HELSINKI UNIVERSITY OF TECHNOLOGY
Department of Electrical and Communications Engineering
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Peter Lindqvist

RFID MONITORING OF HEALTH CARE ROUTINES AND PROCESSES IN HOSPITAL ENVIRONMENT

Master's Thesis
Supervisor: Professor Jukka Tulkki
Instructor: Professor Jukka Tulkki
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HELSINKI UNIVERSITY OF TECHNOLOGY — ABSTRACT OF MASTER'S THESIS

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This thesis discusses radio frequency identifications (RFID) and its applications in hospital environment. RFID technology opens up possibilities to construct novel intelligent systems for monitoring and tracking purposes. Tracking systems can collect data on daily processes and care routines and this information can be used both for quality control and for improving care processes and logistics.

The work consists of a literature review and an applied systems design. The literature review looks into the basics, theory and applications of RFID technology today. Various proposals of RFID use in health care are reviewed and evaluated. Central applications are quality control and positioning, in order to avoid human mistakes using RFID cross-checking and for improving the utilisation rate and minimising waste of equipment, respectively.

As an application of RFID process control the thesis considers monitoring of hand hygiene. Hand hygiene is a single most important counter-measure for nosocomial infections. However, studies have shown that there is much to improve in the compliance with hand hygiene recommendation. For this purpose we suggest a monitoring system based on personal identification that may significantly improve the rate of compliance. We consider technical, privacy and ethical issues that are associated with personal identification at work.

Keywords: RFID, process, monitoring, tracking, healthcare, hand hygiene, nosocomial infection

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Detta examensarbete handlar om radiofrekvens identifiering (RFID) och dess tillämpningar i sjukhusmiljö. RFID teknik möjliggör skapandet av nya intelligenta system som kan användas för övervakning och spårning. Övervakningssystem kan samla information om dagliga processer och vårdrutiner och denna information kan används både som kvalitetskontroll och för att förbättra vårdprocesser och logistik. Speciell fokus placeras på användandet av RFID teknik för att övervaka handhygienen på sjukhus.

Arbetet består av en litteraturöversikt samt av en tillämpad systemplanering. Litteraturöversikten går igenom grunderna, teorin och tillämpningarna av RFID teknologi idag. Olika föreslagna RFID användningsområden inom hälsovården granskas även. Centrala tillämpningar är kvalitetförsäkran, d.v.s. att förhindra mänskliga misstag genom maskinell dubbelkontroll, samt lokalisering med avsikten att öka användningsgraden och minska svinnet av utrustning.

Som en tillämpning av RFID överväger diplomarbetet övervakningen av handhygien. Handhygien är det främsta vapnet mot sjukhusinfektioner. Trots detta visar många studier att det finns mycket att förbättra i efterföljandet av handhygien rekommendationerna. För detta ändamål förslår vi ett övervakningssystem för handhygien som baseras som baserar sig på personlig identifikation, vilket kan bidra till en tydlig förbättring av handhygienen. Vi undersöker de tekniska, sekretess- och etiska problem som är förknippade med ett dylikt system.

Nyckelord: RFID, process, övervakning, spårning, hälsovård, hand hygien, sjukhusinfektion
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Abbreviations and Acronyms

AD	Analogue Digital
ADE	Adverse drug experience
ANSI	American National Standards Institute
ASK	Amplitude Shift Keying
BCMA	Bar Code Medication Administration
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administration
DoD	Department of Defence, USA
EAS	Electronic Article Surveillance
EIRP	Effective Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EPC	Electronic Product Code^{TM}
ERC	European Radiocommunications Committee
ERP	Equivalent Radiated Power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDA	Food and Drug Administration
FDMA	Frequency Division Multiple Access
FET	Field Effect Transistor
FSK	Frequency Shift Keying
HCW	Health Care Worker
HF	High Frequency
IDAS	Integrated Drug Administration System
IR	Infra Red
ISM	Industrial/Scientific/Medical
ISO	International Standards Organization
JIT	Just-In-Time
LC	Inductor and capacitor
LED	Light Emitting Diode

LF	Low Frequency
MRSA	Methicillin Resistant Staphylococcus Aureus
NRZ	No Return to Zero
OR	Operating Room
PSK	Phase Shift Keying
RADAR	Radio Detection and Ranging
RF	Radio Frequency
RFID	Radio Frequency Identification
RTLS	Real Time Location System
SAW	Surface Acoustic Wave
SDMA	Spatial Division Multiple Access
TDMA	Time Division Multiple Access
UHF	Ultra High Frequency
UWB	Ultra Wide Band
VISA	Vancomycin Intermediate Staphylococcus Aureus
VRSA	Vancomycin Resistant Staphylococcus Aureus
Wi-Fi	Wireless Fidelity (see WLAN)
WILHO	Wireless Hospital
WLAN	Wireless Local Area Network
WORM	Write Once / Read Many

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Chapter 1

Introduction

RFID technology has recently opened up doors to many new applications like remote identification, cheap real-time tracking of objects and high speed communication over short distances. This gives us the possibility of acquiring detailed information on real world systems. For example, we can trace patients and material in hospitals in order to optimise the health care process. RFID technology can also be used as smart devices to minimize human errors, a system could double-check drugs that are administered to a patient, in order to avoid mistakes.

