Kingdom of Saudi Arabia
Ministry of Education
Umm Al-Qura University
Faculty of Applied Science
Physics Department

Management of Crowded Places in Hajj Using Radio Frequency Identification

A graduation project is submitted to the Physics Department in partial fulfillments for the degree of Bachelor of Science in Physics

By

Afra'a Mohammed Al-Otaibi
Arwa Abdul Razzaq Fallata
Bushra Zaben Al-Otaibi

Supervised by
Fatima Ahmed Bajafar

Makkah-KSA
1437 H –2016 G

بسم الله الرحمن الرحيم

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Dedication

This thesis is dedicated to our dear families.

ACKNOWLEDGEMENT

Praise be to **Allah**, who has given us the ability and helped us to complete this thesis.

We are honored to offer our deepest gratitude and appreciation to our supervisor **Ms. Fatima Bajafar** who paved the way to knowledge for us and did not skimp in direction and advice that helped us.

We would like to express our special thanks to **Umm AL-Qura University** for its continuing efforts to raise students' knowledge and experience; in addition, we offer sincere thanks and gratitude to the **Department of Physics** at the university.

We also offer our thanks to the **Atlas RFID Store,** which provided us with the tools for the project and thank the programmer **Salem Masrahi** for providing the required software programming and consideration; we do not forget to offer thanks to the engineer **Abdul Razzaq Fallata** for helping us choose the required tools, in addition to scrutinizing and reviewing our thesis.

With all love, we thank **our families**, who believed in us and gave us the moral and financial assistance to succeed in the work we have chosen, and who offered their continuous prayers for us to succeed.

Finally, we give thanks to all who gave us help and assistance of any kind.

Management of Crowded Places in Hajj Using Radio Frequency Identification

Abstract

Hajj is the fifth pillar of Islamic pillars. Muslims perform it annually at the same time in certain specified places. This regularly causes problems of human congestion, which has caused deaths and injuries from crushing and suffocation among pilgrims.

This work aimed to offer a practical solution for the overcrowding problem by monitoring, managing, and organizing pilgrims using radio frequency identification (RFID) technology. The proposed RFID system consists of tools like RFID reader, RFID tag, RFID antenna, controller, computer and auxiliary equipment such as automatic gate openers and visual-audible alarms.

The constructed prototype suggests the reconstruction of the pilgrims' pathways into the main paths that are surrounded by emergency side pathways to the left and right that allow the dispersion of crowds of pilgrims through open gates.

According to the project plan, the RFID system will identify crowd locations and initiate a pre-alarm system to enable authorities to perform certain actions to prevent overcrowding. Then, if those actions failed to prevent overcrowding, the system would open the gates and start audible and visual alarms at the congested locations to direct people away from these dangerous areas. The result of prototype testing was successful.

Additionally, the report included measurement of the received signal strength indicator (RSSI) for the RFID reader used with one of the packages supplied tags. This measurement indicates the strength of the signal received by the reader from the tag. The RSSI graph was successfully plotted; accordingly, it paves the way for the inclusion of such input in future work to serve as a filter that prevents signal interfaces among readers and tags and to localize actions to only the affected zones.

We recommend considering the application of the idea of this model and the undertaking of future studies based on this study to reduce the number of deaths and injuries that occur during Hajj seasons due to problems with pilgrim congestion.

إدارة مناطق الحشود في الحج باستخدام تقنية (RFID)

المستخلص

الحج خامس ركن من أركان الإسلام يؤدونه المسلمون سنوياً في صعيد واحد وزمن واحد ، وتحدث في الغالب مشاكل مثل الازدحام الذي قد يؤدي إلى حدوث بعض حالات الوفاة والاختناق بين صفوف الحجاج .

وفي هذه الرسالة نهدف إلى تقديم حل عملي لإدارة الحشود وتنظيمها ومراقبتها ومنع حدوث التزاحم من خلال استخدام تقنية RFID والتي تعني تحديد الهوية بموجات الراديو.

النظام المقترح لRFID يتضمن أدوات وهي قارئ (RFID reader) وبطاقات (RFID tag) وهوائيات (RFID antenna) و المتحكم(controller) والحاسب(computer) بالإضافة الى أدوات مساعدة أخرى كالبوابات الأوتوماتيكية والإنذار الصوتي والمرئي.

لتطبيق النموذج أُقترِح إعادة بناء لمسارات الحجاج إلى مسار أساسي بجانبيه مسارات طوارئ تساهم في توزيع اكتظاظ الحجاج من خلال احتوائها على بوابات تفتح عند تواجد الازدحام.

خطة المشروع تعتمد على التعرف على مناطق الازدحام وتفعيل نظام الإنذار الأولي لتمكين الجهات المعنية من القيام بما يجب لاجتناب الازدحام، وإن استصعب تدارك الوضع، فإن النظام يقوم بالتعامل مع الازدحام الحاصل، من خلال فتح البوابات المؤدية لمسارات الطوارئ وإطلاق الانذارات الصوتية والمرئية لتوجيه الحجاج الى مسارات الطوارئ وتخفيض الازدحام.

تم تصميم النموذج الأولي المتكامل وأظهرت النتائج نجاح آلية عمله بالشكل المطلوب.

إضافة إلى ذلك يتضمن البحث قياساً لمؤشر قوة الإشارة RSSI بين القارئ المستخدم والبطاقات بحيث يحدد قوة الإشارة بينهما وعلى أساسه تم رسم العلاقة بين الRSSI والمسافة وتحققت العلاقة الخطية بينهم بنجاح.

هذا القياس يعمل كعامل تصفية لتداخلات الإشارات بين القارئات والبطاقات والتي قد تحدث اثناء تطبيق النموذج على أرض الواقع بالإضافة إلى أنه يحدد أعمال النظام (من فتح للبوابات وتفعيل الإنذارات) فقط للمنطقة المطلوبة.

نوصي بتطبيق فكرة النموذج والمسارات للتقليل من حالات الوفاة والاختناق التي تحدث بسبب مشاكل الازدحام، ويمكن تطوير النموذج ليصبح أكثر كفاءة وملائمة لظروف البيئية.

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LIST OF SYMBOLS AND TERMINOLOGY

AC	Alternative Current
ACS	Automatic Crowd Solution
API	Application Programming Interface
ASK	Amplitude-shift Keying
CO	Component Object Model or Communication
dBi	Decibels Relative to Isotrpic
dBmW	Decibels mill watts
DC	Direct Current
GHz	Giga Hertz
H	Height
HDX	Half Duplex
HF	High Frequency
ID	identification
L	Length
LF	Low Frequency
mc	Micro controller
MHz	Mega Hertz
mm	Millimeter
ms	Millisecond
PC	Personal Computer
RF	Radio Frequency

RFID	Radio Frequency identification
RP-TNC	Reverse-polarity - Threaded Neill–Councilman
RSSI	Received Signal Strength Indicator
SDK	Software Development Kit
UHF	Ultra High Frequency
V	Voltage
W	Weight
USB	Universal Serial Bus

CHAPTER I

INTRODUCTION

Chapter I

INTRODUCTION

This thesis presents a new practical solution for main cases that resembles last year (2015), crowded problem, which resulted in the death of hundreds of pilgrims.

Initially, it proposes a modification in the pilgrims' roads between the holy places. Then it suggests the utilization of RFID (Radio Frequency Identification) technology to track crowds' location. Finally, it introduces a realistic solution based on readily available devices.

1.1 Motivation

RFID stands for Radio Frequency Identification technology, a technology that utilizes electronic components and communication antennas to identify and track remote items.

RFID technology proved to be practical in the performance of many tasks and among them tasks that are related to the tracking of assets and people movements. Accordingly, this technology can be associated with other available devices and management solution to prevent overcrowds in Hajj and accordingly avoids the dangerous consequences.

1.2 Objective of This Research

The aim of this research is to present a simulation model utilizing RFID system to locate people crowds in hajj and manage them in order to avoid suffocation cases and more badly deaths among pilgrims.

1.3 Thesis Outline

This thesis is arranged into six chapters, as follows:

1^{st} chapter includes an introduction about a research problem, motivation and the objective of our study.

2^{nd} chapter gives general information about Hajj, the basics of RFID technology, demonstrating of RFID system components and the physical principles of RFID systems.

3^{rd} chapter introduces a literature review on previous studies in RFID technology to track the location of crowds.

4^{th} this chapter talks in details about the methodology that we worked on and the methods which we have developed to complete the project.

5^{th} chapter explores results and discussion of data obtained from the program and observed some influential factors on the system

6^{th} chapter contains the conclusions and outlook to the future of this research.

CHAPTER II

THEORY OF RFID TECHNOLOGY

Chapter II

Theory of RFID Technology

This chapter as an introduction to the basic concepts of our project, we generally talk about the fifth Islamic pillar (Hajj), and then discuss the principles of RFID systems, their properties and applications.

2.1General information about Hajj

Hajj (pilgrimage) is the fifth pillar of Islam. Muslims travel to Makkah to perform Islamic duties and activities associated to Hajj. It is mandatory once in a lifetime for Muslims who can afford it.

Hajj has ritual worship doings that are known as rites (Manask) of hajj that are performed during specific days within the final month of each Islamic lunar year, which is called Zulhijjah.

Annually, a large number of pilgrims, ranging from one to three million, come from all over the world to participate in this event. In addition, hajj's activities are restricted to be performed in specific locations (Al. Haram, Mina, Arafat, Muzdalifah) which great crowds sizes and make their management a hard task to be handled.

Overcrowding is the most prominent problem facing pilgrims as it includes a series of complications varying from loss of luggage to loss of lives. Therefore, management of crowds in Hajj is very critical work and the identification of crowd zones needs to be detected quickly in order to direct people out of these dangerous zones to avoid unsafe consequences. However, such task would be very hard to handle without technology exploitation and RFID is one of the practical technologies that can help to achieve such mission.

