Lahden ammattikorkeakoulu
Lahti University of Applied Sciences

Automated Monitoring System

Designing a Laboratory Equipment Tracking System

LAHTI UNIVERSITY OF APPLIED SCIENCES
Faculty of Technology
Degree Programme in Information Technology
Telecommunications Technology
Thesis
Spring 2016
Samrand Elyasizadeh

Lahti University of Applied Sciences
Degree Programme in Information Technology

ELYASIZADEH, SAMRAND:

Automated Monitoring System
Designing a Laboratory Equipment Tracking System

Bachelor's Thesis in Telecommunications Technology, 45 pages

Spring 2016

ABSTRACT

Many organizations aim to finding an effective method for an automated, accurate and reliable system for monitoring and tracking items. In places where there are lots of items accessed by many users, loss rate it often high due to weakness in items monitoring.

This thesis focuses on improving the laboratory equipment monitoring system of Lahti University of Applied Sciences (LUAS). The conventional method of checking items for every laboratory session is based on manual monitoring, which leads to a challenge for the lab administrator to monitor the flow of the items.

The objective of this thesis was to provide a design to replace this old-fashioned manual system with a system that is based on new technologies. The main task of the designed system is to automatically identify personnel, students, and laboratory equipment for every loan of equipment in a laboratory session. To present a systematic and practical design for automated monitoring, a solution has been provided, using Radio Frequency Identification (RFID) technology. Therefore, an RFID-based monitoring system was designed and developed to solve the problem associated with the handling of laboratory equipment.

RFID is a wireless Auto-ID technology that has received considerable worldwide attention. It is widely used in monitoring and tracking systems, ranging from human identification to product identification. In the designed solution, any important object is equipped with RFID tags. The RFID reader is located at each laboratory to record and verify the RFID tags in the area. The system enables the university to give permission to selected individuals to access locations, permit movement of items, record the important data and also enable the viewing of records online.

Key Words: monitoring, tracking, RFID, laboratory equipment

Lahden ammattikorkeakoulu
Tietotekniikan koulutusohjelma

Elyasizadeh, Samrand:

Automatisoitu seurantajärjestelmä
Laiteseuranta-järjestelmän suunnittelu laboratorioon

Tietoliikennetekniikan opinnäytetyö, 45 sivua

Kevät 2016

TIIVISTELMÄ

Monet organisaatiot pyrkivät löytämään tehokkaan menetelmän seurata esineiden kulkua tarkalla ja luotettavalla automatisoidulla seurantajärjestelmällä. Heikosta seurannasta johtuen tavaroiden hävikki on usein suuri etenkin paikoissa, joissa tavaroihin pääsevät käsiksi useat ihmiset.

Opinnäytetyössä keskitytään parantamaan Lahden ammattikorkeakoulun laboratoriolaitteiden seurantajärjestelmää. Koulun laboratoriossa esineiden valvonta hoidetaan edelleen manuaalisesti, mikä aiheuttaa ylläpitäjälle haasteita seurata esineiden kulkua.

Työn tavoitteena oli suunnitella uuteen teknologiaan perustuva järjestelmä korvamaan koulun vanhanaikainen manuaalinen järjestelmä. Suunnitelman päätehtävänä on tunnistaa automaattisesti henkilökunta ja opiskelijat sekä laboratoriolaitteet lainausprosessissa. Ratkaisuna tässä suunnitelmassa on käytetty radiotaajuista etätunnistustekniikkaa (Radio Frequency IDentification). RFID-pohjainen valvontajärjestelmä on suunniteltu ja kehitetty ratkaisemaan laboratoriovälineistön käsittelyyn liittyviä ongelmia.

Radiotaajuinen etätunnistus on langaton Auto-ID-tekniikka, joka on saanut merkittävää maailmanlaajuista huomiota. Sitä on käytetty laajalti valvonta- ja seurantajärjestelmissä, jotka tunnistavat automaattisesti ihmiset sekä välineet. Suunnitelmassa jokainen tärkeä kohde on varustettu RFID-tunnisteella. RFID-lukija on sijoitettu kuhunkin laboratorioon tallentamaan ja tarkistamaan RFID-tunnisteita. Järjestelmän avulla koulu voi antaa luvan määrätyille henkilöille päästä tiettyihin paikkoihin, sallia esineiden liikkuvuus, tallentaa tärkeitä tietoja ja katsella tallennettuja tietoja verkossa.

Asiasanat: valvonta, seuranta, radiotaajuinen etätunnistus, laboratoriolaitteet

CONTENTS

1 INTRODUCTION

The purpose of the thesis is to design an automated laboratory equipment tracking system for Lahti University of Applied Sciences. The thesis presents a systematic and practical design for automated tracking of laboratory equipment. The main idea and concept can be used in other similar cases.

Lahti University of Applied Sciences (LUAS) is an international multidisciplinary higher education institution located in the city of Lahti. The fields of study include culture, design, business, social and health care, technology, and tourism. It has currently around 5,000 students studying towards a Bachelor’s or a Master’s Degree. (LUAS 2016.)

The conventional manual approach of keeping track of items is a time-consuming and inaccurate process, as most laboratories are being used by more than 20 students per session. This old-fashioned system is a very annoying task, and it is challenging for the lab administrator to monitor the flow of these items. This system was found inefficient in tracking, and has a lot of weaknesses such as misuse of the equipment log records, loss of equipment, absence of an in-out transaction record and misplacing of equipment.

This thesis focuses on finding and describing a new solution for this old problem. This solution is to be easy to use, reliable and effective.

2 AUTOMATIC ID SYSTEMS AND RFID

The main objective of the project is to find a solution for automatically identifying items and gathering data on them without human intervention or data entry. Automatically identifying of items requires one or several of Automatic Identification and Data Capture (AIDC) technologies. These technologies, such as RFID, barcode, magnetic inks, optical character recognition, voice recognition, touch memory, smart cards, biometrics, etc. represent a broad category of technologies that are used to help machines identify objects, humans, or animals (Pandian 2010, 3).

In the present system the tracking of laboratory equipment is performed manually by the lab administrator during each laboratory session. This operation, which is open to mistakes and uncontrolled operation, wastes time of the lab administrator on each laboratory session. This manual and paper-based process without any systematic control cannot be improved and must be changed totally to fulfill new requirements.

2.1 Comparing barcode and RFID

Until two decades ago, the human eye served the primary mechanism for discriminating between objects of different types. However, with the introduction of barcode technology, for the first time, machines could identify objects. (Wyld 2005, 9.)

Ever since barcode technology became the dominant standard in the last century, there have been limitation and difficulty to its use, such as keeping accurate inventory, in-out transaction records and line-of-sight, i.e. barcode scanner has to see the barcode in a short distance to read it. Radio frequency identification (RFID), which uses radio waves helps overcome some of the drawbacks associated with barcode technology, such as line-of-sight. The information on the RFID microchip can be read automatically, at a distance, by a wireless device called RFID reader. It makes RFID easier to use and more efficient than barcodes. (Pandian

2010, 3-6.) The specific differences between barcode technology and RFID are summarized in Table 1.

TABLE 1. RFID and Bar Codes Compared (Wyld 2006)

Bar Code	RFID
Bar Codes require line of sight to be read	RFID tags can be read or updated without line of sight
Bar Codes can only be read individually	Multiple RFID tags can be read simultaneously
Bar Codes cannot be read if they become dirty or damaged	RFID tags are able to cope with harsh and dirty environments
Bar Codes must be visible to be logged	RFID tags are ultra-thin and can be printed on a label, and they can be read even when concealed within an item
Bar Codes can only identify the type of item	RFID tags can identify a specific item
Bar Code information cannot be updated	Electronic information can be over-written repeatedly on RFID tags
Bar Codes must be manually tracked for item identification, making human error an issue	RFID tags can be automatically tracked, eliminating human error

The RFID system's concept is simple: place a tag on an item and then read data off of the tag's chip by a reader using radio waves. The reader passes the information to a computer, so data can be analyzed. (Violino 2005b.) An RFID-based system builds a wireless bridge between the physical world of an item and the virtual world of digital data.

2.2 Problem statement of the traditional tracking system

Currently, the tracking of laboratory equipment is performed manually by the lab administrator during each laboratory session. Table 2 illustrates a comparison of the service procedure of traditional tracking of laboratory equipment and expected advantages of using RFID in the tracking system.

TABLE 2. Problem statement and expected advantages of using RFID

Problems of manually tracking system	Expected advantages of using RFID in tracking system
No in-out transaction record	Information checking automatically.
Prone to human error	Eliminating manual data entry.
Misplacing of equipment	Tracking and tracing items
Preventing counterfeits	Increasing security and reducing theft
Manual data entry	Improved inventory management
Inefficient data collection	Comprehensive total item visibility
No real time information	Reducing labor in asset management
Misuse of the equipment log records	Improved check-in/check-out
Loss of equipment	Reducing inventory time

By considering all aspects of the project and the future of technology, to automate the present system, investing in barcode is not suitable for this case, and the advantage of RFID is clear. RFID is identified as a practical and applicable system.

3 OVERVIEW OF RFID TECHNOLOGY

RFID is a wireless Auto-ID technology that uses radio frequencies to identify, track, and trace an object or product. In the recent years RFID technology has gained a lot of interest and publicity, especially after Wal-Mart and the U.S. Department of Defense in an effort to cut logistical costs mandated their suppliers to use RFID tags (Roberti 2004 ; Roberti 2005).

RFID refers to a tag containing a chip and an integrated antenna for sending and receiving data, an interrogator, also called reader, and its antennas to communicate with the tag. An RFID system also contains a middleware software that manages, filters, aggregates and routes the data captured. All these elements are essential to constitute a ‘basic’ RFID system. (Pandian 2010, 5-6.) RFID systems can be grouped into four categories (AIM 2001):

- **EAS (Electronic Article Surveillance) systems:** These systems are typically used to sense the presence or absence of an item. The large use for this system is in retail stores where each item is tagged and large antenna readers are placed at each exit of the store to detect unauthorized removal of the item.
- **Portable Data Capture systems:** These systems are using hand-held readers or portable data terminals with an integral antenna, which enables this system to be used in variable settings.
- **Networked systems:** These systems can be generally characterized by fixed position readers which are connected directly to a centralized networked information management system. The tags are attached on people or moving/moveable items, depending upon application.
- **Positioning systems:** These systems are used for automated location identification of tagged items or vehicles.

3.1 Brief history of RFID

It is difficult to trace RFID's true history because most research has been done behind closed doors for military purposes (Reyes 2011, 11-12). RFID uses electromagnetic energy, which was discovered in the 19th century, by pioneers such as Michael Faraday, James Clerk Maxwell and Guglielmo Marconi (Wyld 2005, 9). Radar was invented in 1922, and its practical applications date back to World War II, when British planes were equipped with radio frequency transmitters to identify them as friendly aircraft to British forces on the ground (Wyld 2005, 9 ; Reyes 2011, 11).