The scope of this thesis changed somewhat during the writing process. First the aim was to build a functioning prototype of a hand hygiene monitor device that identifies people with RFID technology. During the study, I found several companies that have worked on similar hand hygiene monitoring systems. By focusing less on RFID, I found multiple products on the market and many patents for methods of monitoring the hygiene. This shifted the scope of the thesis towards a review of existing solutions rather than designing of completely novel systems. The purpose of this thesis is to illuminate new methods of monitoring processes and routines in health care. Special focus is placed on improving hand hygiene.

The aim of the study is to review technologies for monitoring processes. Special focus is placed on RFID technologies. In Chapter 2 we will take a closer look at RFID technology to understand what is possible to achieve and what is not, using different RFID techniques. This chapter also describes common RFID applications and the technology behind them. We also look into potential problems like security and privacy issues.

In Chapter 3 we review several proposed RFID solutions for health care applications. We also take a look at which RFID techniques are suitable for different purposes.

In Chapter 4, we discuss hand hygiene at hospitals and its relationship with infections. We look at potential systems for improving hand hygiene and consider RFID schemes for monitoring hand hygiene.

Finally Chapter 5 evaluates the facts and ideas presented in the previous chapters and critically assesses them. We will give some thoughts on the monitoring of processes and hand hygiene.

Chapter 2

RFID technology

The aim of this chapter is to give a overview of the broad field of RFID technology. This chapter deals with the fundamental principles of operation and the physical background of RFID.

RFID stands for radio frequency identification, and is a common name for all means of identifying objects by radio frequency waves. RFID refers to systems that consist of transponders (tags) and scanners (transceivers, interrogators, readers or sensors). The transponder is usually a small, cheap and often passive electronic circuit with an antenna tuned to a particular frequency. The scanner can detect and communicate with the transponders without having a direct line of sight. Today a typical RFID system can read and write information to multiple RFID tag at ranges from a couple of centimeters to meters depending on the frequency used [46]. RFID systems are proposed to replace bar codes, that are nowadays used for product identification in consumer goods. RFID tags are similar to bar codes but are superior in many ways. RFID tags can contain much more information than bar codes and the information can be updated. They can also be read without a clear line of sight and at a much faster pace than bar codes. The main obstacle for their widespread use is price. It is difficult for a electronic circuit to compete in price with ink on paper.

Usually when speaking of RFID, we mean passive tags that contain some kind of data that can be read by a scanner. However, there are two different types of RFID. Inductive RFID uses inductive coupling to connect the transponder with the scanner. The technology needed is not very complex but the range of such systems is limited. The other type is backscatter RFID. It uses electromagnetic radiation that is reflected back from the transponders for communication. This method offers ranges of up to 7 meters, but it is much more susceptible to materials interfering with the transmissions. Sometimes such RFID tags are equipped with a battery to improve the detection rate and range. Such tags are called battery-assisted or semi-passive.

Positioning methods are sometimes called RFID, too. These usually involve an active radio transceiver that can be localised inside a network of antennas through triangulation or other schemes. There are for example WLAN tags that can be positioned inside an existing WLAN network. Such active RFID technologies are not discussed in detail in this chapter.

2.1 Automatic Identification Systems

The purpose of RFID systems is to automatically identify objects and gather information about systems. Bar codes and biometrics can also be used for this purpose, but RFID has many advantages compared to these. In the modern world of information technology we need to acquire lots of data in order to get information. Information systems are not very useful if data is entered manually because this is both very slow and prone to errors.

Since some time back bar codes have been used for machine reading of physical objects, e.g. at the checkout in the supermarket. Bar codes work on the principle that a laser beam is reflected in different ways on black and white coloured areas. Bar codes are both efficient and cheap. All that is needed is the reader, the bar codes can be printed by virtually any desktop printer. The only drawback is that a direct line of sight is needed between the bar code and the reader. This means that the reading process cannot be completely automated. If the bar code is on the wrong side of the object, it must be turned around. For this a human operator is usually needed.

RFID is superior to bar codes. Since RFID tags can, in theory, be read without a direct line of sight, the reading can be completely automated. RFID tags can also contain much more information, thus enabling identification of specific items, whereas bar codes usually only identify types of items. However, the reliability of RFID systems is not perfect yet. Some materials may cause unwanted effects and block the RFID scanning of tags. Price is also a drawback, today RFID tags cost close to 50 cents in small batches [46]. The price is rapidly falling but will remain significantly higher than for bar codes, due to the fact that RFID tags consist of a silicon chip attached to an antenna in some kind of a protective shell compared to the paper and ink used for bar codes.

2.2 History of RFID

In 1886 Heinlich Hertz discovered measurable waves propagating from sparks of electricity. Later these waves came to be used for the transfer of useful information over distances, the radio.

Radar, short for Radio Detection And Ranging, is very close to RFID. The idea of the radar is that a radio signal is sent out and then the reflected signal is detected and analysed. During World War II, radars were developed for detecting aircraft. Allied airplanes were identified as friendly through a system on board the aircraft that reflected radar waves in a particular way. This can be thought of as the first application of RFID.