2.2 RFID Technology

Radio Frequency Identification (RFID) is one of the best techniques that used to manage the crowds. RFID is contactless and does not require that the readers and tags to be within line of sight [1]. RFID allows a target, place or human to be automatically identified [2]. Automatic Identification in this technique is specified by allocating each object or location its own ID code or RFID tag.

Lately, RFID technology has been utilized in many applications that cover safety and management applications [3]. Usually, the RFID system includes hardware and software parts. The hardware part involves three components: RFID reader, RFID tag and antenna. The software portion comprises the RFID middleware.

2.2.1 Hardware part

2.2.1.1 RFID Reader

RFID reader is a device which displays the information recorded on the RFID tag after reading it via radio signals [3]. Normally, the RFID reader communicates this information to a host computer for further processing and analysis. The RFID reader comes in three basic types: Hand-held reader, Fixed reader installed in the area, and Fixed reader installed at choke points such as bridges or narrow passages [4]. Every reader has three basic compounds: the antenna which can be one or more and may be integrated or external, the radio interface which is working on reception, transfer, modulation and demodulation and the control system which communicates with a tag and interact with applications and it is usually equipped with small control unit (micro-controller) [5].

2.2.1.2 RFID Tag

It is a small device that can be put on or attached to products and objects. It has a unique identifier (ID) which distinguishes each tag from another. Also, it function as an instrument that saves specific information [4], holds unique identifier code (ID) [6]. The RFID tag might be also called either a card or a transponder. It consists of (coil, chip, and memory) [7]. The RFID tag is commonly classified into passive and active types [4].

- **Passive RFID tags**

They do not need batteries and typically the RFID reader sends the signal out to the tag, accordingly, the tag transform the received signal into power and return it back to the reader. Passive tags preference is attributed to their lower price compared to active tags, smaller in size, their reading space is short and has a low size of memory [8]. As indicated above, passive tag mainly gains its power from the communication signal that is originated from the reader [3]. Currently, passive tags are the most commonly used ones [6]. Another name for the passive tag is pure passive or reflective [9].

- **Active RFID tags**

This type of tag needs an internal battery. It is big and expensive. It can be read at a wide range of distance that can reach up to 300 feet or more [4]. The transmission rate of data is the main benefit of active tag [8]. The active tag transfers the information saved on its microchip by broadcasting signals [10].

2.2.1.3 Antenna

The antenna has an active role in the RFID system. Antennas are supposed to consume high-energy to get the signals, so it is manufactured from conductive materials such as copper that we have, adding that in the choice of lengths and lateral sides of the antennas must care for working to improve efficiency[5].

2.2.2 Software part

2.2.2 .1 Middleware

It is software that collects the received data from several readers. The passage of information between the reader and the host computer will be communicated by the middleware. Moreover, by middleware the computer displays reader's data to users [4].

2.3 Physical Principles of RFID Systems

The physical fundamental properties in RFID systems will be discussed in the following subsections.

2.3.1 Operating frequency

The operating frequency is the frequency of the electromagnetic wave used by the card (tag) to communicate with the reader or to get its power from [11].

2.3.1.1 Bands of Operating Frequency

Operating frequency stretch out on several bands; it begins with the low frequency band (LF) and ends with the microwave band. *The frequency ranges are most* *commonly used in RFID are the 125/134kHz, 13.56 MHz, 860-960 MHz, and 2.45 GH(See table2.1*) [11, 12].

Table 2.1: Kind of operating frequency

Name	Frequency Range	Common RFID Band	Typical max. read range
LF(Low frequency)	30-300 kHz	125/134 kHz	50 cm
HF(High frequency)	3-30 MHz	13.56 MHz	30 m
UHF(Ultra High frequency)	MHz-3 300 GHz	860-960 MHz	9 m
Microwave	Smaller than 3 GHz	2.45 GHz	Greater than 10m

2.3.2 Inductive Coupling

Inductive coupling is the commonly used form of remote coupling. Reader in inductive coupling interacts with coupled tags. The inductive field strength increases when a coil antenna is used to produce magnetic field that could cover wider area.

This type of coupling is also referred to as *transformer coupling*; in which the transformer transfers energy between two coils. Similarly, in inductive coupling the current is originated on the tag's coil by means of induction.

When the field initiates the minimum required energy on the tag circuitry, it will enable the microchip fixed on it to communicate, through load modulation, with the reader in similar way to backscatter coupling which will be described later.

Successively, a resistor which is another part of the tag's components switches on and off to induce a fluctuated magnetic field on the reader's antenna to communicate the tag message in the form of changes in the circuitry voltages.

2.3.3 Backscatter Coupling

Backscatter coupling describes one of the methods of communication between the reader and the tag. The reader spreads its signals at a certain frequency. Then at the tag side, the received signal energize the tag circuitry and subsequently, the tag gets activated and echo back the received signal with no alteration to its frequency.

Backscatter coupling is normally used for long range RFID systems during which the gap between reader and tag's antenna reaches up to or more than 1 m and it operates at Ultra High Frequency (UHF) frequencies [9].

Backscattering changes various qualities of the reflected signal to send information to the reader. Tag do this scattering and changing of qualities either by its physical properties or via switching load which is connected in parallel to the antenna of tag causing the antenna to reflect weaker signal when the load is electrically coupled.

The essential property in backscatter coupling which should be considered is that the tags redirect the received signal back with no alternation to its frequency after utilizing part of the power in them while at that sequence of time the reader is expecting to receive the reflected signal back at the same level of frequency.

Therefore, the reader and the associated tag will typically take turns. Once the tag sends its signal, then it turns off which means that there is no powering signal coming from the reader at that time because the reader is expecting to receive the echo of the previously sent signal. Accordingly the RF communication between them is half duplex (HDX) which means that at a certain sequence of time there is only one sender and one receiver and none of them can send and receive simultaneously.

In backscatter coupling, Amplitude-Shift Keying (ASK) which changes the signal amplitude while keeping its frequency and phase without any sort of change is used mainly to convey the message from the tag back to the reader at the sent frequency.

The Physics of backscattering occurs immediately when the current that flows through to the reader's antenna causes an induced voltage on a tag's antenna.

As mentioned earlier, the tag's antenna, which refers as receiving antenna can reflect back the wave to communicate with the reader. Also, it can use a fraction of the signal's energy to energize the tag's implanted small chip.

The main function of the small chip is to control a resistor (load) which is located between two halves of the receiving antenna. The resistor works as a barrier and its function is to make it difficult to the current to pass through. When the connection between the antenna's halves occurs with low resistance, the induced current is no different from the current that started at the transmitting antenna in the reader. Therefore, radiation will occur between receiving antenna in the tag and transmitting antenna in the reader, the gain which we get is of high amplitude. In contrast, if the resistor separates the two halves of the antenna, there will be no induced current on the receiver and subsequently backscattering will not happen in this case. Accordingly, the induction of the reader's transmitted signal at the tag side is sensitive to the changing resistor connected to the receiving antenna in the tag.

Through the alteration of the resistance value, the chip is able to create a load-modulated ASK signal to transfer a unique ID number stored in the memory of the chip [3, 8].

2.3.4 Reciprocal influence between wavelength and frequency

Electromagnetic waves speed in vacuum is equivalent to the speed of light which is $(\mathrm{c} = 3 \times 10^{8}\,\mathrm{m/s})$, and the relation between the wavelength λ and frequency f (where the wavelength is the distance measured between the two successive high points or low points of the same amplitude) gives the formula;

$$\lambda = \frac{\mathrm{c}}{\mathrm{f}} \quad \text{(2.1)}$$

Therefore, if the wave's frequency is 300 000 Hz, the wavelength will be;

$$\lambda = \frac{300\,000\frac{\mathrm{km}}{\mathrm{s}}}{300\,000\frac{\mathrm{peaks}}{\mathrm{s}}} = 1\ \mathrm{km} \quad \text{(2.2)}$$

Wavelengths that are used commonly in RFID communication vary from 2000 m to 12 cm. The largest utilized RFID antenna has a diameter size of one meter while the smallest could reach up to 1-4 cm.

In inductive coupling system, the antenna is much smaller than the wavelength. Systems with a wavelength close to antennas' diameter size usually use backscatter coupling or radiative coupling to perform the required communication between the tag and the reader. The reader antenna creates a traveling electromagnetic wave, with an intensity that falls off as the square of the distance traveled in the absence of obstacles. In contrast with inductive coupling, the communication between the tag and he antenna occurs at a later time, where the fraction of the propagation time of the signal is much longer than the time taken for a complete cycle of the RF voltage.

The differences between inductive and radiative coupling have an important effect on the detection sensitivity of the RFID tags. The read range in inductive coupling is relevant to the size of the antenna the reader utilizes and dependent on the direction in which the tag communicate with the antenna. Consequently, the read will be more reliable when the tag is close to the antenna, and become invisible when the tag is far away from it.

However in radiative coupling, because signals power weaken slowly in relevant to distance of travel and the signals wavelength are smaller than the standard distance between the reader and its associated tag, reflected signals from obstacles that are located within the range of the reader-tag distance can reflect back into the area and interface with the direct signals of communication between the reader and the related tag resulting in a creation of complex signals that the receiver (either the reader or the tag) cannot read well.

We can increase the power of the received signal at the reader by moving the radiative coupled tag far from the antenna in a distance that is in multiple to half of its wavelength. This may result in tag disappearance and then reappearance several times to the observing reader as the tag moves far from the antenna. In practice, the complexity of the radiative coupled zone can be reduced by increasing the number of readers in the targeted zone.

In fact, read range of radiative coupling system is longer than inductive coupling.

However, this is at higher cost of complex communication zone that results in discontinuous and unreliable communicated data.

The frequency of operation has a great influence on the type of antennas used as shown in figure 2.1.

For inductive coupled system, the voltage induced in the receiving antenna is proportionally related to the number of turns of the coil, the coil size and the frequency of communication used to operate the system.

The size of reader antennas determines by the desired range, which includes 10-20 turns of wire. At 13 MHz, the frequency is higher for 100 times, 3-6 turns are enough for a tag to produce volts at range which is reasonable of a few tens of centimeters.