Before RFID technology could be used in asset management, livestock tracking, transportation, and even payments, it took decades of development in a variety of different fields, such as computers, radar and radio technology, supply chain management, transportation, quality management, and engineering (Wyld 2005, 10). The development of radio frequency identification can be divided into 10-year periods as follows (Table 3):

TABLE 3. Summary of RFID history (adapted from Landt 2005)

Decades	Event
1940s	• Major WW II development efforts • RFID invented in 1948
1950s	• Early exploration of RFID technology • Long-range transponder systems for "ID of friend & foe" (IFF) for aircraft
1960s	• The first RFID companies Sensormatic & Checkpoint are founded • First commercial application Electronic Article Surveillance (EAS) is released to counter theft
1970s	• Very early adopters • RCA & Fairchild publish "Electronic ID System" • NY & NJ Port Authority test electronic toll applications
1980	• Commercial applications for RFID enter the mainstream • Applications emerge in transport, industrial, personnel access and animal tagging • Toll roads world-wide are equipped with RFID
1990	• Emergence of initial RF open standards • RFID widely deployed in toll collection, animal tagging and personal identification • MIT founds the Auto-ID Center
2000+	• First CPG / Retailer auto-ID pilots launched • Gillette buys 500 million tags from Alien Tech. • Wal-Mart, Tesco & The US Department of Defense announce supplier mandates • Cost of RFID continues to fall • Private authentication develops as key concern in library implementation

3.2 RFID today

Nowadays RFID can be found everywhere and it has been getting more attention for these reasons (Michael 2007, 2):

- Prices of RFID chips have dropped dramatically.
- Integrated Circuit (IC) technologies have advanced in terms of speed and size.

RFID does not provide much value on its own; just as Internet it is an enabling technology, which enables companies to develop applications that create value. The most common RFID applications are asset tracking, manufacturing, supply chain management, retailing, payment systems, security and access control, e-passport and library systems. (Violino 2005a.)

RFID systems can be used to monitor objects in real-time, which allows for mapping the real world into the virtual world. Therefore, they can be used in a wide range of application scenarios (Atzori, Iera & Morabito 2010). In recent years, precise localization of an object with attached RFID tag is required for many future applications like the internet of things, augmented reality or distributed sensor networks (Carlowitz, Strobel, Schäfer, Ellinger & Vossiek 2012).

3.3 Overview of RFID in Internet of Things

At the first spread of the internet, users typically had to sit in front of a computing device (usually a PC) and dial up to the internet over their telephone connection. Today users can connect from almost any location at any time, through always-on connectivity (wired and wireless broadband). The next step of internet is to connect inanimate objects and things to each other and to communication networks. (ITU 2005, 3-4.)

The Internet of things (IoT) is a conceptual vision and an upcoming topic as things get smarter and are able to connect themselves with each other to create a ubiquitous computing world using enabling technologies like

RFID and sensors (ITU 2005, 27). Things with attached RFID tags and wireless sensors that are connected with the IT infrastructure systems can be identified automatically.

IoT is the extension of the internet and it will take the world into a new era (ITU 2005, 5). The Internet of Things requires various technical components to enable communication between devices and objects including (Forrester Research 2012, 3):

1. fixed or wireless network infrastructure
2. sensors, RFID endpoint devices, and external hardware
3. software and middleware applications and services
4. systems integration, engineering, and professional service organizations

RFID as an enabling mature technology provides capability to collect raw data about things, their location and status, which are necessary for IoT technology (ITU 2005, 9). RFID tags are cheap to manufacture nowadays, and tags are already being used in many fields, such as logistics, tolling, manufacturing, etc., so RFID is a proven concept and has the potential to be used for IoT.

4 THE TECHNOLOGY BEHIND RFID SYSTEMS

RFID system consists of a transceiver (reader) device and a number of transponders (tags) attached to the objects to be identified. An RFID tag is a small microchip attached to an antenna and it includes a memory, where the identification code and possible additional information of the object are stored. The antenna enables the chip to transmit identification information to a reader. A reader is a device with large memory and computing capability.

Typically, when a reader accesses the information stored on a tag attached to a product, it passes three things to a host computer system: the tag identification information, the reader's own information, and the time the tag was read. By knowing this information and the location of the reader, the product can be tracked.

There is a variety of RFID systems, which differ in terms of range, size, cost and underlying technology. RFID systems can be classified based on different characteristics, such as coupling, operation frequency, transponder powering and implementation. (Pursula 2009, 10.)

4.1 Transmission methods of an RFID system

In an RFID system, tags and readers communicate mostly through a coupling method. The typical coupling methods of the readers and tags can be based on (Pursula 2009, 10):

- Capacitive coupling (electric field)
- Inductive coupling (magnetic field)
- Electromagnetic coupling (radiation field).

Capacitive coupling (1 cm to 2 cm)

Capacitive coupling utilizes the electric field and it is used for contact to a few centimeters of read range as shown in Figure 1. The system uses the effect of electric current for coupling between the tag and the reader.

Because of small proximity, this type of coupling system is not used by many RFID systems on the market today. (Smiley 2016 ; Poole 2016a.)

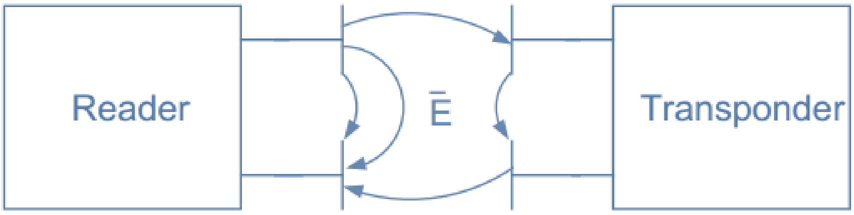

FIGURE 1. RFID capacitive coupling (Pursula 2009)

Inductive coupling (1 cm to 1 m)

Inductive coupling uses the magnetic field of a coil, which means that this coupling only occurs in the near-field as shown in Figure 2. The inductively coupling tags are usually operated passively and the distance between the coils of readers and tags must be kept within the range of the effect; normally this is about 0.15 wavelength of the frequency in use. (Pursula 2009, 10 ; Poole 2016a.)

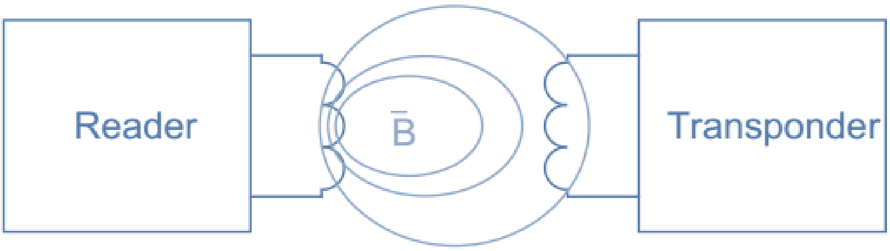

FIGURE 2. RFID inductive Coupling (Pursula 2009)

The operation frequencies of both the inductive and capacitive coupling systems vary from low frequencies band (125kHz-135kHz) to high frequencies band (3MHz-30Mhz). The 13.56MHz frequency band is globally reserved for inductive RFID. (Pursula 2009, 10)

Electromagnetic coupling (1 m to +4m)

RFID electromagnetic or backscatter coupling is based on wave propagation of both magnetic field and electric field as shown in Figure 3 (Pursula 2009, 10). Electromagnetically coupled systems operate at higher frequencies, usually from 400 MHz to 5 GHz. Most of the electromagnetically coupled systems operate at ultra-high frequencies band (860MHz-930MHz). Passive transponders do not have their own power supply, and therefore they are powered by the reader transmission. (Pursula 2009, 10 ; Poole 2016a.)

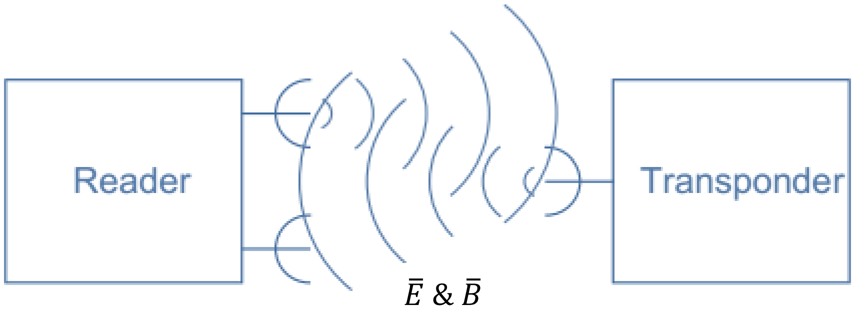

FIGURE 3. RFID electromagnetic coupling (Pursula 2009, 10)

The way that the tag circuit and reader circuit couple can determine the read range and frequency of the RFID system (Smiley 2016). Read ranges and coupling methods in different frequencies are shown in Figure 4.

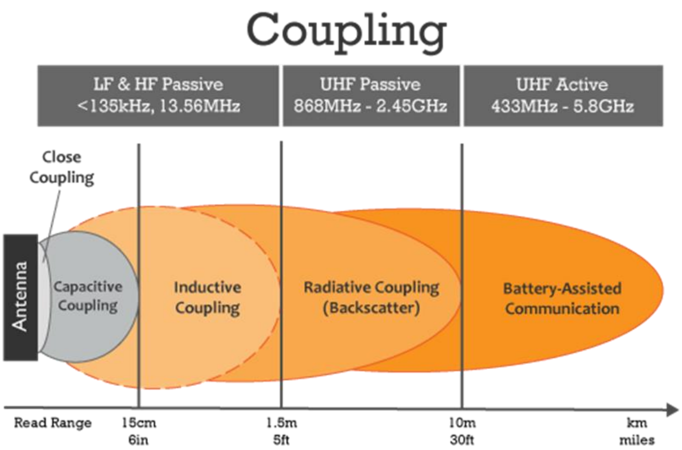

FIGURE 4. Read ranges of coupling methods (Smiley 2016)

Physical layer

An RFID system uses modulated radio waves to transmit an object's identity. The modulation suggested in RFID systems is Amplitude Shift Keying (ASK) for its simplicity. ASK modulation is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave (as seen in Figure 5). (Sheu, Tiao, Fan & Huang 2010.)

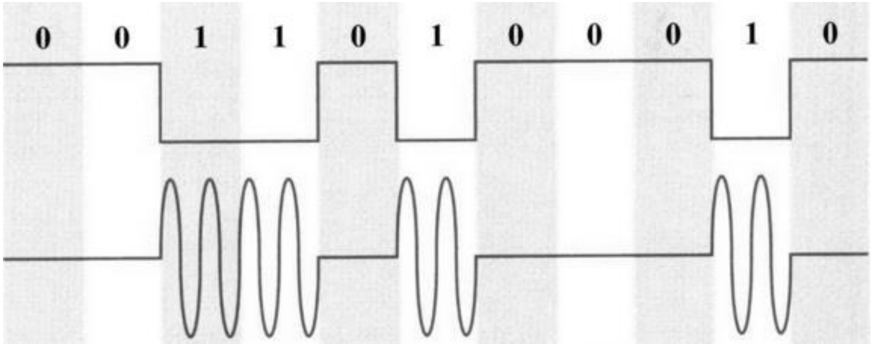

FIGURE 5. Two Amplitude levels (0&1) ASK modulation (Data Communications 2016)

In addition to radio regulations, the physical layer of RFID systems, including modulation, encoding etc., is standardized by ISO (International Standardization Organization) and EPCglobal. The standards are identical, and only differ in a few application identifiers in transponder memory mapping. These standards have become the most utilized in the field in recent years. (Pursula 2009, 16.)

UHF RFID air interface standard EPC Gen2 is summarized in Table 4. Regulations and standards are introduced in more detail in the following section.