In 1948 a paper was released on "Communication by Means of Reflected Power" by Harry Stockman. It described the principles of modern RFID but the author stated that "Evidently, considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored."

During the 1960's radio technology was developed further and advanced aircraft identification methods were taken into use. In the 1970's Electronic Article Surveillance became widespread. The first tests with toll collection using RFID of vehicles were implemented in the late 1980's in Norway. The 1990's was a turning point with RFID access control and other applications becoming common.

2.3 RFID Techniques

RFID covers a lot of different technologies used for identifying objects by using radio frequency electromagnetic waves. Next we will categorise and point out the differences between the different kinds of RFID systems.

The simplest form of RFID tags are 1-bit tags that are detected if present. The Electronic Article Surveillance system (EAS) used in shops to prevent shoplifting is an example of a 1-bit RFID system. Tags usually referred to as RFID have a memory of several bits or even kilobytes.

Read-only systems can be considered low-end. These tags usually only contain an individual serial number that is transmitted when queried by a reader. These systems can be used to replace the functionality of bar codes. Due to the structural simplicity of read-only tags, costs and energy consumption can be kept down.

More advanced tags contain logics and memory and they support writing. Information can be updated or changed remotely. High end tags have microprocessors enabling complex algorithms for encryption and security. More energy is needed for these than for less complex electronics.

Concerning the energy source all tags can be divided into two distinct categories, passive and active. Passive tags don't contain any energy source of their own, they simply harvest the transmitted energy of the RFID reader. This means that they need to operate on very small energy levels and the signal reaching back to the reader is even smaller. Tags can also contain a energy source. Usually, the battery only supplies power to the electronics in order to extend the range of the applications. Such tags are often called battery assisted or semi-passive. Active tags, on the other hand, transmit a signal themselves and for this, more energy is needed. Active tags are quite different from the passive RFID tags because of the radio transmitter.

RFID systems work on different frequencies, the most common are 128 kHz, 13.56MHz, 869 MHz(US 915 MHz) and 2.45 GHz. [10]

2.3.1 One bit tags

One bit tags can be detected but they do not contain any other information. This is very useful for protecting items in a shop against shoplifters. A system like this is called Electronic Article Surveillance (EAS) and has been in use since the 1970's [29]. In practise this system can be identified by the large gates of coils or antennas at the exits of shops. However, this function can be performed by various different systems [1]. We will take a look at the most common solutions in order to understand radio frequency detection.

RF / Induction EAS

The RF 1-bit tag consist of a coil and a capacitor. This is called a LC resonant circuit because it resonates with external magnetic fields at certain frequencies, depending on the magnitude of the LC-components. A tag like this can be detected when it enters a magnetic field. When the tag starts to resonate it draws energy from the oscillating magnetic field of the primary coils, see Figure 2.1. This can usually be seen as a dip in the voltage of the primary coil. The magnitude of the dip depends on the distance between the tag and the reader, the quality of the LC tag and how quickly it enters the field.

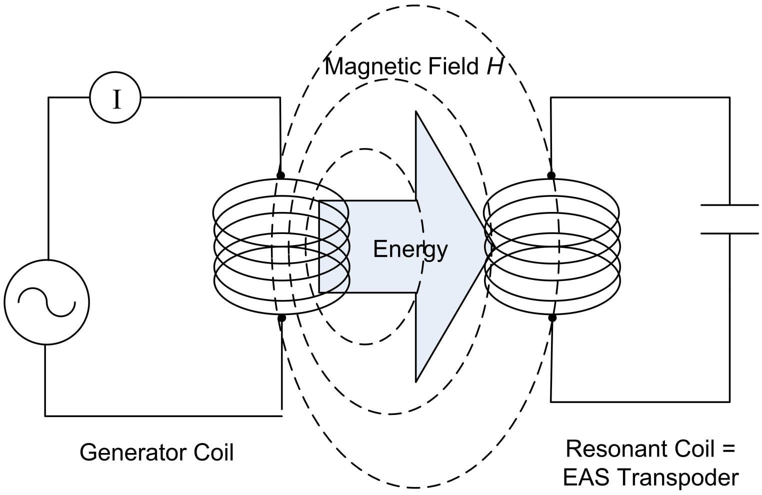

Figure 2.1: The LC resonant circuit is inductively coupled to the primary circuit. [10]

In order to make the signal as strong as possible, the frequency of the coils is not constant but sweeps over a range, thus compensating for the speed of the approaching tag. This means that the sensitivity of the system depends on the sweeping frequency. This way a detection rate of 70 % can be achieved. However, metals interfere with the magnetic fields making it hard to detect tags near large metal surfaces.

Nowadays RF tags can often be found behind the bar code sticker. Usually, RF tags are not removed but destroyed at checkout. A strong voltage is induced in the LC-circuit, which results in the short-circuiting of the capacitor, thus destroying the tag.