At HF, reader antennas use a single coil, at UHF frequencies tags use different dipole design, what prevent UHF from using the coils is that the diameter inside it needs to be in few centimeters, which is not effective in UHF[13].

A normal size of the dipole antenna is about half of the wavelength, usually 15 cm at 900 MHz, or 6 cm at 2.4 GHz.

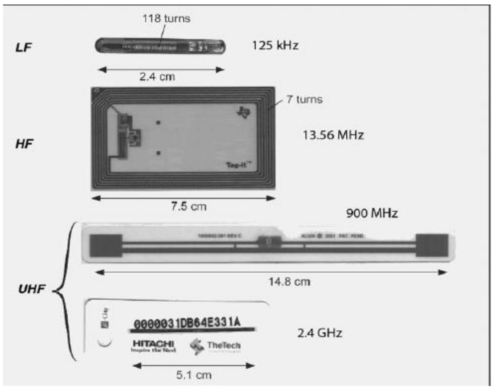

Figure 2. 1 examples of tag antenna configuration designed for different operating

Chapter III

Literature Review

Chapter III

Literature Review

Radio Frequency Identification (RFID) was born in the early years of World War II as a mechanism of planes identification. Afterward, with the exponential growth of technologies, RFID has been excessively used in many major advanced applications. In recent years, many literatures studied the use of RFID in Hajj as part of crowd management systems.

M. Yamin *et al.* in 2008 [14] studied the use of RFID technology in crowd management events such as Hajj by providing pilgrims during their arrivals through ports wireless and smart RFID tags in sort of "wrist strap” . In addition, the study suggested that Saudi Ports have to have gates that are equipped with RFID readers, which will read and identify pilgrims through their tags, which are worn as a bracelet when they pass through these gates in order to speed up the process of immigration clearance. They gave suggestions to prevent the infiltration of pilgrims to other cities, as well as to keep track of the pilgrims and monitor their movements, and achieve ways of improving pilgrims' welfare, safety and health.

M. Mohandes et al. in 2008 [2] presented a solution based on RFID technology to help in controlling the large numbers of pilgrims. The proposed system allows the concerned authorities to know the sites that are potential for having accidents. This technique required that RFID tags to be used as bracelets on the wrists of pilgrims and utilize them to record additional useful information about them.

In 2011, F.Abdessemed[3] suggested a way to solve the troubles experienced in the control of pilgrimages transportation, through the identification of buses by the use of RFID tags that are fixed on them. Moreover, passengers existing the buses are identified on the basis of carried RFID cards and fingerprints.

In 2011, E.Khan[4] study recommended a system based on RFID technology to manage pilgrims coming to the pilgrims stations at Jeddah Airport. In such system, each pilgrim is given an ID card with a special number to identify the pilgrim in different stages of the arrival process.

In 2012, T. Mantoro et al.[5] offered a system called Hajj Locator for tracking pilgrims in a crowded pervasive environment. They proposed solutions to the problem of the crowd through the use of less costly technologies such as Wi-Fi, SMS and GPS where they expected that these techniques help to monitor pilgrims and facilitate the quick accessibility to their identification data.

In 2013, Fakir et al.[6] used RFID technology for controlling pilgrims' movement, by linking RFID system with a mobile application. In such system, they proposed to give each one of the pilgrims an RFID tag, RFID readers to be distributed in strategic places and the data that the RFID readers collect to be sent to the control center, which supposed to be equipped with a web-based user interface system, at which the collected data to be processed and utilized to provide the required support. In addition, pilgrims who use the mobile application can easily find the location of their families and friends that happen to be available in Hajj area. In addition, users are supposed to be able of sending emergency requests and receiving notification from the system.

A. Al-hashidi *et al.* in 2013[15] studied the RFID applications in the Hajj management system. This system can help to solve the major problems facing the Hajj as in past years, through wearing pilgrims RFID wristband tag where be equipped with the most important information about the Pilgrim includes name, age and blood type, and can be retrieved and displayed on the RFID reader.

In 2015, M. Yamin[16] studied the problems caused by large crowds like the pilgrimage season in Makkah and ritual Kumbh in India and his focus was from the health point of view, especially for the cases arising from the communicable viruses and diseases. He suggested some solutions including the use of RFID technology worn by pilgrims on their wrists.

In this work, we will build on the mentioned studies outcomes by evaluating their studies conditions and the way that we can benefit from their findings and utilize them for the success of our study.

CHAPTER IV

METHODOLOGY

Chapter IV

Methodology

In this part of the thesis, we will first talk about the hardware components that were used to carry out the project from the conceptual stage to the final application. This will include a brief description of each hardware component. Then, we will explain the project concept and how the RFID technology should integrate with the other components in order to materialize that concept. After that, we will discuss the hardware detailed connection. Afterward, Receive Signal Strength Indicator (RSSI) will be discussed in details, including its importance for the intended application. Finally, the simulation programs including both the configuration and coding parts will be described with emphasis on their inputs, outputs and logical operations.

4.1 materials and method

In our work, we used one RFID reader, 30 RFID tags, one antenna, and cables.

4.1.1 Materials

Reader (ThingMagic USB Pro RFID reader**)**

We have selected this type of reader, because of its affordability and inclusion of certain features that made it more suitable for our application, such as: The range of reading which can reach up to 1.2 meters with internal antenna and can be extended to 6.1 meters with an external 6dBi linearly polarized wideband antenna , its ability to read 50 tags/second, its compact size (97 mm L × 61 mm W ×25 mm H) which make it more easy to fit on our prototype (figure 4.1), more than that it can be operated within a temperature range (-40℃ to +60℃) that is appropriate to our testing environment, and finally its operating frequency according to ESTI in the range of 865.6-867.6 MHz which falls within the allowable frequency range of our geographic location, as shown Figure 4.1.

Figure 4.1: The RFID reader

- **Tag** **(**The commercial name for the used sample package is RFID Ultra High Frequency (UHF) Passive Tag Sample**)**

As mentioned previously, there are two types of tags, passive and active. In our project, we used passive tag. The reason for choosing this type of tags is because it does not need batteries which make it lighter to carry by users and has no need for power charging. Accordingly, it is more suitable for pilgrims to use. We used one package of passive tags out of the two given packages. Inside this package, there are a variety of RFID passive tags like durable tags, converted labels, metal mount tags and hang tags, as shown in Figure 4.2. The size of RFID tags vary in size starting from 1 by 1 inch, to 4 by 4 inches.

Figure 4. 2 : The RFID tags

- **Antenna** (MT 242025_TRHA)

The Antenna we have used has certain specifications such as; it operates at a global frequency of range 865-956 MHz, at a temperature range of -55℃ to +71℃. Its polarization is right-hand-circular and has body dimensions of 7.4 * 7.4 * 1.1 inch

(190*190*30 mm), as shown in Figure 4.3, which made it compatible to our developed prototype.

Figure 4.3: The RFID antenna

In addition, we used auxiliary tools like warning alarm, light, microcontroller, relay and slider.

- **Warning alarm**

In this project, the warning alarm gives an alert when there is congestion after being activated by the program.Figure4.4

Figure 4.4 : Warning alarm

- **Warning Light**

Will be activated together with the gates opening and the alarm sound.

- **Relay**

That is an electrically and mechanically operated switch. The switching mechanism is performed by energizing an electromagnetic coil, which will move an inserted rod causing several electric contacts to change their status from the open to closed position or vice versa. In this project, the relays will be controlled by the microcontroller with a voltage level of 5VDC. They are used to activate the 12VDC components such as the warning alarm, the slider and the horn. Figure4.5

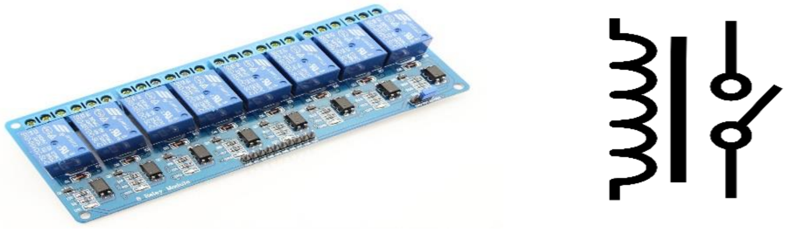

Figure 4.5 : The Relary and symbol of it

- **Microcontroller**

It is a small computer presented in a single integrated circuit, Typically this includes a CPU, RAM, some form of ROM, I/O ports, digital outputs, analog inputs, and timers. Figure 4.6

Figure 4.6: Microcontroller

- **Linear Slide Actuator**

Linear slide actuator combines electric rod, which has the shape of ball-screw with the guide rod. There is a plastic piece attached to the guide rod able to mount blocks and bearings to it. The motor drives the ball-screw back and forth.

Its speed varies between 4 to 36 mm/second. It can operate in a temperature range between -26 to 65℃. It uses a direct current DC of input voltage 12-24V.

Figure 4.7: The Linear Slide Actuator

4.1.2 Project Concept

The idea of our project is to manage people crowds during Hajj by preventing people buildup to overcrowd during their movement in the Mashaer. The idea suggests that pilgrims roads to be designed in a way to disseminate overcrowd quickly with the help of RFID technology in order to prevent pilgrims deaths and injuries. Accordingly, it proposes that people pathways to be reconstructed into a fenced main-lane that is surrounded by two fenced side-lanes. The barriers or fences between the main path and side paths have gates at certain distances that can be controlled and opened during crowds' stagnation. It assumes that the total width of the both sides track is one-third of the main-track. This means that the width of each side track is about one-sixth of the main-track.

The main-track gates opening depends on the pilgrims' movement situation, if the area is congested, means that the number of pilgrims is greater than n_m where n_m is the limited value of pilgrims in our application for specific time duration, then the instruction in the application that is stored in the microcontroller will send an open command to the side gates in order to disperse the crowd and eliminate the risks of overcrowding stagnation, as shown in figure 4.8.