TABLE 4. Physical layers of EPC Gen 2 air-interface standard for UHF RFID (EPCglobal Gen2 2015, 22-23)

Standard	**Reader to Tag (Downlink)**		**Tag to Reader (Uplink)**	
	Modulation	Encoding	Modulation	Encoding
EPC Gen2	PR-ASK DSB-ASK SSB-ASK	PIE	ASK PSK	FM0 MMS

A reader sends information to the tag by modulating an RF carrier using Double-SideBand Amplitude Shift Keying (DSB-ASK), Single-SideBand Amplitude Shift Keying (SSB-ASK), or Phase-Reversal Amplitude Shift Keying (PR-ASK) using a Pulse-Interval Encoding (PIE) format. The tag receives operating energy from this same modulated RF carrier. The tag sends information back to the reader using ASK and/or PSK modulation. Readers shall demodulate both modulation types. Tags shall encode the backscattered data as either FM0 baseband or Miller modulation of a subcarrier at the data rate. The reader specifies the encoding type. (EPCglobal Gen2 2015, 22-32.)

4.2 Regulations and standards of RFID

The purpose of standardization for any technology in industry is to help to make products interoperable. This increases competition and brings the prices of products down, so both vendors and customers benefit from standardization. (Pandian 2010, 12-13.)

RFID standards provide guidelines or specification for all RFID products and provide information about how and at which frequencies RFID systems operate. Standards also provide information about how data is transferred, and how communication works between the reader and the tags. (IMPINJ 2016b.)

The International Standards Organization (ISO) and EPCglobal are involved in preparing standards for RFID technology. The ISO is responsible for regulating air interfaces, data protocols, and applications. The EPCglobal is responsible for trade, allocating different products a unique code called EPC (Electronic Product Code), which is similar to barcode. (Pandian 2010, 14.). Some of the main RFID standards are summarized in Table 5.

TABLE 5. Some of the main RFID standards (Poole 2016c)

RFID STANDARD	DETAILS
ISO/IEC 10536	For close coupled cards
ISO/IEC 11784	Defines the way in which data is structured on an RFID tag.
ISO/IEC 11785	Defines the air interface protocol.
ISO/IEC 14443	Provides the definitions for air interface protocol for RFID tags used in proximity systems - aimed for use with payment systems
ISO/IEC 15459	Unique identifiers for transport units (used in supply chain management)
ISO/IEC 15693	For use with what are termed vicinity cards
ISO/IEC 15961	For Item Management (includes application interface (part 1), registration of RFID data constructs (part 2), and RFID data constructs (part 3).
ISO/IEC 15962	For item management - data encoding rules and logical memory functions.
ISO/IEC 16963	For item management - unique identifier of RF tag.
ISO/IEC 18000	For the air interface for RFID frequencies around the globe
ISO/IEC 18001	For item management - application requirements profiles.
ISO/IEC 18046	RFID tag and interrogator performance test methods.
ISO/IEC 18047	Defines the testing including conformance testing of RFID tags and readers. This is split into several parts that mirror the parts for ISO/IEC 18000.
ISO/IEC 24710	Information technology, automatic identification and data capture techniques - RFID for item management - Elementary tag license plate functionality for ISO/IEC 18000 air interface.
ISO/IEC 24729	RFID implementation guidelines - part 1: RFID enabled labels; part 2: recyclability of RF tags; part 3: RFID interrogator / antenna installation.
ISO/IEC 24730	RFID real time locating system: Part 1: Application Programming Interface (API); Part 2: 2.4 GHz; Part 3: 433 MHz; Part 4: Global Locating Systems
ISO/IEC 24752	System management protocol for automatic identification and data capture using RFID
ISO/IEC 24753	Air interface commands for battery assist and sensor functionality
ISO/IEC 24769	Real Time Locating System (RTLS) device conformance test methods
ISO/IEC 24770	Real Time Locating System (RTLS) device performance test methods

There are separate standards for active RFID, passive LF RFID, passive HF RFID, and passive UHF RFID and all have their own unique standards governing their associated products (IMPINJ 2016b). The following are the most popular RFID standards (Karygiannis, Eydt, Barber, Bunn & Phillips 2007):

- **ISO/IEC 14443** describes proximity smart cards that operate at 13.56 MHz in the range up to 10 cm. The standard contains four parts, which are physical characteristics, radio frequency power and signaling initialization and anti-collision and transmission protocols.

There are two variants for ISO/IEC 14443 known as ISO/IEC 14443A and ISO/IEC 14443B, which have different communications interfaces.

- **ISO/IEC 15693** describes vicinity smart cards which operate at 13.56 MHz in the range of up to 1 meter that can be read from a further distance than proximity cards. The standard has three main parts, which are physical characteristics, signal interfaces, and transmission protocols.

- **ISO/IEC 18000** standard is for item management and describes a series of diverse RFID technologies for various frequencies. ISO/IEC 18000 consists of the parts outlined in Table 6.

TABLE 6. ISO 18000 series standards (Poole 2016c)

ISO/IEC 18000 STANDARD	DETAILS OF THE PARTICULAR ISO 18000 SERIES STANDARD
ISO/IEC 18000-1	Generic parameters such architecture and definition of parameters for air interfaces for globally accepted frequencies
ISO/IEC 18000-2	Air interface for 135 KHz
ISO/IEC 18000-3	Air interface for 13.56 MHz
ISO/IEC 18000-4	Air interface for 2.45 GHz
ISO/IEC 18000-5	Air interface for 5.8 GHz
ISO/IEC 18000-6	Air interface for 860 MHz to 930 MHz
ISO/IEC 18000-7	Air interface at 433.92 MHz

Most of the recent interest in RFID has been concentrated on UHF passive systems, which is defined in EPCglobal UHF Gen 2 V1 and the updated version UHF Gen 2 V2 standard. UHF Gen 2 defines the communications protocol for a passive RFID system operating in the 860 MHz-960 MHz frequency range. The updated version of the standard, which is called UHF Gen 2 V2, or just G2, is based on the original V1 standard, but ensures that RFID communications have more powerful security options to protect data and prevent tag counterfeiting. (IMPINJ 2016b.)

4.3 RFID operating frequency

RFID systems currently operate in four main ranges of the frequency spectrum: Low Frequency (LF), High Frequency (HF), Ultra-High Frequency (UHF), and Microwave frequency range. The frequencies at which RFID systems operate affect the speed, range, and accuracy of the system’s operation. (Poole 2016b.) All RFID system components must be selected and configured according to the system’s operating frequency.

RFID systems use the frequencies classified worldwide as ISM frequency ranges (Industrial–Scientific–Medical). In addition to ISM frequencies, the entire frequency range below 135 kHz is also suitable for inductively coupled RFID systems. The most important frequency ranges for RFID systems are therefore 0–135 kHz, and the ISM frequencies around 6.78 MHz, 13.56 MHz, 27.125 MHz, 40.68 MHz, 433.92 MHz, 869.0 MHz, 915.0 MHz (not in Europe), 2.45 GHz, 5.8 GHz and 24.125 GHz. (Finkenzeller 2003, 161-162.) Some of RFID frequency band allocations are shown in Table 7.

TABLE 7. RFID frequency band /Spectrum allocation (Poole 2016b)

RFID FREQUENCY BAND	FREQUENCY BAND DESCRIPTION	TYPICAL RANGE	TYPICAL RFID APPLICATIONS
125-134.2 kHz & 140-148.5 kHz	LF	Up to ~ 1/2 meter	These frequencies can be used globally without a license. Often used for vehicle identification. Sometimes referred to as LowFID.
6.765 - 6.795 MHz	Medium frequency		Inductive coupling is used on these RFID frequencies.
13.553 - 13.567 MHz	HF Often called 13.56 MHz	Up to ~ 1 meter	These RFID frequencies are typically used for electronic ticketing, contactless payment, access control, garment tracking, etc.
26.957 - 27.283 MHz	Medium frequency	Up to ~ 1 meter	Inductive coupling only, and used for special applications.
433 MHz	UHF		These RFID frequencies are used with backscatter coupling, for applications such as remote car keys in Europe
858 - 930 MHz	UHF	1 to 10 meters	These RFID frequencies cannot be accessed globally. When they are used, it is often used for asset management, container tracking, baggage tracking, work in progress tracking, etc.
2.400 - 2.483 GHz	SHF		Backscatter coupling, but only available in USA / Canada
2.446 - 2.454GHz	SHF	3 meters upwards	These RFID frequencies are used for long range tracking and with active tags.
5.725 - 5.875 GHz	SHF		Backscatter coupling. Not widely used for RFID.

4.3.1 Low-Frequency RFID

Low-Frequency (LF) RFID systems are inductive, and typically operate between 125 kHz and 134 kHz. There are some LF applications that can operate on a larger bandwidth from 30 kHz to 300 kHz. (Smiley 2015.)

Low-Frequency bands provide a shorter read range and slower read speed. These systems have the strongest ability to read tags on objects with water or metal content, compared to any of the higher frequencies.

4.3.2 High-Frequency RFID

RFID systems at High-Frequency (HF) band ranges from 3 MHz to 30 MHz are inductive (similar to LF RFID). HF RFID systems feature a longer read range and higher-read speed than LF systems. (IMPINJ 2016c.)

Most of the HF RFID systems operate at 13.56 MHz with read ranges between 10 cm and 1 m. There are several standards concerning HF RFID systems, including the ISO 15693 standard for tracking items, and the ECMA-340 and ISO/IEC 18092 standards for Near Field Communication (NFC). (IMPINJ 2016c.)

4.3.3 Ultra-High Frequency RFID

The ultra-high frequency (UHF) band utilizes ranges from 300 MHz to 3 GHz. The UHF RFID systems complying with the UHF Gen2 standard operate at 860 to 960 MHz band. While there is some variance in UHF RFID frequencies from region to region, these frequencies cannot be used internationally. (IMPINJ 2016c.) The specific differences between the UHF RFID frequency band in different regions are summarized in Table 8.

TABLE 8. UHF RFID frequency band details (Poole 2016b)

COUNTRY	COMMENTS
North America	Here the UHF RFID band can be used unlicensed within the limits of 915 MHz ± 15MHz (i.e. 902 - 928 MHz). There are restrictions on transmission power.
Europe (less exclusions)	Within this region, the RFID frequencies (and other low-power radio applications) specified ETSI recommendations EN 300 220 and EN 302 208, and ERO recommendation 70 03. These allow RFID operation within the band 865-868 MHz, but with some involved restrictions. RFID readers must to monitor a channel before transmitting - "Listen Before Talk".
France	The North American standard is not accepted within France as it interferes with frequencies allocated to the military.
China & Japan	There are no license free RFID bands or frequencies. However it is possible to request a license for UHF RFID which is granted in a site basis.
Australia & New Zealand	Within this area the RFID band exists between 918-926 MHz as these frequencies are unlicensed, but there are restrictions on the transmission power.

The UHF RFID systems are radiative, and they feature longer read range and faster data transfer than LF or HF RFID systems, but they are more sensitive to interference. Table 9 summarizes the features of LF, HF and UHF frequency bands.

TABLE 9 A summary features of HF, LF and UHF frequency bands (Krieber 2010)

Frequency	LF 120 ~ 134 kHz	HF 13.56 MHz	UHF 850 ~ 960 MHz
Read Range	0.5 ~ 1 m	< 1 m	> 3 m
Cost	Relatively expensive	Less expensive	Least expensive
Penetration of Materials	Excellent <---→ Poor		
Affected by Water?	No	To some extent	Yes
Antenna	Coil	Coil	Dipole, Slot
Data Rate	Slower <--→ Faster		
Reading Multiple Tags	Poor	Good	Very good
Applications	Immobilisers, industrialidentification	"Pharma", libraries brand protection, tickets, payments, passports	Pallet/case tracking, tolls baggage tracking

4.3.4 Microwave RFID

Microwave RFID systems typically operate at the 2.45 GHz and 5.8 GHz bands, but there has also been some research at 24 GHz frequency bands (Finkenzeller 2003, 162 ; Pursula, Vähä-Heikkilä, Müller, Neculoiu, Konstantinidis, Oja & Tuovinen 2008). Microwave based RFID systems are the most expensive systems and have a limited read range of up to 1 m (3 ft.) (Hossain & Karmakar 2006).