Microwave EAS

The principle of the microwaves tags is also quite simple. It uses the generation of harmonics by diodes, i.e. frequencies that are an integer times the original frequency. The tag is a small antenna that has a diode in the middle, see Figure 2.2. As the diode only lets current pass one way, the oscillations that get trapped behind the diode generate a frequency twice the original one. The system sends out a microwave signal, e.g. 2.45 GHz and listens for the first harmonics, i.e. 4.90 GHz. If a tag is present it generates harmonics that can be detected. However, false alarms may be caused by other sources of this particular frequency. In order to avoid such false alarms, a modulation

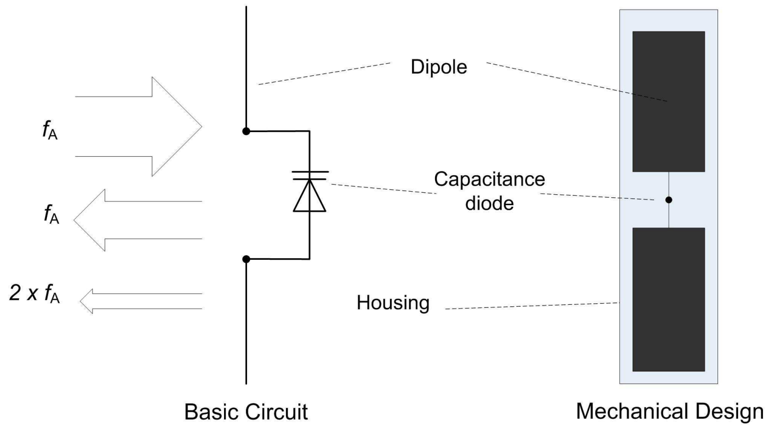

Figure 2.2: An antenna with a diode generates a harmonics wave that is twice the frequency of the original. This is because of the diode's property to let current pass only one way, thus trapping part of the oscillations. [10]

signal of e.g. 100kHz is added to the interrogation signal. This means that the same modulating signal can also be found in the any reflections from the tags.

Microwave EAS tags are usually used to protect clothing. They are removed at the checkout and reused.

Electromagnetic EAS

The electromagnetic EAS system consists of an alloy with high permeability that can be detected when subjected to an oscillating magnetic field. When a alloy with a high permeability is subjected to a high enough magnetic field it gets saturated. The alloy used are specially designed to reach their magnetic saturation very abruptly, in other words, their hysteresis curve is very steep [19, 10].

Electromagnetic tags use a low frequency magnetic field at about 20 Hz. Each time the magnetic alloy reaches its saturation point, it produces small disturbances in the oscillating field. These disturbances can then be detected by the system, see Figure 2.3.

The advantage of the electromagnetic system is that it can be deactivated and reactivated. If the alloy is polarised by a strong magnetic field, the alloy can no longer be depolarised by the weak fields of the detection system. Thus,

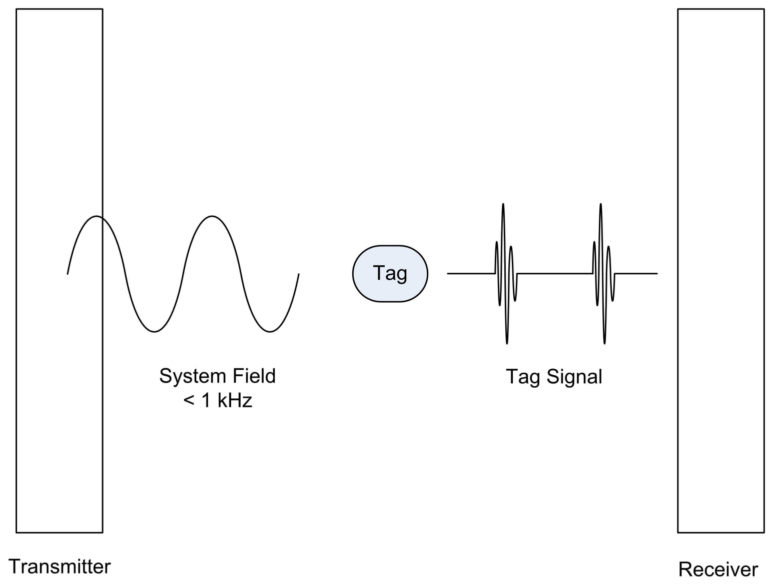

Figure 2.3: The electromagnetic EAS detects the disturbances in the magnetic field each time the magnet in the tag reaches its point of saturation. [1]

the polarisation deactivates the alloy. Tags are reactivated by depolarisation. These systems are usually used in libraries where articles are returned and tags are needed to be reactivated.

Acousto-magnetic EAS

Acousto-magnetic electronic surveillance is based on the fact that a magnetostrictive metal can convert magnetic energy into mechanical and vice versa. A magnetostrictive metal physically shrinks when subjected to a magnetic field. When the magnetostrictive metal receives a short pulse of an oscillating magnetic field it starts to ring like tuning fork. It starts to oscillate mechanically and emits small amounts of electromagnetic radiation.

The detection system sends out short signal pulses at about 58 kHz and listens for replies. If an acousto-magnetic tag is present the tag will absorb energy and oscillate during the pulse and slowly die out during the break, just like a tuning fork, see Figure 2.4. The system detects the reply signal and in order to ensure the correct origins of it, both the phase and the amplitude are matched with the interrogation signal.