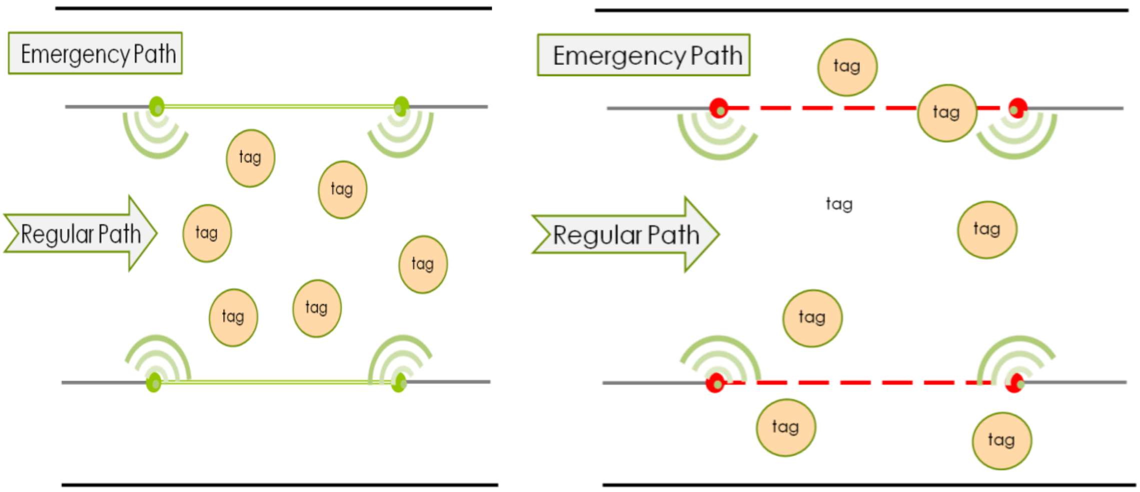

Figure 4.8: The idea of the project

Visual Basic was used as a programming language to develop the required codes that were uploaded to the microcontroller in order to manipulate and carry out the suggested scenario. The team has used a piece of wood to assemble the project hardware components and performed the required connections as indicated in Figure 4.9

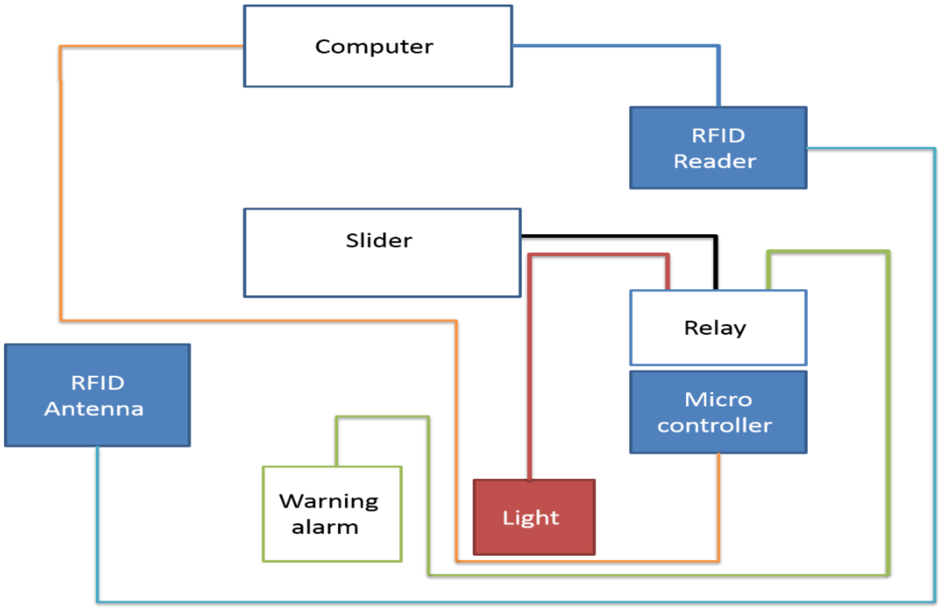

Figure 4.9: the scheme of the hardware and software

4.1.2.1 Connections Details

First, we have connected the reader to the antenna by using a coaxial wire through adapters, RP-SMS Male to RP-TNC Female. Figure 4.10 shows the male connection.

Figure 4.10: The coaxial wire

In the meantime, we have used a voltage converter (220V AC /12V DC) to drive the hardware components through the microcontroller. These components included the slider, the warning alarm and the lighting device. Then, we have connected normal copper wires between the warning alarm and one of the relays on the relay module, another wire between the light and second relay and we have connected a third relay to the slider. After that, the relay module was placed in a box to protect it and prevent wires tangling. We have used the same box to house the microcontroller but separated them with a barrier. The microcontroller (Arduino) was linked to the computer's communication port COM 2 (Component Object Model or communication) in order to download the developed codes from the computer.

Moreover, we have connected the RFID reader to the other computer port in order to perform the required reader configuration and collect the reader information during its operation.

The gates mount to the slider, which moves back and forth to open it or close it.

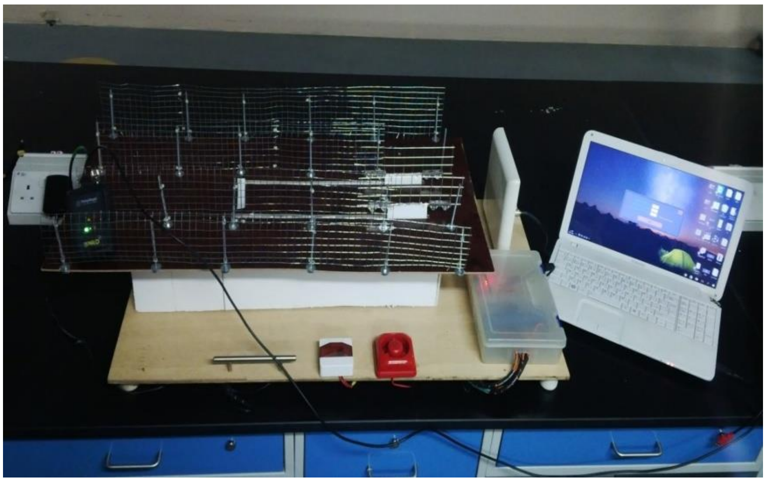

Figure 4.11 : Model of the project

4.1.2.2 RSSI (Receive Signal Strength Indicator)

RSSI is a reading that shows the strength of the signal where the reader was received from the tag. With consistent RSSI reading, the parameter can be used to predict the position of the wireless device which is in this case the tag, estimate the distance between the reader and the tag, and predict the direction of the tag's movement and consequently help in finding the lost tags or pilgrims if applied to our case.

Obstructions in the vicinity between the reader and tags may have effects on the RSSI values. Factor that can change the value of RSSI can be; metal structures which cause signals to reflect uncontrollably, liquid materials which may absorb or attenuate signals and finally the height between the tag and reader which will be interpreted by the leader as a longer distance than the actual one. However, since the RSSI reading is beneficial, the mentioned obstruction and misleading effects can be accounted for and corrected during the system installation and configuration in order to gain these benefits.

In this research, we have recorded the RSSI for one of the supplied tags. The records included both the MAX and MINI RSSI values in dBm. MAX RSSI values registered with minimum read distance and maximum read distance with the registered MINI RSSI values. Thus, two curves were constructed showing reading distances with MAX RSSI values and MINI RSSI values. Then, combining the two curves together will give a read range area that has the same RSSI value for the bounded area.

The purpose of finding these read ranges is to estimate the distance of each pilgrim to the reader. Then, depending on the power of the tags which the reader gets, the related gate will open instead of directing the command to several gates. In the real environment, the readers and antennas will be distributed along the pathways and fitted on the fences and for each group of readers and antennas number of gates will be linked to those zone readers.

Because of the availability of many antennas and readers in the inspected areas or pathways, signals will interfere with each other and accordingly building RSSI curve for each group of readers in a network system will work as a filter that will be more suitable solution to determine the congested locations and accordingly perform the required actions.

4.2 Simulation program

We have mentioned previously the steps that were used to build the project prototype and the assembly of the hardware parts to make it more representative to the project concept.

The simulation program was built with the consideration of limitation we have in the number of tags that were given in the purchased package, the available fund to purchase the required materials and the allotted time to complete the project.

The program codes were developed in Visual Basic and its concept is shown in flowchart given in figure 4.12.

The program will collect the RFID reader input on a continuous basis and compare it with two limits. First, the pre-alarm limit, which will be entered as a pre-request to run the program, is the number that indicates the number of pilgrims has started to reach overcrowd according to the specific pilgrimage path capacity. Accordingly, it gives people at the control center at which the computer and the hosted program reside time to find a resolution to the crowd issue by means other than the ones that the program will action.

Then, if the number of tags continues to accumulate passing the pre-alarm limit until it reaches the alarm limit which identifies that the area is congested, the program in the microcontroller will open the gates, initiate the alarm and start the warning lights.

The program is set in a way that the alarm sound can be acknowledged and muted. In addition, the main path gates will remain opened until a reset command, password protected, has been initiated through the control monitor.

4.2.1 Program Input

The following parameters are the inputs that are needed in order to run the program:

1) Arduino (controller) COM port number.

2) RFID max tags limit.

3) Pre-alarm tag limit.

Note: the pre-alarm and alarm limits are dependent on the pilgrims path capacity.

4.2.2 Program Output

After entering the variables represented above and starting to run the program, then once the limits have been reached the following program output will be initiated:

1) Pre-alarm will be announced.

2) Gates will be opened.

2) Warning alarm will sound.

3) Warning light will activate.