Microwave RFID systems are usually used in real-time locating systems (RTLSs) for tracking the location of tags. The real-time locating systems usually require an active tag (a tag with battery). (Finkenzeller 2003, 313 ; Pursula et al 2008.)

4.3.5 Millimeter RFID or Millimetre Wave Identification

The Millimeter Wave Identification (MMID) has been theoretically studied and experimentally verified at 60 GHz. There are already applications where millimeter-wave radars are used, as in automotive radars. These radars could, in principle, be used as MMID reader devices that could communicate with the tags. (Pursula 2009 ; Pursula et al 2008.)

The basic operation and the main components of MMID system are similar to an RFID system. The main difference between the RFID and MMID systems is the wavelength (Pursula 2009). MMID has several advantages (Pursula et al 2008):

- High data-rate communications with even gigabit data rates (at millimeter waves, e.g., 60 GHz) to a distance of a few cm, which could be used in wireless passive mass memories.
- MMID reader device with a small directive (narrow-beamed) antenna, which would provide the possibility of selecting a transponder by pointing toward it, which helps in locating tags in high-density sensor networks or other places where transponders are densely located, e.g., in item level tagging.
- Automotive radars could, in principle, be used as MMID reader devices that could communicate with the transponders.

4.4 RFID system components

Discussion on RFID technology tends to focus mainly on tags, but a complete RFID system includes not only tags, but there are also other important components. The basic components of an RFID system are:

- A tag has unique ID and is attached to objects in RFID systems.
- An antenna is used for reading tags.
- A reader handles antenna signals and the tag's information.
- Application software enables the user to see RFID information; this can be database, application routines or user interface.

The RFID system works effectively if all components are logically connected together, and they are compatible with each other. Typical RFID system components are illustrated in Figure 6.

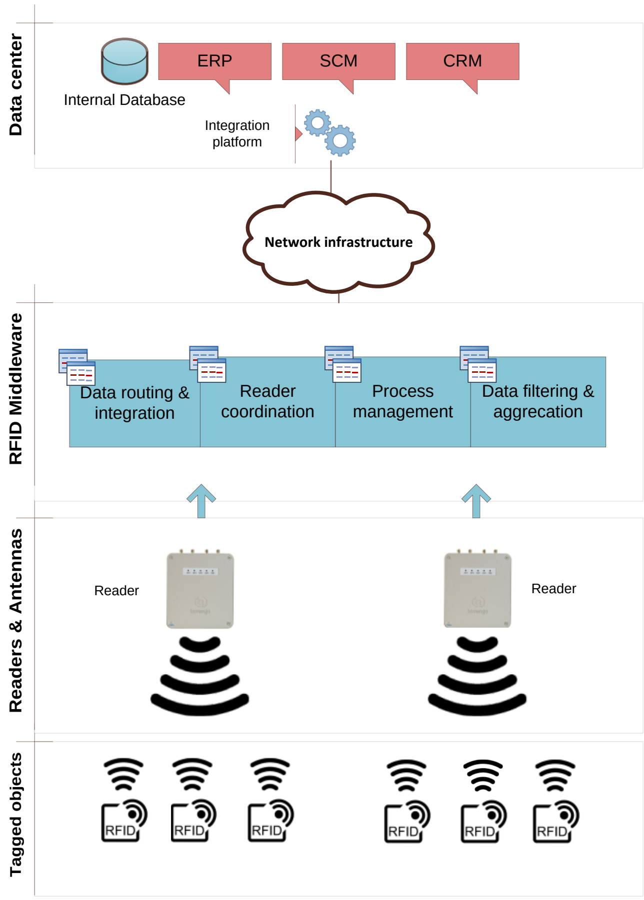

FIGURE 6. Typical RFID System Components

4.4.1 RFID tag

RFID tags, also called transponders, are the heart of an RFID system. One of the key factors to successfully implement RFID technology in operation is the selection of RFID tags. RFID tags can be categorized from various aspects like frequency band, power supply, read/write status, physical attributes and shape. Frequency band is discussed in the previous section and in this part other aspects are presented.

The tag comes in various forms designed according to the customization, but basically it is composed of the chip, the antenna and the substrate. This will be encapsulated with plastic or polyester in order to make it durable and resistant to higher temperatures. Tags can be in various sizes depending on their usage and applications.

Power Sources

The power source is an important property of a tag. It will determine a tag's potential read range, lifetime, cost, and what kind of functionalities it may offer. There are three main types of tags (Weis 2016):

- **Active tags** have their own internal power supply (a battery). They are able to initiate communication to a reader or other active tags.
- **Semi-passive** (or semi-active) tags have also their own internal battery, but they are not able to initiate communications. They remain dormant until they receive a signal from the reader. Therefore, they have longer battery life than active tags. Similar to active tags, semi-active tags can rely on their battery to transmit data to the reader, so they offer a longer read range than passive tags, but at a higher cost.
- **Passive tags** do not have their own power supply. They do not have the ability to initiate communication, either. Passive tags obtain energy from the energy provided by the reader both for receiving and sending data.

The operating range of passive tags is lower than that of active or semi-active tags, but they are significantly cheaper.

RFID tag memory

RFID tags have different types of memory for the reading and writing process. The types for reading and writing of memories are (Pandian 2010, 24):

- **Read only** tags contain pre-written data such as serialized tracking numbers.
- **Write Once Read Many (WORM)** tags enable to write data to the tag at the first instance of use, and then data becomes locked and cannot be changed.
- **Fully read-write** tags allow updating the data on the tag as needed and writing over the original data.

Read only tags often require the least amount of memory and they are the cheapest, but they rely on an infrastructure and readily available database to retrieve useful information. Where this is not possible, read/write tags are often used. (IDTechEx 2004.)

RFID tag Inlays

An RFID tag has three components, the chip, antenna and the substrate. The chip, antenna and substrate together form a Dry Inlay, and if it has got adhesive on one side to make it stick, it is called Wet inlay. In both cases the inlay is often supplied to a converter where it is inserted into a label whatever type of construction is required for the application (Avery Dennison 2016). These inlays are manufactured in a roll and supplied to the customers.

RFID tag shape

RFID tags come in a wide range of shapes and sizes. The following are the most common shapes of RFID tags (IDTechEx 2004):

- **Label:** The tag is a flat, thin, flexible form

- **Ticket:** A flat, thin, flexible tag on paper
- **Card:** A flat, thin tag embedded in tough plastic for long life
- **Glass bead:** A small tag in a cylindrical glass bead, used for applications such as animal tagging (e.g. under the skin)
- **Integrated:** The tag is integrated into the object it is tagging rather than applied as a separate label, such as molded into the object
- **Wristband:** A tag inserted into a plastic wrist strap
- **Button:** A small tag encapsulated in a ruggedized, rigid housing

Different sizes and shapes of RFID tags present options to select the suitable RFID type based on the specified need. Tag shape may have an effect on read range but there is no other difference between them in system design and implementation.

4.4.2 RFID reader

The RFID reader is the brain of the RFID system, and selecting the right RFID reader for an application is of the utmost importance. Readers are devices that transmit and receive radio waves in order to communicate with RFID tags (atlasRFIDstore 2016b). There are three types of readers (atlasRFIDstore 2016b):

- **Fixed RFID readers** stay in one specific location, and they typically come in 2-port, 4-port, or 8-port options for supported antennas. There are a few types of fixed readers that have the ability to utilize multiplexers to expand and support up to 32 RFID antennas.
- **Handheld RFID readers** are mobile computing devices with the reader and antenna built into the device, and they can be carried around while scanning items. Usually, they also contain barcode scanners, Bluetooth, and Wi-Fi.
- **Integrated RFID readers** have a built-in RFID antenna and usually another port to support up to one additional antenna.
- **USB RFID readers** with an integrated antenna are powered and controlled through a PC. A USB RFID reader is a cost effective and easily deployable device.

Fixed and integrated RFID readers can be directly connected to the host computer via an RS-232, Ethernet and USB cable. To connect the readers to a network, Ethernet or Wi-Fi can be used. Using an RFID system over a network can help to reduce overall system costs if there are multiple reader set-ups, because there is no need for a host computer for each reader (Smiley 2014b).

Another aspect to consider when choosing an RFID reader is how to power it. Handheld RFID readers have their own batteries, but fixed and integrated readers require AC power or Power-over-Ethernet (PoE) (atlasRFIDstore 2016b).

RFID Development Kits

RFID development kits offer all the basic RFID equipment needed for developing, testing, and implementing a new system. RFID Developer Kits include a reader, various tag samples, antennas, antenna cables, power supplies, a sample program for reading and encoding, as well as access to the reader’s SDK (Software Development Kit). (atlasRFIDstore 2016b.)

4.4.3 RFID antenna

Another necessary element to successfully implement an RFID system is selecting the right RFID antenna. Antennas are devices which use power from the reader to generate a field for the reader to transmit and receive signals from the RFID tags. Antennas vary in size, gain, IP rating, polarization, and connector type. The price of an antenna depends on the type, size and level of ruggedness. (atlasRFIDstore 2016b.)

Choosing an antenna can be a confusing task, because the antennas typically look physically similar, so it is primarily their technical specifications that set them apart from each other. When selecting an RFID antenna a few key variables to consider are, gain/beamwidth, polarization, and IP rating (atlasRFIDstore 2016b).

RFID antenna Gain/Beamwith

Gain and beamwidth are both electrical components of an antenna and are distinctly related. A higher gain creates a more focused, narrower beamwidth, and a narrower area of coverage, but the beam will travel a longer distance. Beamwidth and gain are comparable to the beam of a flashlight (as seen in Figure 7). (Smiley 2014a.)

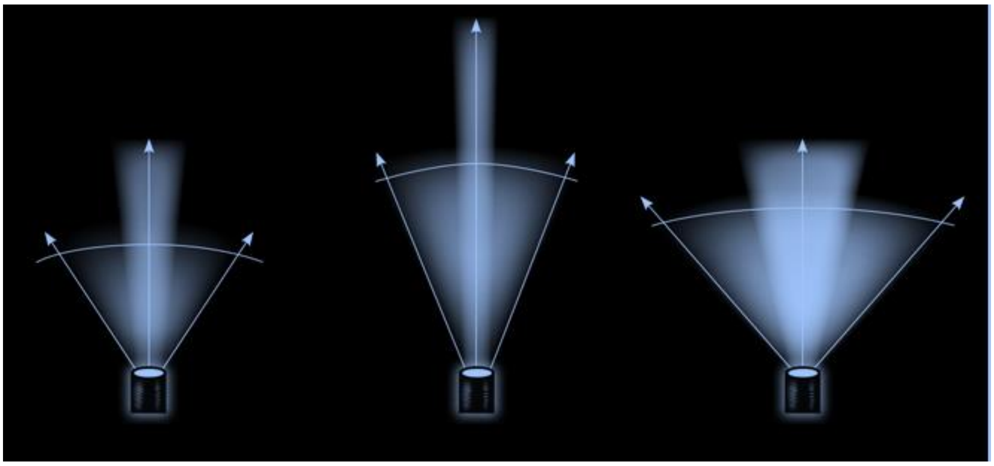

FIGURE 7. Beamwidth is determined by gain (Smiley 2014a)

The ideal beamwidth and gain will depend on the distance between the tags and the antenna. If tags are a short distance away, it would be more advantageous to use a wide beamwidth antenna with relatively low gain as illustrated by the flashlight beam on the right in Figure 7 (Smiley 2014a).