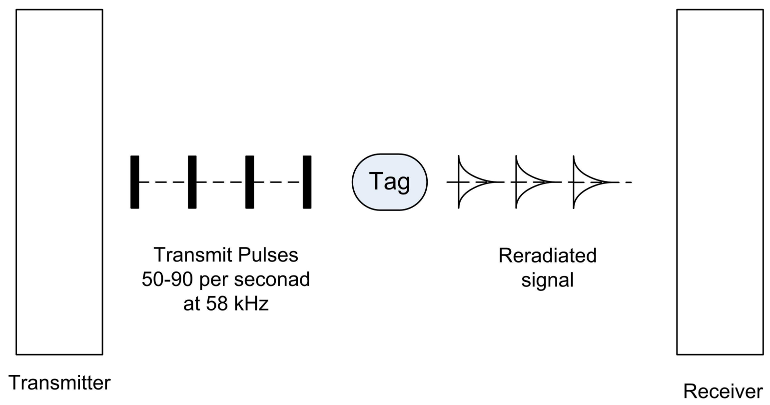

Figure 2.4: The acousto-magnetic tag works much like a tuning fork. The tag starts to oscillate to the activation signal and the echo can be detected.[1]

The advantage of this type of EAS is that the acousto-magnetic tags can be turned on and off and have the ability of functioning in the vicinity of metals [19]. Opposite to electromagnetic tags, acousto-magnetic ones are deactivated by depolarising and reactivated by polarising.

2.3.2 Read-only systems

From now on we will concentrate on RFID tags that contain more information than 1 bit. These tags have some kind of memory to store information and they can communicate with the reader.

Read-only tag are simple ones that only contain a unique serial number [6] that it transmits on request. The contents of the read-only chips are usually written during manufacturing. The serial number can, for example, be coded by cutting small bridges on the chip. Usually these simple chips also contain some logic for anti-collision, i.e. allowing multiple tags to be read simultaneously, see Section 2.5.2.

SAW crystal

Surface Acoustic Wave or SAW chips are passive, read-only RFID tags that operate on extremely low energy levels. It is not an electronic chip but an acoustic one. It consists of a piezo crystal that shrinks or grows depending on the surrounding electric field. It has a small antenna that captures the electric field and leads it to the crystal, see Figure 2.5. The piezo crystal

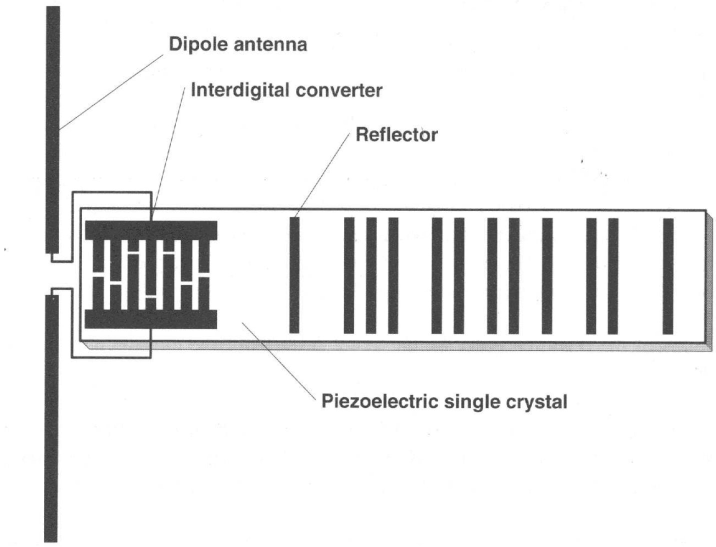

Figure 2.5: The SAW tag consists of a piezo crystal with an array of reflecting barriers at the surface. [10]

experiences the oscillating field and generates acoustic waves that propagate along the surface at about 3-4 km/s. The surface wave is then reflected back to the antenna by several reflectors at the crystal. The reflected waves are transformed back to electromagnetic pulses that can be detected by the sensor. The surface acoustic waves are substantially slower then electromagnetic waves, which means that the reflection from the SAW crystal comes much later than waves that are directly reflected. For example, a reflection of the radio waves at over 100 m takes about 0.5 ms and is damped by $>$ 160 dB. Since it takes about 1.5 ms for the SAW chip to reply, all radio reflections from the initial signal have died away. This leaves little room for interference and makes the SAW signal much easier to detect even at small quantities.

2.3.3 Read-write systems

Some chips allow writing only once. They are often referred to as Write Once/Read Many (WORM). These tags are more versatile since they can be written with a serial number when applied to an item, instead of linking a pre-defined serial number to an item.

More advanced chips allows both reading and writing multiple times. The contents of a tag can be altered remotely by a scanner. Such a tag can contain information about its owner, manufacturing date or when it was last scanned. All of these actions require more logics from the chip, which makes it more complex. Additionally, the chip must be able to resolve who can access it and prevent wrong people from altering its contents. For secure data transmission some kind of encryption is needed.

2.3.4 Ranges of RFID techniques

All RFID systems have two basic ways of exchanging information, inductive coupling or electromagnetic backscatter.

Inductive coupling means that the magnetic field of the sensor gets coupled with the coil of the tag, much like in a transformer. This requires that the tag is within the near field of the sensor, see Section 2.4.1. Electromagnetic backscatter, on the other hand, implies that a wave is reflected from an antenna under certain conditions and not under others. In this way, a sensor can detect the backscatter or the lack of it and interpret this as a digital signal. Electromagnetic backscatter communication works beyond the near-field region of the scanner.