4.2.3 Flowchart of the program

The flowchart of the program is shown in Fig 4.12

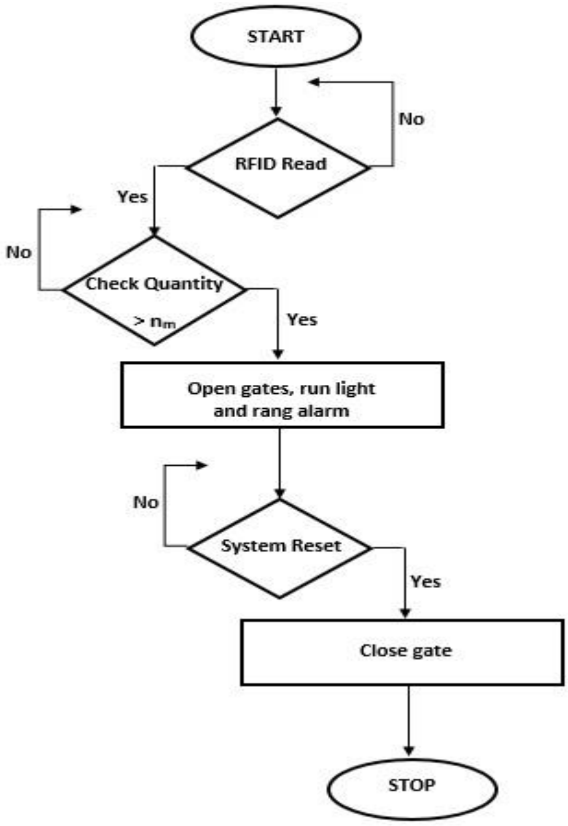

Figure 4.12: Flowchart of the ACS program

4.2.4 ACS program

In ACS (Automatic Crowd Solution) application configuration, there are two windows. The first one represents the base of the program, it's part of the vendor's package (ThingMagic). It recognizes the tag's code (EPC), calculates the RSSI (Received Signal Strength Indicator), registers the timestamp, indicates the read-count, and shows the phase and frequency of each tag.

This program is linked with the server of ThingMagic Company, it works as an interface between the reader and the PC (Personal Computer), and then it supplies the ACS application with the net reading from the reader. The steps to run the program is shown in the following below Fig 4.13

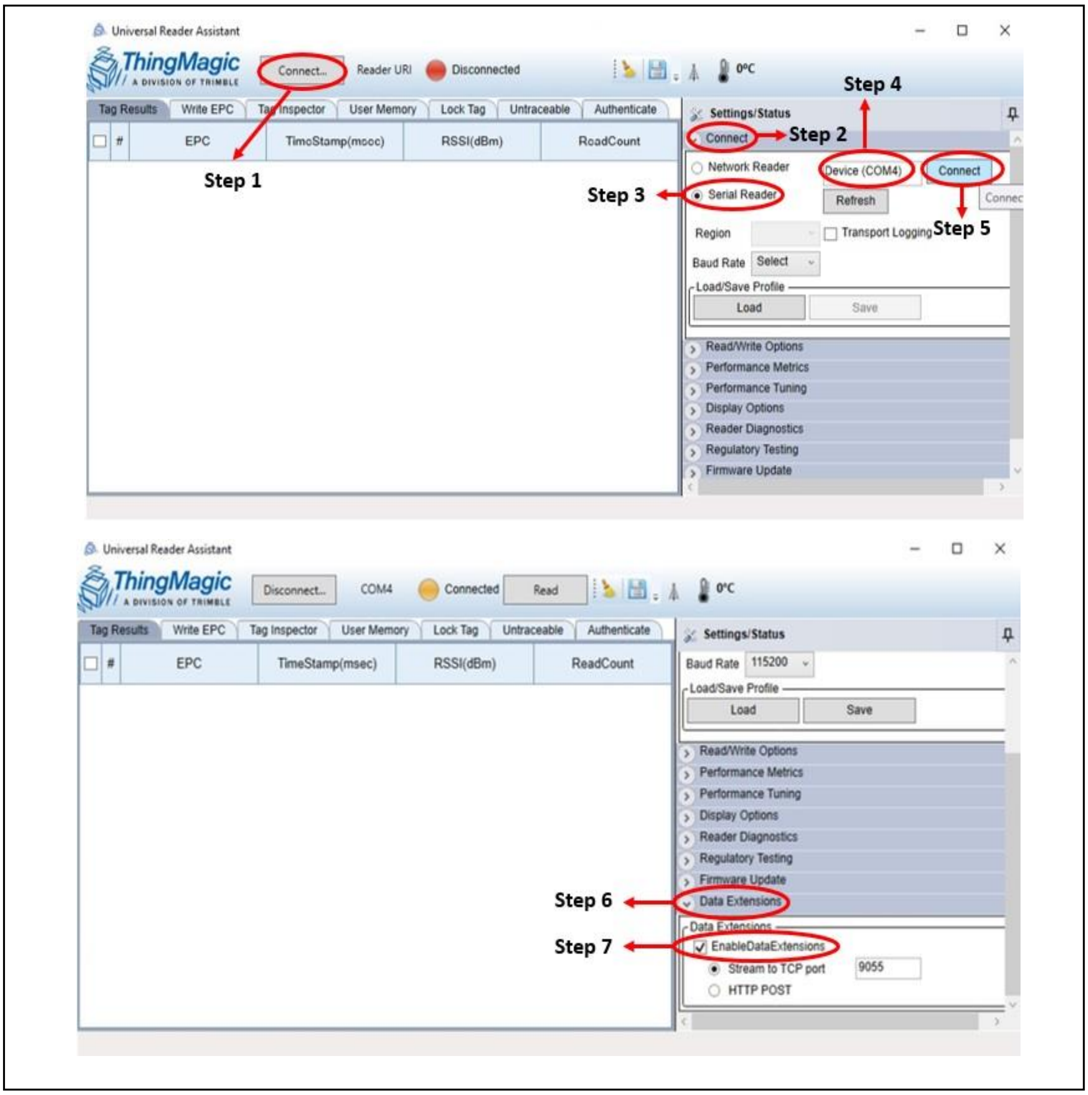

Figure 4.13 : ThingMagic Window

ThingMagic supplies the ACS program with net reading on real time basis and counts the number of pilgrims (tags) found in the major track.

Figure 4.14 shows the second window of the program. As noted there are three (taps) Arduino COM port, RFID max tags limit and pre-alarm tags limit. In the first tap we the input is always number two which represents the number of the port which connects the PC to the microcontroller, the second tap determines the maximum number of pilgrims at which the gates will open, the last one specified the number of pilgrims at which the pre-alarm will be initiated.

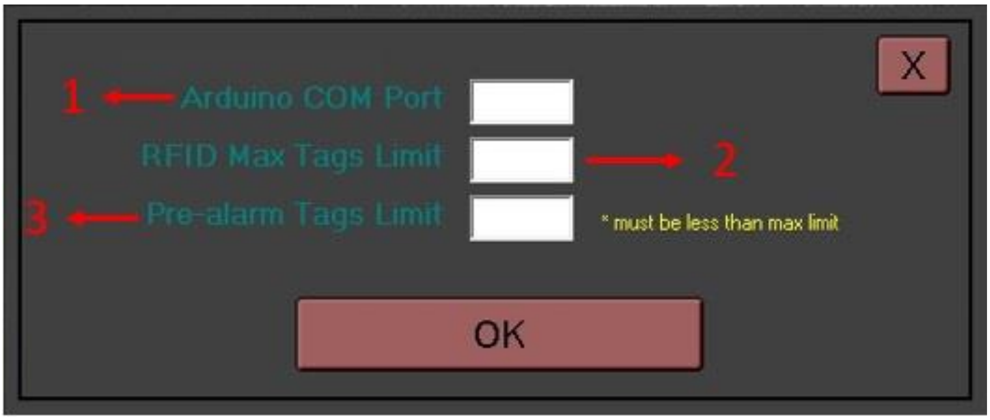

Figure 4.14: The windows of ACS program

Chapter V

RESULT AND DISCUSSION

Chapter V

Result and Discussion

In this part of the thesis, we will talk about the results obtained from the hardware components integration, the software configuration and coding; and the RSSI collected readings.

5.1 Hardware Integration

The integrated hardware components which included the hand constructed parts and the purchased components represented the team intended project concept and operated smoothly and in harmony toward that objective.

5.2 Software Activities

The software work included two parts; the configuration of the vendor supplied Software Development Kit (SDK) and Application Programming Interface (API); and the development of Arduino applicable codes to program the microcontroller to drive the auxiliary hardware components. Both works have successfully helped to simulate the project concept through the successful operation of the utilized hardware elements.

5.1.3RSSI Measurement

As mentioned earlier, RSSI is a reading that shows the strength signal of the reader receives from the tag. The importance of these readings is to develop the required filter that will facilitate the RFID system readings by minimizing the interfaces between the tags' signals and consequently restricting the system actions, such as gates opening and alarms initiation, only to the relevant zones.

The following steps summarize the RSSI measurement procedure that the team has taken to complete the task. The selected tag was put on the primary path and the reader was fixed on the prototype model. The reader started to read the tag on continuous basis at a successive time of 1000 ms. Within that time, the RSSI values also vary continuously while the tag is still at the same location. Accordingly, within that snap of time, we recorded the maximum and minimum RSSI values. Thus, we limited the time of reading for each tag position to one minute. This procedure was applied for different points along the 40 cm primary path. During the test, we noticed that the temperature of the reader started to increase rapidly from 30 ℃ to 80℃ and therefore each reading point was recorded at different reader temperature. This phenomenon has affected our reading results and accordingly it forced us to repeat the tests for several times.

Our tests were performed three times in order to build a meaningful graph that shows a good filtering area. In the first test, the values of RSSI of the tag were taken along the path for every centimeter without taking in mind the effect of reader's temperature on the RSSI readings. In addition, the direction of the reader was in front of the tag.

The values of RSSI were meaningless and as a result, the plotted curves were irregular. This means that the relation between the proximity of the tag to the reader and the resulted RSSI maximum and minimum readings are not changing linearly with distance change. Then, the test was done over again at the same conditions and the reader stopped reading about half of the primary path (20 cm).