RFID antenna Polarization

Most antennas are either linearly or circularly polarized. Linearly polarized antennas, seen in Figure 8, emit RF energy in a single plane either horizontally or vertically (atlasRFIDstore 2016b).

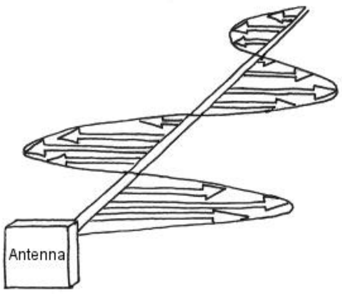

FIGURE 8. Linear Polarization (horizontal) (Armstrong 2013)

Circularly polarized antennas send RF energy in a circular motion either clockwise or counterclockwise. As seen in Figure 9, when the waves rotate clockwise, the antenna is a left-hand circularly polarized (LHCP) antenna; when the waves rotate counterclockwise, the antenna is a right-hand circularly-polarized antenna (RHCP) (Smiley 2014a).

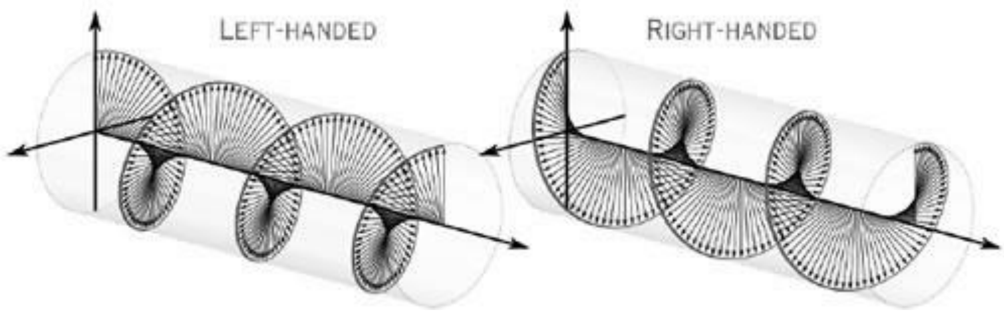

FIGURE 9. Circularly polarized RF waves (Smiley 2014a)

Choosing a linearly or circularly polarized antenna depends on tag orientation: when the tag orientation is controlled a linearly polarized antenna gives longer read ranges, when the tag orientation is not known a circularly polarized antenna gives better consistency.

RFID antenna IP rating

IP (Ingress Protection) rating is a two-digit number established by the International Electro Technical Commission, specifying the environmental protection the enclosure provides against dust and water ingress. The two digits represent different forms of environmental factors, which are protection against ingress of solid objects (1st digit) and protection against ingress of liquids (2nd digit) (as seen in Table 10). (MPL 2016.)

TABLE 10. IP table (MPL 2016)

IP..	First digit: Ingress of solid objects	Second digit: Ingress of liquids
0	No protection	No protection
1	Protected against solid objects over 50mm e.g. hands, large tools.	Protected against vertically falling drops of water or condensation.
2	Protected against solid objects over 12.5mm e.g. hands, large tools.	Protected against falling drops of water, if the case is disposed up to 15 from vertical.
3	Protected against solid objects over 2.5mm e.g. wire, small tools.	Protected against sprays of water from any direction, even if the case is disposed up to 60from vertical.
4	Protected against solid objects over 1.0mm e.g. wires.	Protected against splash water from any direction.
5	Limited protection against dust ingress.(no harmful deposit)	Protected against low pressure water jets from any direction. Limited ingress permitted.
6	Totally protected against dust ingress.	Protected against high pressure water jets from any direction. Limited ingress permitted.
7	N/A	Protected against short periods of immersion in water.
8	N/A	Protected against long, durable periods of immersion in water.
9k	N/A	Protected against close-range high pressure, high temperature spray

In short, the larger the number of each digit, the better protected the antenna is against environmental factors. Most indoor antennas have a rating of IP 54, while a good outdoor antenna will have a rating of IP 66 or IP 67. (atlasRFIDstore 2016b.)

RFID antenna cables

An RFID antenna cable is used for transmitting and receiving data between the reader and the antenna. There are a few key factors to consider when choosing the type of RFID antenna cable (atlasRFIDstore 2016b):

- Connector options for cables, which is determined by the connector types of the reader and the antenna
- Insulation rating of the cable, which will be determined by the length needed as well as the read range desired.

RFID antenna cables are available at three different insulation ratings - LMR195, LMR240, and LMR400. When transferring data between the reader and the antenna, power loss occurs. The longer the length of the cable, the higher the loss. Using a better-insulated (higher rated) cable can combat that loss and maximize efficiency along the length of the cable. The downside to using a better-insulated cable is that it is thicker and, will be more difficult to work with as it does not bend as easily as lower-insulated (lower rated) cables. (atlasRFIDstore 2016b.)

5 BUSINESS PARTNERS OF RFID SYSTEMS FOR LABORATORY

Business partners are an important part of RFID implementation. A trend within the RFID industry is that several companies partner together to provide a complete solution. This may be an option if one partner cannot fulfill all the requirements. With the growing interest in RFID in the item management arena and the opportunity for RFID to work alongside barcode, there are more and more companies entering the marketplace. (Pandian 2010, 78.)

5.1 RFID companies

There are many different RFID vendors with different areas of expertise. The manufacturers of RFID systems can be divided into manufacturers of complete systems, manufacturers of subsystems, and system integrators. The top companies that focus on developing Gen 2-compliant ultrahigh-frequency (UHF) RFID applications tailored for item tracking applications include (RFIDTAGS.com 2016 ; technavio 2015 ; Roberti 2013):

- The manufacturers of readers: Zebra (Motorola), Alien Technology, Applied Wireless RFID, CAEN RFID, GAO RFID, Impinj, Mojix, and ThingMAgic.
- The manufacturers of chips: Alien Technology, Impinj, and NXP Semicondudtors
- The manufacturers of inlays include: Avery Dennison, Invengo, and Smartrac Technology.

The companies that will be discussed here are: Impinj, Alien Technology, and Smartrac technology. An overview of their product range is given in the following section.

IMPINJ

Impinj is a manufacturer of UHF RFID solutions for identifying, locating, and authenticating items. Impinj offers integrated sets of RFID hardware, software, and application interface. Impinj provides RFID chips, readers, software, gateways, and antennas. (IMPINJ 2016a.)

Alien Technology

Alien Technology provides UHF RFID products and services to customers in retail, consumer goods, manufacturing, defense, transportation and logistics, pharmaceuticals, and other industries. The Alien RFID product line includes RFID chips, tags, readers, antennas, and related RFID accessories. (Alien Technology 2016.)

SMARTRAC

SMARTRAC offers a wide range of RFID inlays and tags that cover all the current frequency standards: low frequency (LF), high frequency (HF), and ultra-high frequency (UHF). Additionally, SMARTRAC provides near field communication (NFC) inlays and tags. (SMARTRAC 2016.)

5.2 Discussion and comparison of features offered by RFID companies

Choosing the right RFID system for a laboratory application can be a frustrating experience. The suitable RFID solution for the project is the one that has: lower cost per tag and longer read range. By comparing different types of RFID systems, which is presented below in Figure 10, the UHF RFID system offers longer read range and cost effective passive tags.

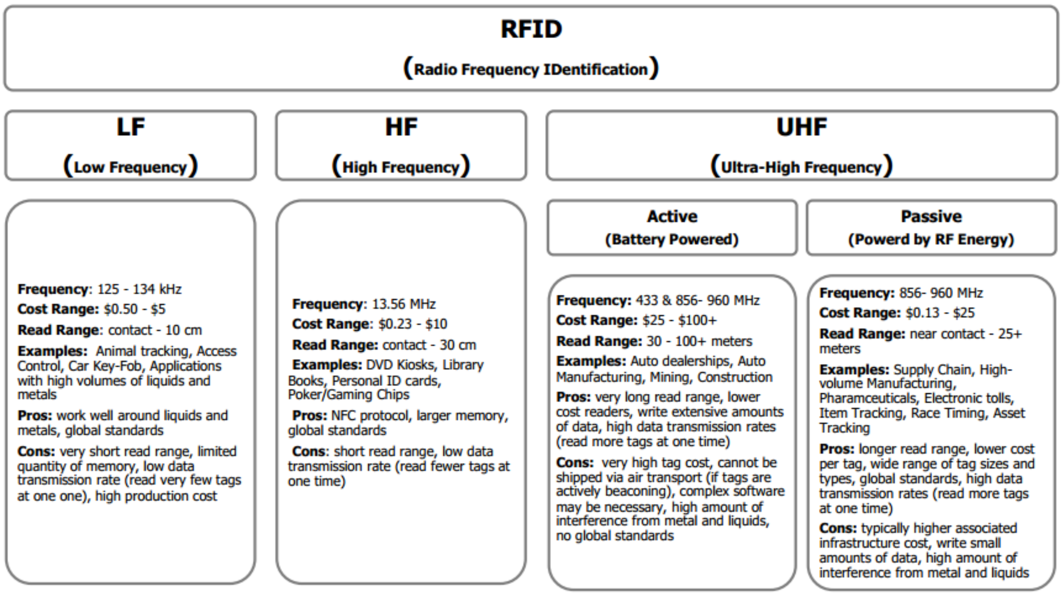

FIGURE 10. Comparing RFID systems (atlasRFIDstore 2016b)

Some vendors offer every component to make a complete RFID system while others are resellers or supply only hardware for specific functions. As seen in previous sections on product ranges of RFID companies, IMPINJ and Alien Technology offer individual RFID components such as tag chips, readers, antennas and software, whereas SMARTRAC offers RFID inlays and tags. Table 11 provides some of the features that are relevant for product selection.

TABLE 11. Comparison of features offered by RFID companies

Requirement	Companies		
	Impinj	**Alien Technology**	**SMARTRAC**
Compliant to ISO18000-6, EPC Gen2	Yes	Yes	Yes
Memory in tags	N/A	EPC 96/128/480 bit User 128/512 bit TID 32/64 bit	EPC 96/128 bit User 0/32/144 bit TID 48/64 bit
Inlay	N/A	Wet Label	Wet Dry Paper
Data Interface	RS-232 Ethernet	LAN RS-232 USB Host USB Console	N/A
Power over Ethernet (PoE)	Yes	Yes	N/A
RFID Development Kit	Yes	Yes	N/A
Reader's antenna port	2 ports 4 ports	4 ports	N/A
Integrated RFID reader	No	Yes	N/A
Host API	.NET	.NET Java Ruby APIs	N/A
Tag max read range	N/A	From 15.24 cm (6 inches) to 6 m (20ft)	From 0.3m(1ft) to 9m(29ft)

N/A = not available

There are many choices in the RFID marketplace, but the key to buying a system that will be a long-term investment is to get RFID tags that meet current standards and can be programmed and used with the majority of RFID readers. This is like insurance for the investment that the laboratory makes in RFID tags that will outlast its commitment to whatever RFID reader hardware is purchased.