RFID applications are usually classified into the following categories, close coupling, proximity, vicinity and long range, see Table 2.1. They are based on the range of the apparatus.

Close coupling refers to RFID tags or smart cards that need to be very close to the reader. This gives an advantage of efficient energy transfer that enables complex microprocessors to be used. Proximity coupling is for smart cards that can be used over a shorter distances. These are used for public transport ticketing. The user needs to place the smart card close to the scanner.

Vicinity coupling has a bit longer range than proximity. It can be used at longer ranges but correct orientation is still needed for successful scanning. Special gate antennas, however, can induce magnetic fluxes in all three dimensions to ensure high detection rates. Long range RFID is usually used for detecting and identifying assets. Tracking containers is one application.

The range of RFID systems can be greatly affected by materials between or close by. Large metal objects always affect inductive RFID systems to some extent. If large metallic objects are present in the vicinity of a circuit, then the resonant frequency of the system is modified because of the inductive coupling. This basically means that the range is reduced. Otherwise, the magnetic field of the inductive RFID penetrates most materials without dampening. Backscatter RFID, on the other hand, is propagated by electro-

Table 2.1: RFID application are usually categorised according to their range.

Name	Range	Method
Close Coupling	$<$ 1 cm	inductive
Proximity (Remote) Coupling	$\tilde{1}5$ cm	inductive
Vicinity (Remote) Coupling	$<$ 1 m	inductive
Long Range	1 - 10 m	backscatter

magnetic waves. They are much more easily affected by different materials, depending on the frequency. UHF or frequencies of about 900 MHz are both easily reflected by metallic surfaces and are effectively absorbed by water. This means that UHF is difficult to use close to aqueous materials or metallic surfaces. Higher frequencies like 2.45 GHz is less dampened by different materials. However, the tags for these frequencies are more expensive and are often required to be semi-passive, i.e. they must include a battery for the powering the electronics.

2.3.5 Transponders with sensing capabilities

Active remote sensors have been used for a long time. However, RFID chips can also be fitted with an A/D converter that allows the measuring of signals. Different measuring device can be used, the only requirement is that the power consumption is low enough for a small battery to provide reasonable operating life time. There are highly miniaturised temperature sensors that can be combined with RFID tags. This gives us small and cheap tags that can sense the temperature [10],[27].

The Doppler effect often used to determine the speed and direction of remote objects. The Doppler effect fundamentally means that the frequency of a wave reflected from a moving object changes, depending on the velocity of the object. A more detailed description of the Doppler effect can be obtained in most basic physics books [52]. RFID scanners that measure the velocity of microwave tags can be constructed [10].

SAW tags have a interesting feature that allows them to be used as sensors. SAW crystals, as described earlier, converts the electromagnetic wave into an acoustic one and back again. However, the velocity of the surface acoustic wave depends on the properties of the surface material. If the material is subjected to physical stress, such as stretching, bending or compression, the velocity of surface wave is modified. In some crystals, the velocity of the surface waves is also dependent on the temperature of the material. Changes in the speed of the surface waves can be detected at the scanner as linear phase shifts from the original interrogation pulse. SAW crystals as sensors have an additional advantage, their temperature range is very broad. SAW tags work at very low temperatures although their sensitivity declines. Special tags made of langasite and platimum can function in up to $1000°C$ [10].

2.4 RFID Theory

2.4.1 Near field vs. Far field

The solution of Maxwell's equations for the fields around an antenna consists of three different powers of the range, $1/r$, $1/r^2$ and $1/r^3$. At very short ranges the higher powers dominate the solution while the first power dominates at longer ranges [49]. This can be interpreted as the electromagnetic wave breaking free from the antenna. There is no clear boundary between the far and near field but usually $\lambda/2\pi$ is considered as the breaking point [10]. What is most interesting concerning RFID is that a wave beyond the near region cannot retroact upon the antenna any more. This implies that inductive coupling is only possible within the near field.

2.4.2 Inductive coupling

Inductive coupling or induction goes back to the basics of electromagnetism. Inductive coupling means that the transponder and the antenna are coupled by the magnetic flux through both coils, much like a transformer. All the energy used in the tag is drawn from the primary coil of the antenna. This requires some conditions to be fulfilled before communication between the reader and the tag is possible. The coil of the antenna must not be aligned with the magnetic flux because then there is no flux through the coil and thus no coupling. For the tag to work, enough energy must be accumulated. This requires the tag to be subjected to the altering magnetic field long enough.

Induction

Because the distance between the reader and the transponder is very small compared to the wavelength of frequency used, the alternating magnetic field can be seen as a pure magnetic field. This is analogous to the near field described in Section 2.4.1.

