ***Handheld Reader Screens***

The first screen you see when you start the application is shown in Figure 6. It shows the tag ID when it is scanned. If the tag is assigned to a pilgrim in the database it will show the pilgrim's name and picture. At the bottom on the screen there are four tabs; each one displays different information regarding the pilgrim.

The second screen that is obtained when you click on the General Info tab, shows the pilgrim's gender, nationality, passport/ID number, local and international phone numbers, and blood group

The third screen that is obtained by clicking the Address tab shows the Current and Permanent addresses. The last screen which you get by clicking the Medical tab shows the medical information of the pilgrim as shown in Fig. 7.

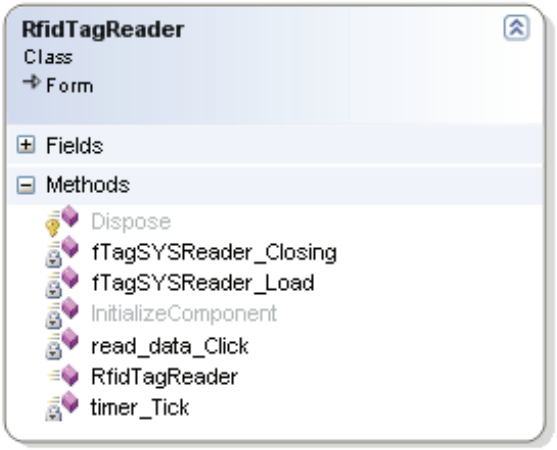

Fig. 5. RfidTagReader class diagram.

Table 1: Fields of the developed database.

Column Name	Date Type	Length
user_name	nvarchar	200
tag_id (primary key)	nvarchar	100
user_pic	varbinary	8000
user_id_no	nvarchar	100
user_birth_date	datetime	8
user_gender	nvarchar	8
user_perm_address	ntext	16
user_local_address	ntext	16
user_med_info	ntext	16
user_nationality	nvarchar	100
user_inter_ph	nvarchar	20
user_local_ph	nvarchar	20

VI. PILOT PROJECT FOR PILGRIM IDENTIFICATION

A pilot project for the developed Pilgrim Identification to demonstrate the advantages of using RFID technology during the Hajj is

Fig. 6. Handheld reader screens 1 and 2.

implemented [11]. We had 1,000 tags and a single reader. Pilgrims from the country of Ivory Coast volunteered for the pilot (see Fig.8). However, the group consisted of about 4,000 pilgrims. We selected the elderly 1,000 and programmed the tags for them. An IT engineer had a complete database that includes picture, name, blood type, date of birth, and address in their back home. The medical team accompanying the group had the medical conditions of all pilgrims. Therefore, programming the tags was a simple process. Wristband tags were distributed to the pilgrims. Due to the fact that only one reader is available and not all pilgrims in the group have wristband tags limited the potential of the applications. Nonetheless, scenarios were created to show some of the possible benefits of the system. In particular, the pilot study has shown that the RFID system would help identification of pilgrims at check points, as there was no need for officer to read Hajj permit to check its validity for every person. Checking the wristband tags by the reader takes a small fraction of the time it takes to authenticate the paper permit.

At the entrance of the hotel, pilgrims with the blue wristband tags did not need to be stopped as it was clear from far that they belong to the group. The same was observed at the entrance of the camp in Mina Arafat and Muzdalipha. Queues for food and access to the buses for transportation through out the Holy areas are other occasions where RFID wristband tags would improve efficiency in checking that only authorized pilgrims use these services. Automation is necessitated further by the fact that the rituals of Hajj are to be performed by pilgrims at the same instant of times. No manual system would perform this authorization process with ease and satisfaction. From the pilot, it was clear that participating pilgrims were identified from the unique blue wristband even without RFID reader. This indicated that in the full implementation, it is better if wristbands with a unique color are used for every group. It is even better if the wristband looks like the flag of the country from where the group of pilgrims came from. This will help drastically guiding lost pilgrims to their camps. Moreover, if tags are programmed at the country of origin before departure then information may be uploaded from the tag to the computer of immigration centre, which improves efficiency and reduces long waiting queues at the airport.

Fig. 7. Handheld reader screens 3 and 4.

Fig. 8. RFID Pilgrim Identification System.

VII. ACTIVE RFID WRISTBAND TAGS FOR PILGRIM TRACKING

Every year a significant number of violators pretend that they want to perform Hajj while their

real intention is to find jobs and stay in the country illegally. The Hajj area is limited to few squared kilometers. Therefore, if a network of RFID readers is distributed in the Holy area and an active RFID wristband is used for each pilgrim, then when a pretend pilgrim attempts to leave the area or cut the wristband an alarm is sent to security officers indicating a violator. Moreover, although short range tags proved useful for identification, a longer range would improve efficiency. At check points, officers need to check the Hajj permit of each pilgrim. Pilgrims enter the Holy area on cars or busses. Short range RFID system would require officers to bring the reader close to the tag to be able to read it. A longer range would allow pilgrims permits to be checked while pilgrims are seated in their vehicles without the need for officers to come close to read the wristband tag. Additionally, statistics about distribution of pilgrims throughout the Holy area help provide better services in future Hajj seasons. Long range RFID systems would provide such statistics without creating bottlenecks in the area. Moreover, sometimes there is a need to locate a pilgrim among the crowd. A long range RFID system with a network of readers could help locate a particular pilgrim when needed.