Table 5.1: The first test took the reading at a distance of 20 cm

Read Distance	MAX RSSI	MINI RSSI
21	-44	-51
22	-46	-55
23	-45	-51
24	-45	-49
25	-47	-53
26	-48	-54
27	-47	-53
28	-47	-53
29	-46	-53
30	-46	-55
31	-45	-57
32	-45	-58
33	-45	-56
34	-46	-59
35	-44	-60
36	-46	-59
37	-45	-57
38	-47	-60
39	-49	-57
40	-49	-57
41	-49	-58
42	-51	-68
43	-51	-68
44	-52	-68
45	-51	-69
46	-53	-61
47	-54	-59
48	-54	-60
49	-53	-59
50	-55	-68
51	-55	-60
52	-55	-60
53	-49	-61
54	-49	-60
55	-48	-60
56	-49	-61
57	-50	-62
58	-51	-60
59	-50	-58
60	-53	-58
61	-51	-60
62	-52	-60

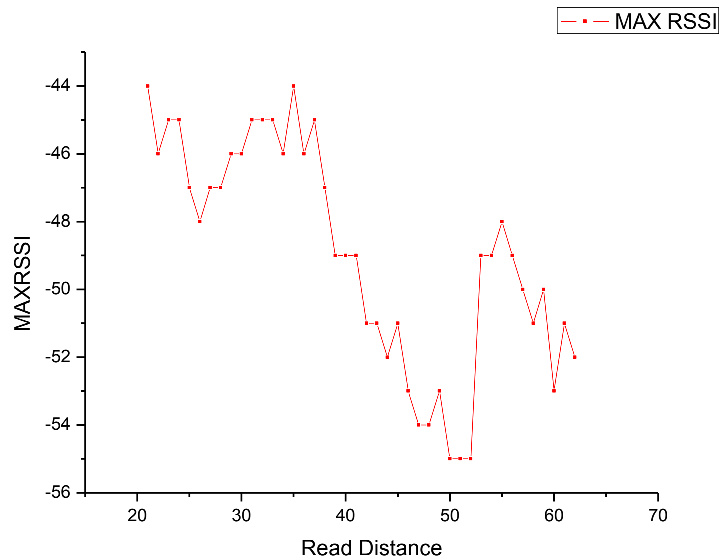

Figure 5.1 : Curve of the MAX RSSI for the first test

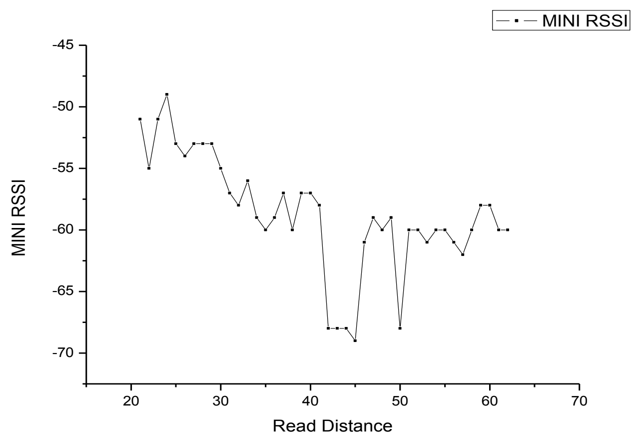

Figure 5.2: Curve of the MINI RSSI for the first test

These graphs show the curves of reading distances with MAX and MINI RSSI values in the first test.

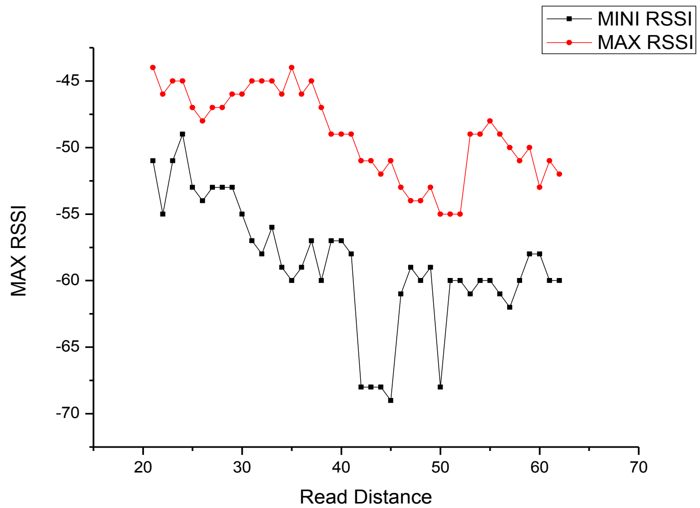

Figure 5.3: Curve of the RSSI for the first test

This graph combines the two curves of reading distances with MAX and MINI RSSI values in the first test.

In the second and the third test, RSSI values were taken for every 5cm along the 40cm pathway. At each point, the RSSI values were only recorded when the reader temperature is within a temperature range of (55℃ to 62℃). We found that the values of RSSI decreasing as the tag is getting further away from the reader (which is the required relationship) and the curves were showing a linear relationship.

In the second test, the reader was repositioned in a way that the tag will be at its right side. We found that the signal disappeared at 30 cm distance of the primary path.

Table 5.2: The second test took the reading at a distance of 30 cm with temperature at constant

Read Distance	MAX RSSI	MINI RSSI
11	-49	-57
16	-51	-57
21	-53	-57
26	-55	-62
31	-57	-66
36	-58	-66
41	-64	-71

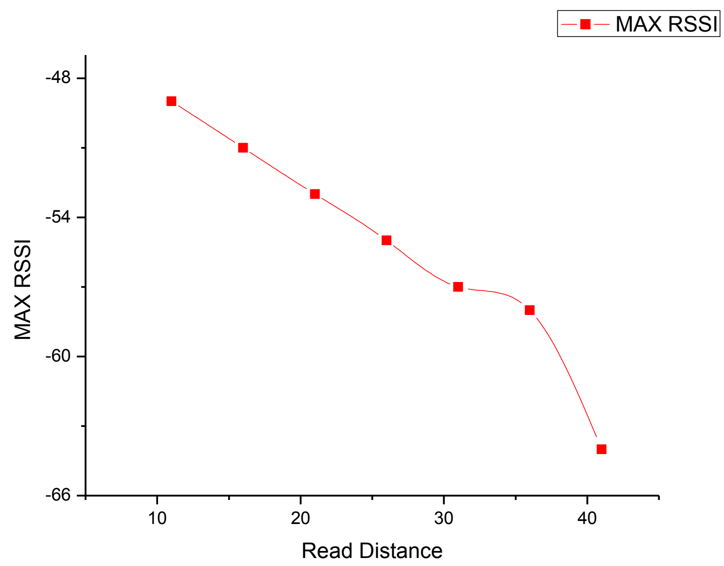

Figure 5.4: Curve of the MAX RSSI for the second test

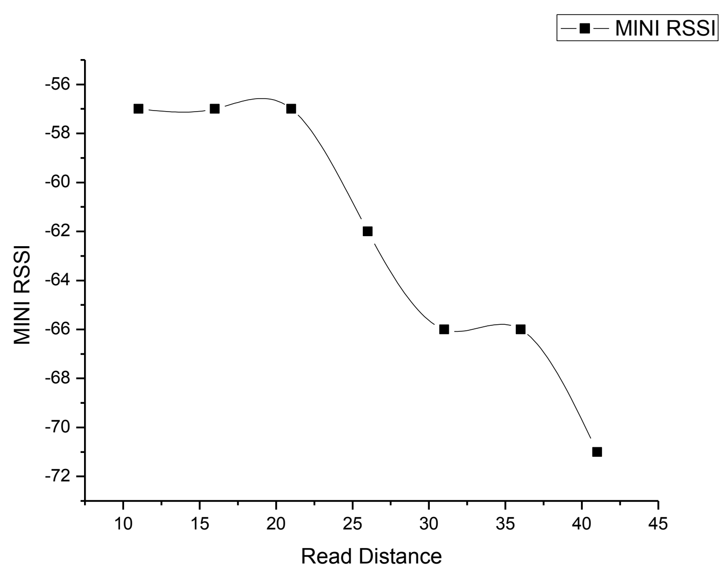

Figure 5.5 : Curve of the MINI RSSI for the second test

The curve of reading distances with MAX and MINI RSSI values in the second test-

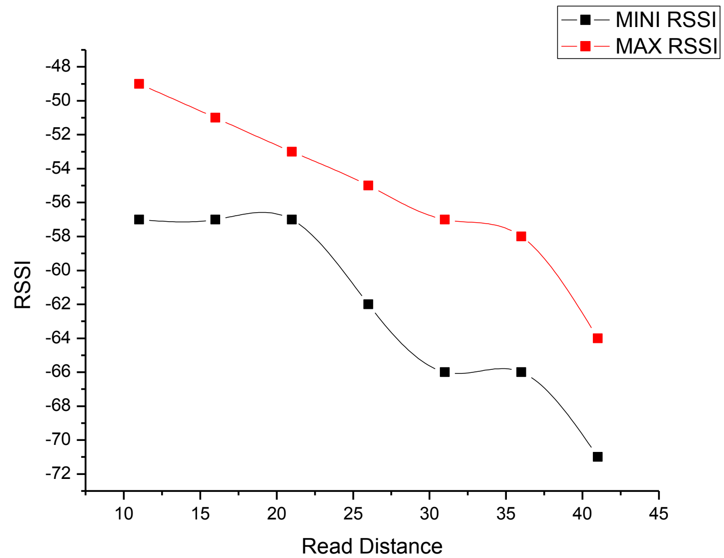

Figure 5.6: Curve of the RSSI for the second test

This graph combines the two curves of reading distances with MAX and MINI RSSI values in the second test

In the third test, the reader was repositioned so that the tag will be at its left side. We found that the readings were available through the whole pathway.