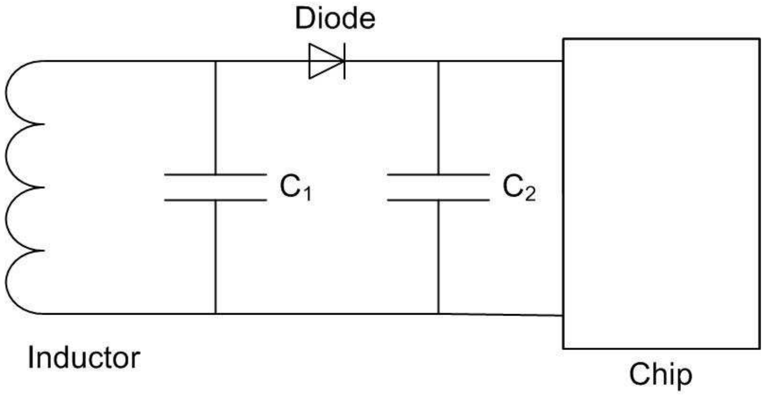

Figure 2.6: The tag powers the electronics over the inductive coupling. The capacitor C_1 tunes the chip to the right frequency. Via the diode, the capacitor C_2 is charged and powers the electronics.[10]

The inductive coupling can be calculated using Faraday's law,

$$\varepsilon = -\frac{d\mathbf{\Phi_B}}{dt}, \tag{2.1}$$

where ε is the induced electromotive force and $\mathbf{\Phi_B}$ is the magnetic flux. The magnetic field generated by a coil can be calculated by Ampere's law,

$$\oint \vec{\mathbf{B}} \bullet d\vec{\mathbf{l}} = \mu_0(i_c + i_d)), \tag{2.2}$$

where i_c is the current going through the integrated path. The displacement current i_d equals a changing electric field also contributing to the magnetic field.

Now we can calculate the mutual inductance between the primary antenna coil and the transponder coil. We get that

$$\varepsilon_2 = -M\frac{di_1}{dt}, \tag{2.3}$$

which means that the induced electromotive force in the transponder coil is proportional to a geometrical factor M and to the change of the current i_1 in the primary coil. The geometrical factor M includes the distance between, the sizes of and the orientation of the coils. When we feed an oscillating current of $\sin(\alpha r)$ into the primary coil we get a similar sine-curved electromotive force in the transponder coil. The energy in the coil can easily be harvested using diodes and capacitors to rectify the current, see 2.6

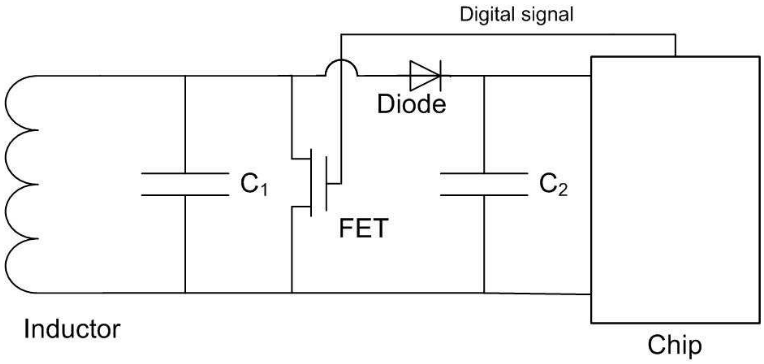

Figure 2.7: Downlink communication by load modulation can be implemented with a variable resistor or a field effect transistor (FET). A digital signal from the chip is connected to a FET that modifies the total resistance of the chip. This change of resistance can be detected as a change of voltage in the scanner.[10]

All the power used in the transponder is drawn from the primary coil, which gives us,

$$U_1 I_1 = U_2 I_2, \tag{2.4}$$

which leads to

$$U_1 I_1 = (-\frac{di_1}{dt})\frac{1}{R_2}, \tag{2.5}$$

using 2.1. From this we see that a change of the resistance in the transponder coil can be detected in either the current or voltage at the primary antenna.

Modulation

In order to send information the signal is modulated, or changed in some way. A basic example is load modulation. This means that varying the resistance in the transponder causes a varying power loss in the primary coil. This loss can then be seen as a small dip in the voltage over the antenna. In Fig. 2.7 we can see a simple circuit for load modulation.

In practise it is a bit complicated to recover the amplitude modulation of the carrier signal. Often a subcarrier signal is used to transfer information, the varying the amplitude of this subcarrier is called amplitude key shifting (ASK). By generating a signal at a lower frequency f_s than the main frequency f_m we get two modulation products at $f_m \pm f_s$. By band-pass filtering on one of these frequencies we can easily recover the original signal and extract useful information. Other ways of modulating signals are frequency key shifting (FSK) and phase key shifting (PKS). These involve the shifting of the frequency or shifting of the phase of the carrier signal to convey digital information.

2.4.3 Electromagnetic Backscatter

The second technique used for RFID is electromagnetic backscatter. This is fundamentally different from the inductive coupling. Electromagnetic backscatter is quite similar to radars. Depending on its characteristics, an antenna reflects part of an incoming electromagnetic wave back to the sender.

Electromagnetic wave are reflected by most objects that are larger than half the wavelength. This is what the radar is based on. The efficiency of this reflection is called the reflection cross-section. This is particularly large for antennas that are in resonance with the incoming waves. However, the reflection cross-section can be dampened by a resistor connected in parallel with the antenna. By varying this resistor we can change the cross-section easily. An electromagnetic backscatter RFID tag uses this mechanism to modulate the backscatter to send information back to the reader. The energy that is reflected back eventually reaches the reader antenna where it can be filtered out from the much stronger outgoing signal with a directional coupler.