To develop a solution for these tasks, an off the shelf development kit is acquired from ActiveWave. Its printed specifications [12] matched our requirements reasonably well. The wristband has a replaceable 3V battery that lasts from one to three years. It's read range for receiving is up to 30 meters while for transmission is up to 85 meters. The user memory is up to 256 Kbits, which is enough to store a pilgrim's information with his picture and a finger print if needed. Anti-collision capability is also available. It sends an alarm if removed or cut. The tag is shown in Fig. 9.

The reader has three basic modes of operation: program, monitor, and call. When in programming mode, the reader configures the tags. When in monitoring mode, the reader listens to all tag activity and relays this information back to the host in real-time. When in call mode, the reader wakes up specific tags, specific groups of tags, or all tags within range. The reader is shown in Fig. 9.

Fig. 9. Active RFID wristband tag and reader.

The development kit has been acquired that includes a reader and about 24 wristband tags. Upon testing the system, 18 tags were found not to be functional. The remaining 6 were programmed to track 6 pilgrims. The reader is placed on the ground and pilgrims were asked to start moving from about 100 meters towards the reader. It was noticed that at about 30 meters the pilgrims were detected, however, if a pilgrim occludes another, both will not be detected by the reader. The same process is observed when more pilgrims stand close to each other. The detection range is observed from all directions consistently. For the crowd in Hajj, the system as it was tested is not useful for the intended purpose of tracking. More refinement of the used frequencies, location of readers, and antennas design is needed.

For detection of passengers of cars, it was possible to detect 5 pilgrims in a passing car at a reasonable speed. This would be very helpful at check points as it allows Hajj permits to be verified while vehicles are on the move. This would improve efficiency and remove bottlenecks on the road.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Hajj season poses many challenges for the authorities. The main challenges have been reviewed in this work based on official reports, interviews with key officials and the authors' personal experience. Using advanced technologies is very promising in tackling these challenges. The pilot study has demonstrated that the use of RFID technology eases some of these challenges.

We carried out a pilot project to experiment our system during Hajj 2007. The prototype RFID-based Pilgrim Identification System was tested with a group of 1000 pilgrims from Ivory Coast. This experiment proved to be very successful in demonstrating the benefits of the system. In particular, it demonstrated the effectiveness of RFID system in removing bottlenecks of the traditional authentication system. This is due to the fact that checking a wristband tag by the reader takes a small fraction of the time it takes to authenticate the paper permit.

It must be noted that the cooperation of pilgrims is very vital for the success of the system; our experiment has shown that pilgrims happily participated after enough explanation was given about the objectives of such a system and improved services it leads to future pilgrims. Moreover, it was shown that collecting the wristband tags to use them in future seasons is not practical, as most pilgrims wanted to keep the tag as a souvenir from Hajj. Pilgrims should be educated in their own countries about the system before coming for Hajj and the importance of keeping the tags as a Hajj permit and that its loss can cause them difficulties during their Hajj.

Distribution of pre-programmed tags in each pilgrim's home country makes the job of immigration officers in Jeddah easier and improves efficiency at the airport as information needs only be verified from the tags rather than inputting the information while pilgrim is waiting.

In the future, applications such as e-purse may be added to the tag, so that all what the pilgrim need to carry is his wristband tag. This saves pilgrims the worry that they may lose money or official documents.

Although 1000 pilgrims is a relatively large number for the current project, it only makes 0.04% of total pilgrims. Moreover, having only 1000 tags and one reader limited the full benefits of the RFID system for such application, especially since the group from Ivory Coast consists of about 4000 pilgrims. Therefore, it is recommended that the experiment be performed on an entire contingent of pilgrims from a country such as Malaysia which has about 14,000 pilgrims coming every year. This will help in validating the system with a relatively good sample size before deploying the system for more than 2.5 million pilgrims.

We have also investigated the use of Active RFID system to track pilgrims using a developed prototype. The system has proved to be useful for detection of Hajj permits while pilgrims are on moving vehicles. More investigation is needed for this system. Improvement of antenna design, selection of readers' location, and communication frequency are also to be tackled in future work. Wireless sensor network with GPS/RFID unit is currently under investigation for the tracking of pilgrims.

ACKNOWLEDGMENT

This work has been conducted under KFUPM Funded Project No. IN060340. The author is grateful to KFUPM for the support. The author would like to thank Usman Malik, Ahmed Abul Hussain, M. Kousa and S. Sharani for their help.

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