Table 5.3: The third test took the readings at a distance of 30 cm with change direction of the reader and the temperature is constant

Read Distance	MAX RSSI	MINI RSSI
11	-43	-45
16	-45	-50
21	-49	-55
26	-50	-57
31	-51	-57
36	-52	-58
41	-53	-59
46	-54	-62
51	-57	-65

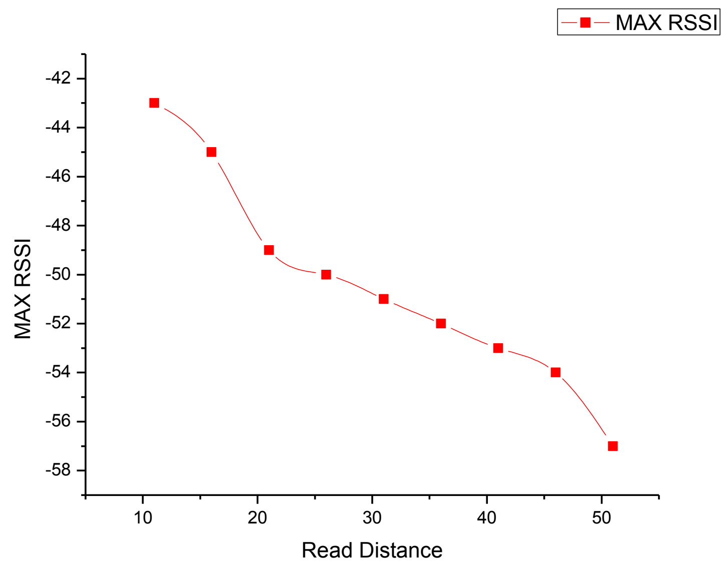

Figure 5.7: Curve of the MAX RSSI for the third test

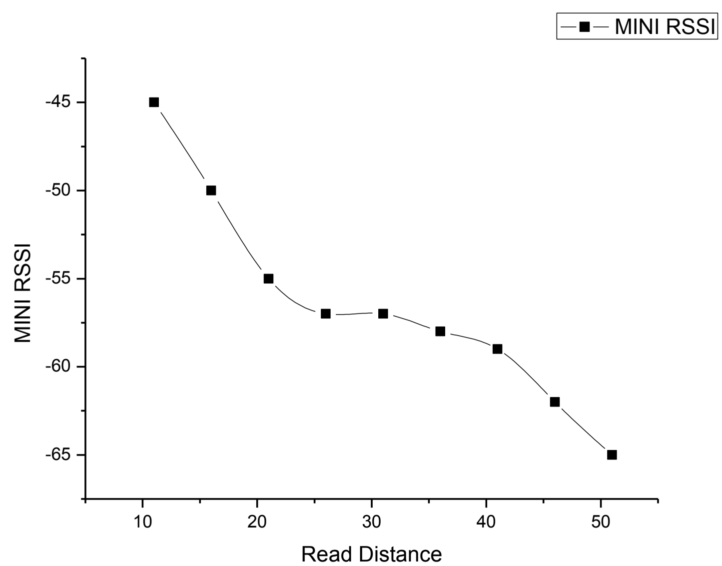

Figure 5.8: Curve of the MINI RSSI for the third test

The curve of reading distances with MAX and MINI RSSI values in the third test.

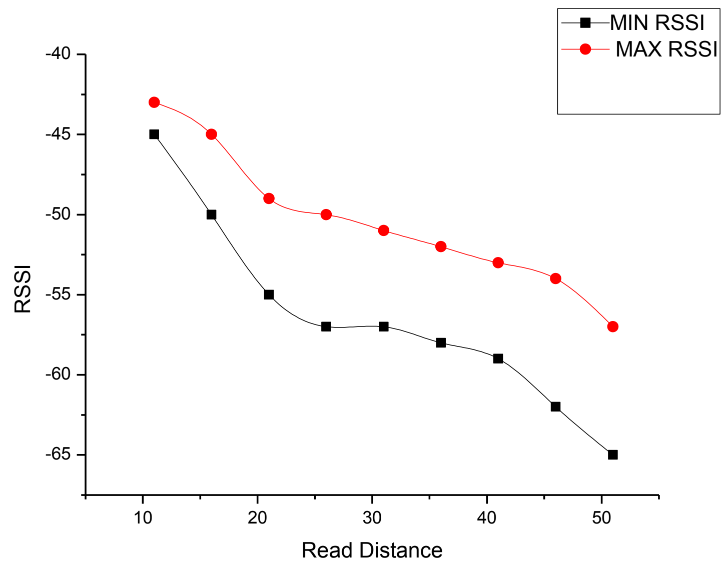

Figure 5.9 : Curve of the RSSI for the third test

The curve shows the two graphs together, the area between the two curves is the area where RSSI value is the same for specific distance range, for example, the RSSI level -50dBm can be found between 17 and 22 cm from the RFID reader.

Therefore, it appears that the location of the tag in relation to the reader has an effect on the signals strength that is initially originating from the reader and then echoed back by the activated tag. Referring to the vendor's product user manual, we found that the reader has its own internal linear antenna and the best tags' reading occurs when the tags are aligned with the long side of the reader.

In addition, we found that the rise in the reader internal temperature has an effect on the consistency of the RSSI readings in relation to the tag position from the reader. Again referring back to the same manual, it indicates that the internal temperature of the reader increases with time because that the plastic case, which keeps the reader in the standing position prevents heat dissipation and accordingly the reader will stop transmitting once its internal temperature reaches 85 degrees C. Then, when we started to perform our readings, we have restricted our work only when the internal temperature falls within the range of (55℃ to 62℃). After that, the RSSI readings in relation to the tag position from the reader began to be more stable.

Lately, the team has found the RSSI filter test that was conducted by Toni Heijari (Applying RSSI filters for optimal RFID performance). Heijari [17] considered in his test that the RSSI value as the independent variable and the record distance at which the RSSI value occurs is the dependent variable. This means that in his approach he looked at a certain RSSI value and recorded the closest tag-reader distance or the first distance at which that reading appears and considered it as the maximum RSSI value detected by the tag. Then the distance beyond which that specific RSSI value will disappear as the point at which minimum or weakest RSSI value detected by the tag.

His final reporting graph was more descriptive to the filter concept. Accordingly, the team decided to draw the RSSI graph in a similar way, however with whatever available data the team has collected before due to the project time limit. Therefore, the team looked at the repeated RSSI value in both the maximum and minimum recorded tables.

The repeated RSSI values will be the key role in determining the minimum and maximum RSSI value. For instance, the RSSI value of -57 was repeated three times at the following distances; 26, 31 and 51. Accordingly, 26 cm represent the closest distance the tag could detect the RSSI value, then it represents the maximum read RSSI value. Also, since 51 cm is the farthest distance at which this RSSI value is detected, then it will be considered as the minimum read RSSI value. The third value 31 cm falls in the middle, accordingly it lies within the RSSI filter. We need to keep in mind that the actual -57 RSSI value minimum or maximum could be further or closer than the reported ones.

According to the filtered data we have included, refer to the table below 5.4, only the repeated RSSI values in order to define the filter boarders. However, the result is not sufficient to draw the filter because the Mini for certain RSSI value happens to be the Max for other RSSI value. This means that the collected data are not located at filter limits or boarders, but inside it and accordingly it means that to draw the filter as per

Heijari's approach, the whole test procedure needs to be performed which cannot be done due the project time limit.

Table 5.4: Repeated RSSI values

RSSI	MINI Read Value	MAX Read Value
-45	11	16
-50	16	26
-57	26	51

5.2 Difficulties

During the conductance of the project's activities, the team has faced several challenges and tried their best to overcome them in order to complete the project on time. The following are some of the major ones:

-The antenna did not work as per the vendor promise. It did not extend the reader ability to read tags at 5meters distance from the reader. Due to the project time limitation, the team did not request a replacement and completed the required tests and activities with the reader internal antenna.

-The reader orientation and internal temperature have a great impact on its performance. At the beginning, the team found difficulties in obtaining uniform RSSI readings. However, with the help of the vendor product manual, the team managed to overcome this difficulty and complete the project activities.

CHAPTER VI

CONCLUSION AND FUTURE WORK

Chapter VI

Conclusion and Future Work

6.1 Conclusion

Despite the difficulties that the team faced during the project implementation, it is clear that RFID is a promising technology for use in monitoring and controlling Hajj crowds . However, RFID technology needs to be supplemented with other planned activities in order to accomplish the required goal. Some of these additional initiatives may include pathway reconstruction and planning, material selection, and programming capabilities. Finally, further research on a large scale needs to be carried out to understand the application's complexities and introduce measures to resolve them.

6.2 Future work

The team believes that the project concept and outcomes are promising and feasible for application during Hajj seasons. However, additional work and research must be performed in order to make the work more feasible.

- The team research was done on a single RFID reader. Future research needs to consider the use of multiple RFID readers in order to study the readers and tag signals' interfaces and develop any required software filters to reduce the impact of interference or false data on system performance. The team suggests the use of a network server-based system to study the large-scale implementation of such a concept.

- Field studies need to be done in the Mashaer area in order to search for the presence of materials that could obstruct RFID signals or cause RFID signal interfaces.

- Pilgrims' roads reconstruction in Mashaer needs to be studied, considering the variations in terrain, elevation, and size. Pathway construction may consider the suggested arrangement outlined in this report or consider multi-level emergency routes in narrower pathways locations.

- A water spray system might be added to the concept, with system activation to occur when the gates open at certain ambient temperatures and humidity levels in order to protect people from heat exhaustion due to the combination of climate and crowd stagnation.

- Material selection for readers, antennas, controllers and auxiliary devices should be based on best industrial practices in order to ensure their reliability, operability, and consistency of performance during the intense, harsh environmental conditions during Hajj seasons.

- Programmers need to ensure that the identification of congested locations does not depend mainly on the number of tags available at certain locations based on pathway capacity. Unauthorized pilgrims will not wear the wristband tags and will share the roads with authorized pilgrims. As a correction factor, programmers need to account for that in their calculation by adding a percentage of unauthorized pilgrims' presence on the pathways, based on previous years' findings and calculations.