6 DESIGNING RFID SYSTEM FOR LABORATORY

Building an automated tracking and self-service application in a laboratory guarantees many benefits. It makes material easier to find and searching more convenient, reduces clerical tasks and eases the management responsibility. The driver for the laboratory to adopt RFID is the need to achieve these aims. RFID has the added advantage that it can also provide security for the range of different reading materials in the laboratory.

A faculty in an educational institution usually has a number of laboratories. Faculties with technical courses such as Information Technology and Engineering usually have more laboratories. To implement the system, an appropriate design is required to make sure it is suitable for the number of laboratories and equipment in all laboratories.

6.1 Operating frequency for laboratory

Selecting the right RFID technology solution involves numerous options in term of frequencies, tag configurations, types of antennas and readers. For example, systems using higher frequencies to communicate between the tag and the antenna provide a faster data transfer rate and longer read ranges but can be limited in terms of sensitivity to interference, while a lower frequency has a shorter read range and a slower data read rate, but increased capabilities for reading near or on metal or liquid surfaces.

The way RFID readers communicate with RFID tags varies from application to application, as does the frequency at which they communicate. RFID tags and readers have to be on the same frequency in order to communicate. There are several different frequencies an RFID system can use. Generally, the most common are Low Frequency, or LF, (125 – 134 kHz), High Frequency, or HF, (13.56 MHz), and Ultra-High Frequency, or UHF, (433, and 860-960 MHz).

Passive UHF RFID has gained a lot of prominence in recent years, based on enabling a wide variety of applications, ranging from retail inventory management, to pharmaceutical anti-counterfeiting, to wireless device configuration. The read range of passive UHF systems can be as long as 12 m, and UHF RFID has a faster data transfer rate than LF or HF. Passive UHF tags are easier and cheaper to manufacture than LF and HF tags. (IMPINJ 2016c.) Based on problem definition of the project and its requirements, the reasonable label cost and the read range of UHF frequency band (as seen in Table 12), UHF RFID frequency band is the most suitable frequency for the laboratory equipment monitoring system.

TABLE 12. Comparison of different frequency bands (IMPINJ 2016c)

UHF	HF and LF
• Single worldwide Gen2 standard	• Multiple competing standards
• 20x the range and speed of HF	• HF-based NFC for secure payment
• Labels cost 5¢–15¢ in 2012	• Labels, cards, inlays cost 50¢–$2
• The technology for item tagging	• Used in immobilizers, ticketing, payment

UHF RFID systems have been around since the mid-1990s and different countries have not agreed on a single area of the UHF spectrum for RFID, so different countries have different bandwidths and power restrictions for UHF RFID systems. Across the European Union, UHF RFID ranges from 865 to 868 MHz with RFID readers able to transmit at maximum power (2 watts ERP) at the center of that bandwidth (865.6 to 867.6 MHz). (Armstrong 2012.)

6.2 RFID-enabled laboratory environment

RFID plays a vital role in redefining the laboratory process to make everyone’s job easier. RFID provides a platform to automate most of the processes performed by the lab administrator such as check-in or check-out, sorting, and inventory. RFID simplifies the operations of laboratory by:

- enabling self-service (check-in/check-out)
- decreasing time associated with the manual check-in and shelving of returned items
- quickly locating missing items

The RFID-based equipment tracking system offers an effective solution of managing items especially for a large-scale environment. It combines the RFID technology and security devices to ensure the items are always being monitored and secured. The system enables the university to give admission to selected individuals to access locations, permit movement of items, record the important data and also enable the viewing of records via internet. A typical RFID system for a laboratory environment consists of:

- tags
- readers and antennas
- application software.
- host computer (database server)

The suitable RFID system solution, which meets the project requirements, is a networked system with fixed RFID readers with long read range. Figure 11 provides a functional overview of an RFID-enabled laboratory environment.

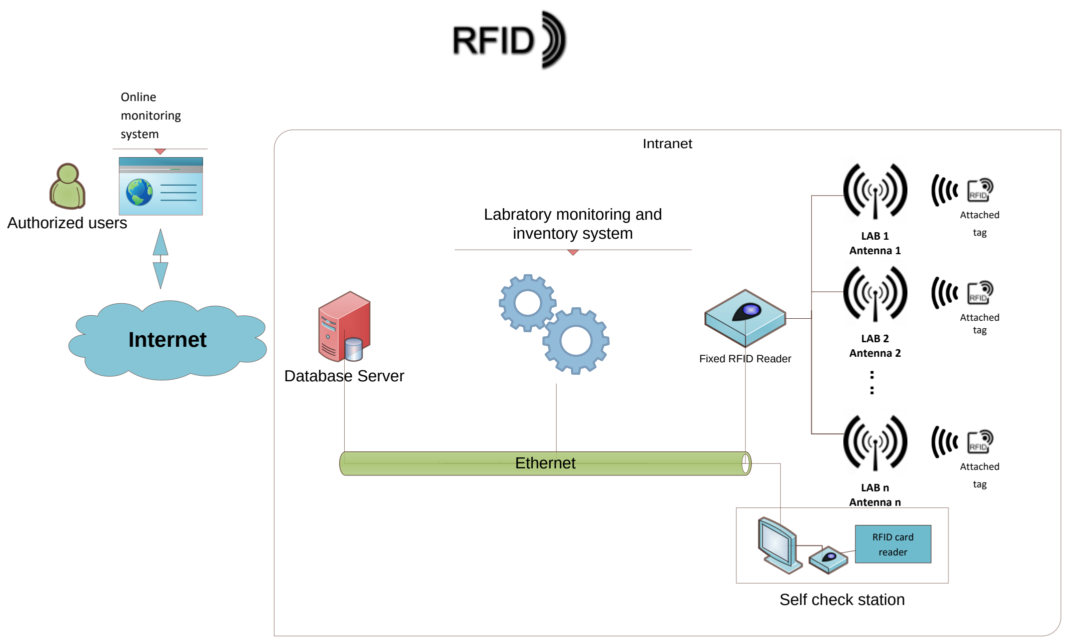

FIGURE 11. Functional overview of RFID-based laboratory environment

In the system, an RFID tag is attached to both users (through RFID card) and equipment. The RFID reader is located at each laboratory to record and verify the RFID tags in the area. Each laboratory is equipped with an alarm indicator to deal with unforeseen circumstance events. The recorded data is stored and managed by a central server. The main purpose of the data which is stored at the central server is to ease the management to have a look at the whereabouts of equipment and the record of in-out information. The administrator will grant the personal level access, equipment status and also permit online monitoring to authorized individuals.

The RFID tags contain antennas to enable the receiving and transferring data, and they are programmed with specific information about the item. It is possible to include many types of information on the tag, such as equipment name, equipment model and manufacturer, but a tag would typically contain a unique identification number. A general overview of the above RFID components was provided in the previous chapter (Chapter 4), we will look at the laboratory-specific RFID components in the following pages.

6.2.1 RFID tags for laboratory

Passive UHF RFID tags that provide the greatest read range are suitable for a laboratory equipment tracking system. Passive tags are smaller, cheaper, and have longer life compared to active tags. Passive tags create power from the magnetic field received from the reader and use it to energize the circuits of the RFID chip and send information back to the reader in the form of radio waves.

RFID tags come in a range of sizes and shapes and having a dry or wet inlay, with a clear or colored backing of PVC, PET or paper. The PVC or PET wet inlays are commonly used to make “RFID Labels” where the inlay is placed on the back of the label with the adhesive side away from the label side so that the label has continuous adhesive (SkyRFID 2016). The tags can usually be overprinted with the name and logo if required.

There are also several attributes that should be considered when selecting a passive RFID tag (Smiley 2014c):

- **Frequency Range:** RFID tags should be tuned to the correct frequency range compatible with the specific region.
- **Environment:** If the application must endure extreme temperatures, sand, water, dirt, or an intensive laundering process, it is essential to select an RFID tag that is built to withstand such conditions.
- **Mounting Surface:** Each RFID tag is designed to be applied to a specific set or sub-set of materials.
- **Size:** RFID tags are manufactured in different sizes and shapes to better accommodate for unique applications.
- **Attachment Method:** The material and shape of the item to be tagged are two of the most important aspects to consider when determining the appropriate attachment method, such as adhesive, epoxy, rivets/screws, cable ties, etc.
- **Read Range:** For determining the optimal range for application, there are many factors to be considered, such as antenna gain, reader transmit power, and tag orientation, which affect the RFID tag's read range.
- **Custom Printing & Encoding:** These are important to consider before purchasing. If an application is customer facing, custom printing may be a feasible option to keep your tags looking professional with a logo or a barcode on the front.

Testing is the best way to find an appropriate RFID tag for the application. Some RFID tags will be a better fit for the application than others, but the only way to know for certain is by testing a variety of tags in the environment on the actual items to tag. (atlasRFIDstore 2016b.)

RFID tags generally come from the manufacturer without unique IDs written onto the integrated circuit. Although some tags do come with sequential unique IDs, they are frequently not in the end user's desired format. Because RFID tags are usually applied to identify specific assets/people/entities, most RFID tags need to be encoded with data before they can be used. (atlasRFIDstore 2016a.)

RFID tag pricing is heavily dependent upon tag type and tag volume. Metal-mount RFID tags and rugged RFID tags are more expensive than RFID wet inlays or RFID labels. Also, the pricing of 100,000 tags will be much different than pricing of 10,000, 1,000, or 100 tags. (atlasRFIDstore 2016b.)

6.2.2 RFID readers for laboratory

There are many different types of tag readers available for UHF RFID applications. Typically, in passive RFID system the reader is responsible for generating the electrical impulse through the reader antenna that causes the information stored on the tag to be read. Readers in the laboratory are fixed and are located in the laboratory as listed below:

- **Tagging station** is used to program the tags to be attached to the laboratory equipment.
- **Self-check station** is used to check in and check out laboratory equipment without lab administrator assistance.
- **Laboratory readers** used to record and verify the RFID tags in the area.
- **Inventory manager** is used for inventorying and verifying that equipment is returned and shelved correctly.
- **RFID-enabled doors** are used to enter a laboratory with an RFID-enabled card to record the entry information.

RFID tagging station

In order to convert to an RFID system, all laboratory equipment must be tagged and programmed. A tagging station is used to affix the tags to the equipment and program them. Programming involves assigning unique identification numbers to laboratory equipment with other information (optional). A tagging station consists of a network PC and close range USB RFID reader with an integrated antenna.

RFID self-check station

An RFID self-check station allows users to self-issue equipment without assistance from the laboratory administrator. A self-check station consists of a network PC, a close range USB RFID reader with an integrated antenna and an RFID card reader. The self-check station can be placed closed to the whereabouts of equipment.

An example USB RFID reader for both tagging and self-check station can be the ThingMagic UHF USB Plus+ RFID reader. It connects directly to the PC and has a short range antenna so that only the desired tag is encoded.

RFID inventory manager

A unique advantage of RFID systems is their ability to scan items on the shelves without taking them out. A fixed inventory reader scans all the items on shelves and detects which items are missing. The inventory manager fixed reader requires a different type of RFID shelving antenna, for example Times-7 A7030C (CP) RFID Shelf Antenna can be used for this purpose.