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Appendix A – Visual Basic scripts

A.1 Application script

```
Dim clearTxt As Boolean 'false
Dim FirstRun As Boolean
Dim Mute As Boolean


Private Sub CloseFlashTimer_Timer()

    If CMD4.BackColor = &H0& Then
        CMD4.BackColor = &H40&
    Else
        CMD4.BackColor = &H0&
    End If

End Sub

Private Sub ClosingWaitTimer_Timer()
    'On Error Resume Next


    Dim strTriger As String

    strTriger = "5"

    ComPort1.Output = strTriger
    DoEvents()

    strTriger = "3"

    ComPort1.Output = strTriger
    DoEvents()

    MC_State.Caption = "Disconnected"
    MC_State.ForeColor = &H808080
    CloseFlashTimer.Enabled = False
```

```
    CMD4.Caption = "Close Side Paths"
    CMD4.BackColor = &H0&
    CMD1.Enabled = True

    CMD2.Enabled = True ' exit

    ClosingWaitTimer.Enabled = False
End Sub

Private Sub CMD1_Click()

    'On Error GoTo myErr

    If CMD1.Caption = "Start" Then
        If ComPort1.PortOpen = True Then
ComPort1.PortOpen = False

        FirstRun = False
        ComPort1.CommPort = "4"
        ComPort1.PortOpen = True
        Sock.Connect("127.0.0.1", "9055")
        CMD1.Caption = "Stop"
        CMD1.BackColor = &H404080

        SoundPic.Picture = UnmutePic.Picture

        CloseFlashTimer.Enabled = False
        MC_State.Caption = "Connected"
        MC_State.ForeColor = vbGreen
        ClosingWaitTimer.Enabled = False

        LEDTimer.Enabled = True
        CMD4.Enabled = False
    Else

        SoundPic.Picture = MutePic.Picture
```

```
        LEDTimer.Enabled = False
        LED.Visible = False

        CMD1.Caption = "Start"
        CMD1.BackColor = &H404040
        Sock.Close()
        'ComPort1.PortOpen = False
        MC_State.Caption = "Disconnected"
        MC_State.ForeColor = &H808080
        CMD4.Enabled = True
        Tag_Count.Caption = "0"
        'CloseFlashTimer.Enabled = True

        URA_State.Caption = "Disconnected"
        URA_State.ForeColor = &H808080
        MC_State.Caption = "Disconnected"
        MC_State.ForeColor = &H808080

        RFID_lst.Clear()
        FRFID_lst.Clear()

    End If


    Exit Sub

myErr:
    If Err.Number = "8002" Then
        MsgBox("Please Connect MC on COM 4 ",
vbCritical)
    ElseIf Err.Number = "34" Then
        MsgBox("Please Start URA with TCP Port = 9055
", vbInformation)
    End If


End Sub
```

```
Private Sub CMD2_Click()
    End
End Sub

Private Sub CMD3_Click()
    Me.WindowState = 1
End Sub

Private Sub CMD4_Click()


    WarnPic.Visible = True
    WarnPic.Left = 269
    WarnPic.Top = 3000

    PassTxt.SetFocus()
    WarnTimer.Enabled = True

End Sub




Private Sub Form_Load()
    clearTxt = False
    Me.Width = 14820
    Mute = False
    FirstRun = False
End Sub


Private Sub Label3_Click()
    WarnPic.Visible = False
```

```
End Sub

Private Sub LEDTimer_Timer()
    If LED.Visible = False Then
        LED.Visible = True
    Else
        LED.Visible = False
    End If

End Sub

Private Sub PassTxt_KeyDown(KeyCode As Integer, Shift
As Integer)
    If KeyCode = 13 Then
        If PassTxt.Text = "topsecret" Then

            CMD2.Enabled = False

            CMD4.Caption = "Please Wait . ."
            CloseFlashTimer.Enabled = True

            Dim strTriger As String
            strTriger = "2"


            ComPort1.Output = strTriger
            DoEvents()
            ClosingWaitTimer.Enabled = True

            MC_State.Caption = "Connected"
            MC_State.ForeColor = vbGreen

            CMD4.Enabled = False
            CMD1.Enabled = False
            WarnTimer.Enabled = False
            WarnPic.Visible = False
            PassTxt.Text = ""

        Else
```

```
            PassTxt.Text = ""
            PassTxt.SetFocus()
        End If
    End If
End Sub

Private Sub Sock_Connect()
    URA_State.Caption = "Connected"
    URA_State.ForeColor = vbGreen
End Sub

Private Sub Sock_DataArrival(ByVal bytesTotal As Long)


    FRFID_lst.Clear()
    Dim strData As String

    TimerClear.Enabled = True

    Sock.GetData(strData, vbString)


    Text1.Text = strData

    AddUnique(Text1.Text, RFID_lst)

    FRFID_lst.AddItem Trim(strData)


    Tag_Count.Caption = RFID_lst.ListCount - 1
    If Tag_Count.Caption < 0 Then Tag_Count.Caption = 0


    If clearTxt = False Then
        clearTxt = True
        FRFID_lst.Clear()
        RFID_lst.Clear()
    End If
```

```
End Sub

Private Sub AddUnique(StringToAdd As String, lst As
ListBox)
    lst.Text = StringToAdd
    If lst.ListIndex = -1 Then
        lst.AddItem StringToAdd
    End If
End Sub

Private Sub SoundPic_Click()

    Dim strTriger As String
    If ComPort1.PortOpen = True And CMD1.Caption =
"Stop" Then

        If Mute = False Then
            SoundPic.Picture = MutePic.Picture
            strTriger = "5"
            ComPort1.Output = strTriger
            DoEvents()
            Mute = True
        Else
            SoundPic.Picture = UnmutePic.Picture
            Mute = False
            strTriger = "6"
            ComPort1.Output = strTriger
            DoEvents()
        End If


    End If

End Sub

Private Sub Tag_Count_Change()

    If Tag_Count.Caption < 1 Then
```

```
        Tag_Count.ForeColor = &H808080
    Else
        Tag_Count.ForeColor = vbGreen
    End If



    If Tag_Count.Caption > 5 And FirstRun = False Then
        FirstRun = True
        TriggerTimer.Enabled = True

    ElseIf Tag_Count.Caption < 5 Then

        TriggerTimer.Enabled = False

    End If


End Sub

Private Sub Timer1_Timer()

    'Tag_Count.Caption = RFID_lst.ListCount - 1

    'RFID_lst.Clear

End Sub

Private Sub Timer2_Timer()
    Image1.Picture = Image3.Picture
    Timer2.Enabled = False

End Sub

Private Sub Timer3_Timer()

End Sub

Private Sub TimerClear_Timer()
```

```
    RFID_lst.Clear()
    FRFID_lst.Clear()
    TimerClear.Enabled = False

End Sub
Private Sub Send2Arduino()

    'On Error Resume Next
    Dim strTriger As String
    strTriger = "1"
    ComPort1.Output = strTriger
    DoEvents()

    'ComPort.PortOpen = False
    TriggerTimer.Enabled = False

End Sub
Private Sub TriggerTimer_Timer()
    Send2Arduino()
End Sub



Private Sub WarnTimer_Timer()
    If WarnPic.Picture = WarnPic1.Picture Then
        WarnPic.Picture = WarnPic2.Picture
    Else
        WarnPic.Picture = WarnPic1.Picture
    End If
End Sub
```

Appendix B – MC code

```
int actuatorOnPlus = 2;
int actuatorOnMinus = 3;

int actuatorOffPlus = 4;
int actuatorOffMinus = 5;


boolean stateOn = false;
boolean mute = false;


int alarm = 6;
int led = 7;

int serialMsg;

 void setup        }()

  pinMode(actuatorOnPlus, OUTPUT)   ;
  pinMode(actuatorOnMinus, OUTPUT);
  pinMode(actuatorOffPlus, OUTPUT)   ;
  pinMode(actuatorOffMinus, OUTPUT);
```

```
 pinMode(alarm, OUTPUT)   ؛
 pinMode(led, OUTPUT)   ؛

  Serial.begin)9600؛(
 stateOn==false؛
{


void loop}()





 if (Serial.available()> 0)}
 serialMsg = Serial.read؛()

  if (serialMsg=='5')}
 mute=false؛

{
  else if (serialMsg=='6')}
 mute=true؛

{
```

```
 if (mute==true)}
 digitalWrite(alarm, LOW) ؛
{ else}
digitalWrite(alarm, HIGH)؛
{

 if (serialMsg=='1')}

digitalWrite(actuatorOnPlus, LOW)  ؛
digitalWrite(actuatorOnMinus, LOW) ؛
// delay)5000؛(
// digitalWrite(actuatorOnPlus, HIGH)  ؛
// digitalWrite(actuatorOnMinus, HIGH) ؛

digitalWrite(actuatorOffPlus, HIGH)  ؛
digitalWrite(actuatorOffMinus, HIGH) ؛

digitalWrite(led, LOW)   ؛
digitalWrite(alarm, LOW)  ؛


//stateOn=true؛
```

```
{
 else if (serialMsg=='2')}

 digitalWrite(actuatorOnPlus, HIGH)  ؛
 digitalWrite(actuatorOnMinus, HIGH)؛


 digitalWrite(actuatorOffPlus, LOW)  ؛
 digitalWrite(actuatorOffMinus, LOW)؛

 digitalWrite(led, HIGH)   ؛
 digitalWrite(alarm, HIGH)  ؛
//stateOff=true؛
{

 else if (serialMsg=='3')}

 digitalWrite(actuatorOnPlus, HIGH)  ؛
 digitalWrite(actuatorOnMinus, HIGH)؛

 digitalWrite(actuatorOffPlus, HIGH)  ؛
 digitalWrite(actuatorOffMinus, HIGH)؛

 digitalWrite(led, HIGH)   ؛
 digitalWrite(alarm, HIGH)  ؛
```

```
{
 {

 if (stateOn==false)}
 stateOn=true؛
 digitalWrite(actuatorOnPlus, HIGH)  ؛
digitalWrite(actuatorOnMinus, HIGH)؛

digitalWrite(actuatorOffPlus, HIGH)  ؛
digitalWrite(actuatorOffMinus, HIGH)؛
// Serial.println('Done!')؛

digitalWrite(led, HIGH)  ؛
digitalWrite(alarm, HIGH)؛

   {
{
```