6.2.3 RFID-based laboratory application software

The RFID-based laboratory software facilitates the fast issuing, reissuing, and returning of the equipment with the help of RFID-enabled modules. It directly provides the equipment information and laboratory member information to the laboratory management system and does not need manual typing. It also provides monitoring and searching of systems. It will continuously monitor the movement of equipment across the laboratory, so that the equipment taken out without proper checkout will be traced easily and will alarm the laboratory administrator. The searching module provides for fast searching of equipment using the RFID readers. The physical location of the equipment can easily be located by using this module.

6.2.4 RFID-based laboratory host sytem or server

The server is the communication gateway among the various components. It receives the information from readers and exchanges information with the circulation database. The server typically includes a transaction database so that reports can be produced.

6.3 Advantages of RFID in laboratory system

RFID's property of non-line-of-sight operation can be very useful within a laboratory environment. With RFID tags attached to equipment we are able to process multiple items simultaneously. No longer does every item require individual handling. While users previously had to see lab administrator in order to check out any laboratory equipment, all it takes now is a visit to the self-checkout station to get equipment checked out by themselves at any time. The benefits can be realized in improvements to productivity, service, materials handling, collection management, etc. Enhanced security precautions are also possible with RFID as readers at entrances and exits can monitor unauthorized borrowing of laboratory materials. In each and every activity within a laboratory, RFID technology will provide a greater amount of efficiency and error-free functioning. Laboratories can thus obtain several advantages:

- Quick check-in/check-out of items
- Fewer repeatable tasks
- More interaction with students
- Better internal security
- Quick inventory check
- Automatic tracking of laboratory assets and their loan processing

6.4 Disadvantages of RFID in laboratory system

As with any technology, RFID has disadvantages too. According to Boss (2004), the major drawback of RFID technology is its cost. This will discourage laboratories from implementing an RFID system.

Privacy concerns associated with item-level tagging is another significant disadvantage of RFID. The problem is that the tags contain static information that can be relatively easily read by unauthorized tag readers. This gives the ability to track the movements of equipment (or person carrying the equipment), and also the ability to build a database of equipment and their associated tag numbers and then use an unauthorized reader to determine who is checking out items. There is also the possibility that the signal from one reader can interfere with the signal from another in the same coverage area and affect the read accuracy.

7 APPLICATION SCENARIOS

The system application of a laboratory monitoring system is an online application that is composed of:

1. Electronic access to the laboratory
2. Inventory control
3. Online data viewing

As mentioned in the previous section, in the designed RFID system, an RFID tag is attached to each piece of equipment and each authorized user in the form of an RFID-enabled contactless card. These cards can be used for access to the laboratories and in the equipment loaning process. The system has two main purposes:

- The first is to register the user, equipment and laboratories to be part of the system, which can be done by the lab administrator.
- The second is to keep track of the equipment and to monitor the activities of the user.

7.1 Electronic access control

An electronic access control system is used to automatically check the access authorization of individuals to laboratories, and the whereabouts of equipment. Each laboratory is equipped with an RFID-based door lock. In order to ensure only authorized users log in to the labs, the system requires that they present their RFID card. Therefore, the RFID card acts as a key to unlock the door and get access to the equipment.

All equipment placed in the laboratories is tagged with RFID and registered in the system. In inventory control, this equipment can be used and borrowed by an authorized user either in the same laboratory or in other laboratories. Once the user’s information is successfully matched by the system, the door will be unlocked and the information is recorded. Otherwise, the door remains locked and a warning message will be recorded to the system. A flow chart illustrating the access to laboratories and equipment is provided in Figure 12.

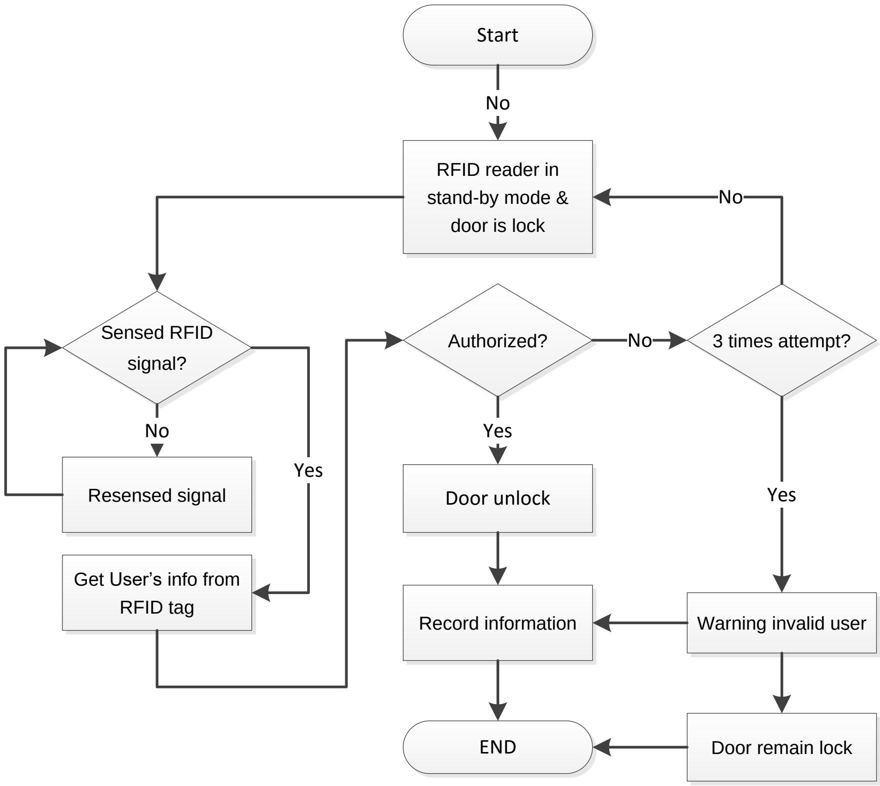

FIGURE 12. Flow chart of access to laboratories and equipment

This system is used to keep track of the record on laboratory equipment. Hence, the laboratory, its equipment and the users who use the equipment in the laboratory need to be part of the system. This can be done by enrolling them in the system.

7.2 Data management and monitoring

The data management can only be accessed by the administrator to maintain the integrity of the data. Thus, the administrator needs to enter the correct password in the login page. The data management flow chart is illustrated in Figure 13.

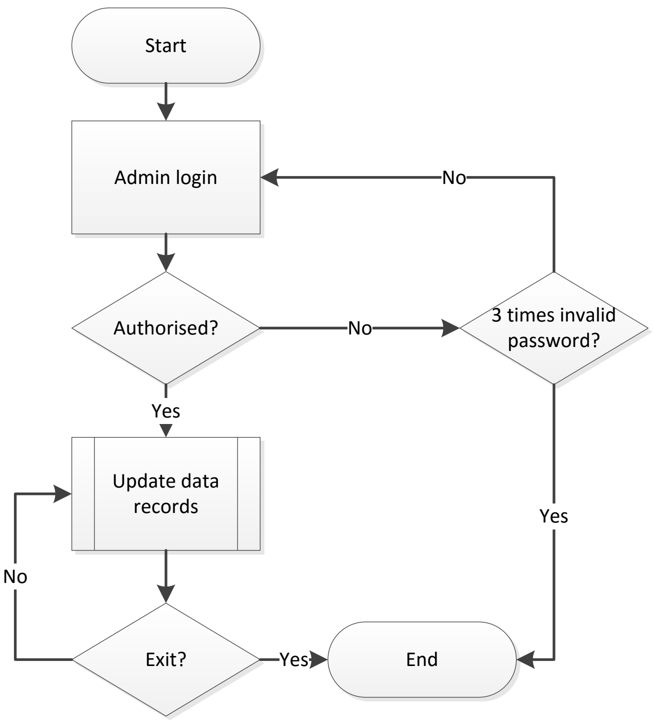

FIGURE 13. Flow chart of data management

The data management allows the lab administrator:

- to add new equipment and maintain the equipment record that is assigned in the laboratory. An RFID tag is attached on the equipment to track down its status.
- to enroll laboratories to the system.
- to enroll a user that wants to be in the system.
- to register the status of equipment; whether it is in place or circulated around the laboratory under an authorized user.

After the user has been registered in the system, they will be given an RFID card. This card is used to authorize access to the intended laboratory. The user needs to bring along the card to enter or to leave the laboratory.

The monitoring of the system allows the administrator to monitor on-loan equipment, user's activity and their status. This part of the system is designed so that it can be viewed by the administrator internally (intranet access) or remotely (internet access). In order to use the monitoring part, either internally or remotely, the administrator needs to log in to the system. The system flow chart of monitoring is shown in Figure 14.

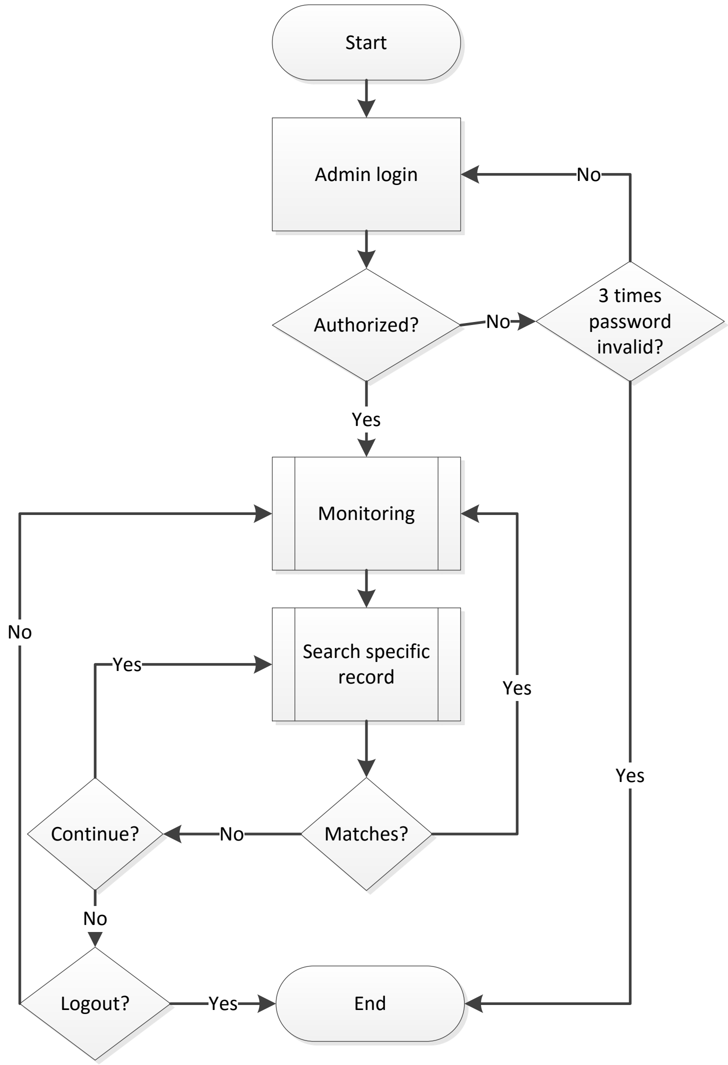

FIGURE 14. Flow chart of data monitoring

8 CONCLUSION

RFID offers significant potential benefits, but one must consider the entire picture of the organization in order to see the greatest benefit. The key to finding the optimal use for RFID is to begin at the beginning and first consider the organization's strategic objectives.

RFID is a costly system that offers some great advantages over barcodes. Improvements in standardization have already occurred, and most large system providers have mainly resolved the problems with interoperability, which reduces the cost of RFID. Today, RFID systems have become broader, deeper, and cheaper. Readers are using less power and are operating faster at longer distances. Nowadays readers also have more ability to handle interference.

RFID is a technology that combines two important features: automatic identification and data transmission via radio communication. However, its adoption is still relatively new and hence there are many features of the technology that are not well understood by the general public. Along with wider adoption, new technologies will help make RFID more reliable and cost-effective for a larger number of applications.

Based on the scope of thesis, the main concept and design of the system is provided, but it needs a high quality hardware implementation too. On the other hand, like in any other project, a detailed project plan and carefully prepared implementation plans are important to the success of implementation. The whole project could be divided in three phases:

- Designing an automated monitoring system (scope of this thesis)
- Hardware implementation
- Software development

The designing part, which was the scope of this thesis, has been done. The hardware implementation can be done by telecommunications technology students or by a qualified hardware company. The software development can also be done by software engineering students or entrusted to external software experts.

REFERENCES

AIM. 2001. Radio Frequency Identification RFID: A basic primer. Automatic Identification Manufacturers [referenced 26 May 2016]. Available on: http://www.8051projects.info/files/RFIDPrimer.pdf

Alien Technology. 2016. Products. Alien Technology [referenced 26 May 2016]. Available on: http://www.alientechnology.com.

Armstrong, S. 2012. Which RFID Frequency is Right for Your Application. RFIDinsider [referenced 26 May 2016]. Available on: http://blog.atlasrfidstore.com/which-rfid-frequency-is-right-for-your-application.

Armstrong, S. 2013. Circular Polarization vs. Linear Polarization: Which is the right RFID Antenna. RFIDinsider [referenced 26 May 2016]. Available on: http://blog.atlasrfidstore.com/circular-polarization-vs-linear-polarization.

atlasRFIDstore. 2016a. FREQUENTY ASKED QUESTIONS. atlasRFIDstore [referenced 26 May 2016]. Available on: https://www.atlasrfidstore.com/custom-rfid-printing-encoding/.

atlasRFIDstore. 2016b. The Basics of an RFID System. atlasRFIDstore [referenced 26 May 2016]. Available on: https://www.atlasrfidstore.com/rfid-resources/#ebook.

Atzori, L., Iera, A. & Morabito, G. 2010. The Internet of Things: A survey. Computer Networks. Computer Networks 2010, Vol.54(15), pp.2787-2805.

Avery Dennison. 2016. Frequently Asked Questions. Avery Dennison [referenced 26 May 2016]. Available on: http://rfid.averydennison.com/en/home/resource-center/faqs.html.

Boss, R.W. 2004. RFID Technology for Libraries. American Library Association [referenced 26 May 2016]. Available on: http://www.ala.org/PrinterTemplate.cfm?Section=technotes&Template=/ContentManagement/HTMLDisplay.cfm&ContentID=68138.

Carlowitz, C., Strobel, A., Schäfer, T., Ellinger, F. & Vossiek, M. 2012. A mm-Wave RFID System with Locatable Active Backscatter Tag. Wireless Information Technology and Systems (ICWITS). IEEE International Conference on Wireless Information Technology and Systems, Nov. 2012, pp.1-4

Data Communications. 2016. Modulation: Making the Message Fit the Medium. Data Communications [referenced 26 May 2016]. Available on: http://ironbark.xtelco.com.au/subjects/DC/lectures/7/

EPCglobal Gen2. 2015. EPC Radio-Frequency Identity Protocols Generation-2 UHF RFID: Specification for RFID Air Interface Protocol for Communications at 860 MHz – 960 MHz Version 2.0.1 Ratified. EPCglobal

Inc [referenced 26 May 2016]. Available on: http://www.gs1.org/sites/default/files/docs/epc/uhfc1g2_2_0_0_standard_20131101.pdf

Finkenzeller, K. 2003. RFID Handbook 2nd edition: Fundamentals and Applications in Contactless Smart Cards and Identification. West Sussex. John Wiley & Sons Ltd.

Forrester Research, Inc. 2012. Building Value from Visibility. ZEBRA [referenced 26 May 2016] Available on: https://www.zebra.com/content/dam/zebra/white-papers/en-us/zebra-iot-report-en-us.pdf

Hossain, S.S. & Karmakar, N. 2006. AN OVERVIEW ON RFID FREQUENCY REGULATIONS AND ANTENNAS. Electrical and Computer Engineering. Conference on Electrical and Computer Engineering, Dec. 2006, pp.424-427

IDTechEx. 2004. RFID tag type options. IDTechEx [referenced 26 May 2016]. Available on: http://www.idtechex.com/research/articles/rfid_tag_type_options_00000041.asp

IMPINJ. 2016a. Products. IMPINJ [referenced 26 May 2016]. Available on: http://www.impinj.com/products/

IMPINJ. 2016b. RFID Standards. IMPINJ [referenced 26 May 2016]. Available on: http://www.impinj.com/resources/about-rfid/rfid-standards/

IMPINJ. 2016c. The Different Types of RFID Systems. IMPINJ [referenced 26 May 2016]. Available on: http://www.impinj.com/resources/about-rfid/the-different-types-of-rfid-systems/

ITU. 2005. The Internet of Things. International Telecommunication Union [referenced 26 May 2016]. Available on: https://www.itu.int/net/wsis/tunis/newsroom/stats/The-Internet-of-Things-2005.pdf

Karygiannis, T., Eydt, B., Barber, G., Bunn, L. & Phillips, T. 2007. Guidelines for Securing Radio Frequency Identification (RFID) Systems. National Institute of Standards and Technology [referenced 26 May 2016]. Available on: http://csrc.nist.gov/publications/nistpubs/800-98/SP800-98_RFID-2007.pdf

Krieber, C. 2010. RFID Selection Guide. EBV Elektronik [referenced 26 May 2016]. Available on: https://cdn-shop.adafruit.com/datasheets/rfid+guide.pdf

Landt, J. 2005. The history of RFID. IEEE. Pages 8-11.

LUAS. 2016. Organisation. Lahti University of Applied Sciences [referenced 26 May 2016]. Available on: http://www.lamk.fi/english/about/organisation/Sivut/default.aspx

Michael, M.P. 2007. Architectural Solutions for Mobile RFID Services on Internet of Things. Helsinki. UNIVERSITY OF HELSINKI.

MPL. 2016. IP Ratings (Ingress Protection). MPL [referenced 26 May 2016]. Available on: http://www.mpl.ch/info/IPratings.html

Pandian, M. 2010. RFID for Libraries: A practical guide. Witney. Chandos Publishing.

Poole, I. 2016a. RFID coupling techniques - backscatter, capacitive, inductive. Radio-Electronics.com [referenced 26 May 2016]. Available on: http://www.radio-electronics.com/info/wireless/radio-frequency-identification-rfid/coupling-backscatter-inductive-capacitive.php

Poole, I. 2016b. RFID Frequencies and Frequency Bands. Radio-Electronics.com [referenced 26 May 2016]. Available on: http://www.radio-electronics.com/info/wireless/radio-frequency-identification-rfid/low-high-frequency-bands-frequencies.php

Poole, I. 2016c. RFID Standards. Radio-Electronics.com [referenced 26 May 2016]. Available on: http://www.radio-electronics.com/info/wireless/radio-frequency-identification-rfid/iso-epcglobal-iec-standards.php

Pursula, P. 2009. Analysis and Design of UHF and Millimeter Wave Radio Frequency Identification. Espoo. VTT.

Pursula, P., Vähä-Heikkilä, T., Müller, A., Neculoiu, D., Konstantinidis, G., Oja, A. & Tuovinen, J. 2008. Millimeter-Wave Identification—A New Short-Range Radio System for Low-Power High Data-Rate Applications. IEEE Transactions on Microwave Theory and Techniques, pp.2221-2228

Reyes, P.M. 2011. RFID in the supply chain. McGraw-Hill.

RFIDTAGS.com. 2016. Provider Directory. RFIDTAGS.com [referenced 26 May 2016]. Available on: http://www.rfidtags.com/manufacturer-directory

Roberti, M. 2004. DOD Releases Final RFID Policy. RFIDJOURNAL [referenced 26 May 2016]. Available on: http://www.rfidjournal.com/articles/view?1080

Roberti, M. 2005. Wal-Mart Begins RFID Process Changes. RFIDJOURNAL [referenced 26 May 2016]. Available on: http://www.rfidjournal.com/articles/view?1385

Roberti, M. 2013. What Are the Leading RFID Companies? RFID JOURNAL [referenced 26 May 2016]. Available on: http://www.rfidjournal.com/blogs/experts/entry?10543

Sheu, M., Tiao Y., Fan, H. & Huang, J. 2010. Implementation of a 2.45GHz Passive RFID Transponder Chip in 0.18μm CMOS. JOURNAL OF INFORMATION SCIENCE AND ENGINEERING, pp. 597-610

SkyRFID. 2016. RFID Tag Inlays. SkyRFID Inc [referenced 26 May 2016]. Available on: http://skyrfid.com/RFID_Tag_Inlays.php

SMARTRAC. 2016. About us. SMARTRAC [referenced 26 May 2016]. Available on: https://www.smartrac-group.com/about-us.html

Smiley, S. 2014a. 3 Guidelines for Choosing a Passive UHF RFID Antenna. RFIDinsider [referenced 26 May 2016]. Available on: http://blog.atlasrfidstore.com/choose-right-rfid-antenna

Smiley, S. 2014b. How to Select a UHF RFID Reader? RFIDinsider [referenced 26 May 2016]. Available on: http://blog.atlasrfidstore.com/how-to-select-uhf-rfid-reader

Smiley, S. 2014c. The Best RFID Tag for Your Application: 7 Key Factors to Consider. RFIDinsider [referenced 26 May 2016]. Available on: http://blog.atlasrfidstore.com/best-rfid-tag-application

Smiley, S. 2015. Low Frequency RFID and Animal Identification. RFIDinsider [referenced 26 May 2016]. Available on: http://blog.atlasrfidstore.com/low-frequency-rfid-and-animal-identification

Smiley, S. 2016. Operating Principles: Coupling. RFIDinsider [referenced 26 May 2016]. Available on: http://blog.atlasrfidstore.com/operating-principles-coupling

technavio. 2015. TOP COMPANIES IN THE RETAIL RFID MARKET. technavio [referenced 26 May 2016]. Available on: http://www.technavio.com/blog/top-companies-retail-rfid-market

Violino, B. 2005a. RFID Business Applications. RFIDJOURNAL [referenced 26 May 2016]. Available on: http://www.rfidjournal.com/articles/view?1334

Violino, B. 2005b. The Basics of RFID Technology. RFIDJOURNAL [referenced 26 May 2016]. Available on: http://www.rfidjournal.com/articles/view?1337/

Weis, S.A. 2016. RFID (Radio Frequency Identification): Principles and Applications. MIT Computer Science and Artificial Intelligence Laboratory (MIT CSAIL) [referenced 26 May 2016]. Available on: http://www.eecs.harvard.edu/cs199r/readings/rfid-article.pdf

Wyld, D.C. 2005. RFID: The Right Frequency for Government. IBM Center for The Business of Government, 2005 [referenced 26 May 2016]. Available on: http://www.ok-safe.com/files/documents/1/RFID_The_Right_Frequency_for_Government_IBM.pdf

Wyld, D.C. 2006. The RFID Value Proposition for Reverse Logistics: RFID—The Next Generation of Identification. Reverse Logistics Magazine [referenced 26 May 2016]. Available on: http://www.reverselogisticstrends.com/rlmagazine/edition03p57.php