Opposite to inductive coupling electromagnetic backscatter works beyond the near field. Thus we need to view the field as EM waves. The fact that this works on longer ranges gives us the challenge of accumulating enough energy in the transponder for the electronics in it to work. We can assess the energy available at the transponder by calculating the *free space path loss* a_F between the reader and the transponder [10]. The free space attenuation is given by

$$a_F = 20\log(4\pi\frac{rf}{c\sqrt{G_T G_R}}), \tag{2.6}$$

where f is the frequency, r is the distance, c is the speed of light and G_T and G_R are the antenna gains. Using this formulae and knowing the power consumption of the microchip we can estimate the range of a system. Since a microchip can draw about $5\mu W$ and the efficiency of the power harvester is about 10% we need a power of $50\mu W$ at the transponder. The limit for RFID transmissions in Europe are $0.5W$ EIRP (effective isotropic radiated power) the free space loss cannot exceed 40 dB. Using a frequency of about 900 MHz we get:

$$\frac{c\sqrt{G_T G_R}10^{(\frac{a_F}{20})}}{4\pi f} = \frac{300,000km/s\sqrt{1\times 1.64}\times 10^{(\frac{40dB}{20})}}{4\pi\times 900MHz} \approx 3m$$

Changing the parameters slightly we can achieve a bit longer distances. As we see the main problem is to power the chip, some chips come with a battery to provide power for the electronics. The transmission, however, is not powered by the battery.

2.4.4 Close Coupling

Close coupling is often used in conjunction with RFID. It describes the coupling of smart cards to readers at ranges below 1 cm. It is basically similar to inductive coupling but the implementation is a bit different. The close range also enables the transfer of much more energy that is needed for smart cards containing microprocessors for more advanced functions.

There are two different kinds of close coupling, inductive and capacitive. The inductive resembles a transformer, i.e. coils that are connected by a ferrite material to strengthen the coupling. Both the reader and the transponder contain ferrite cores that need to be aligned for them to function. The capacitive coupling resembles the inductive one, but it is based on large capacitors that connect the transponder with the reader. This is accomplished by aligning large conductive areas on the transponder with similar ones on the reader that together function as capacitors.

2.5 Signal transmission, coding and security

2.5.1 Duplex or sequential transmission

For a RFID system to work we need three processes, energy transfer, downlink and uplink. According to this we can divide RFID systems into three groups, Full Duplex, Half Duplex and Sequential.[10]

During Full Duplex and Half Duplex the energy is transferred constantly, compared to Sequential when energy is first transferred and then the tag responds.

In Half Duplex systems the information is sent in turns either transferred inductively through load modulation or as electromagnetic backscatter like a radar.

In Full Duplex systems uplink information is sent on a separate frequency, either a sub-harmonic or not. The flow of information can be bidirectional and continuous.

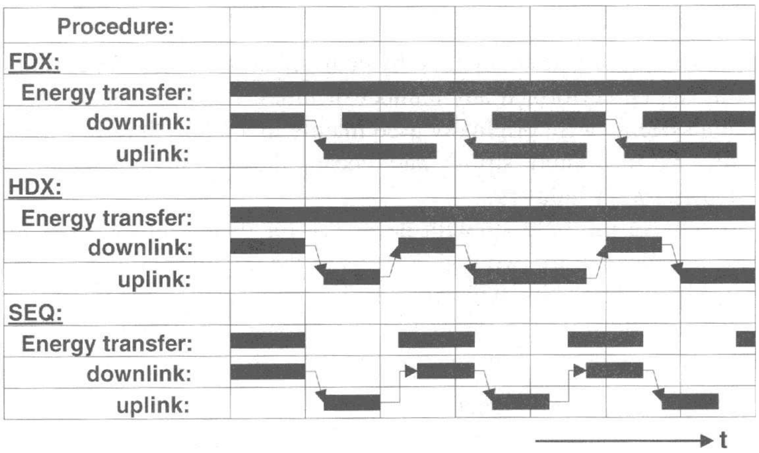

Figure 2.8: Visualisation of full / half duplex and sequential transmission. The terms duplex and sequential transmission are not consistently used in literature on RFID. [10]

Sequential transfer consists of two phases, first energy is sent to the tag that stores it in a capacitor. Then, utilising the power received, it can function for some time and send its reply. This has the advantage that by extending the charging time and enlarging the capacitor you can acquire more energy for the electronics.

2.5.2 Multi Access and Anti-collision

Often RFID systems encounter situation when several tags are in the vicinity of a scanner. This can cause problems because the signals from the different tags can interfere and make it impossible to resolve the original signals. Situations like this are not new, they exist in most radio systems. Fundamentally there are four approaches to this problem. We can use space domain multiple access (SDMA), frequency domain multiple access (FDMA), time domain multiple access (TDMA) or code division multiple access (CDMA). In opposite to many other communications, RFID is characterised by the short bursts of information followed by long silences. A tag is rarely interrogated and does not take up bandwidth except at the brief moment it is scanned. A RFID reader, like the fare readers on public buses, must be able to read the correct RFID card even if a user has several other cards in their wallet. This calls for special anti-collision procedures. Another interesting feature of the tags is that they cannot detect the presence of other tags. Multi access must be initiated or directed by the scanner.

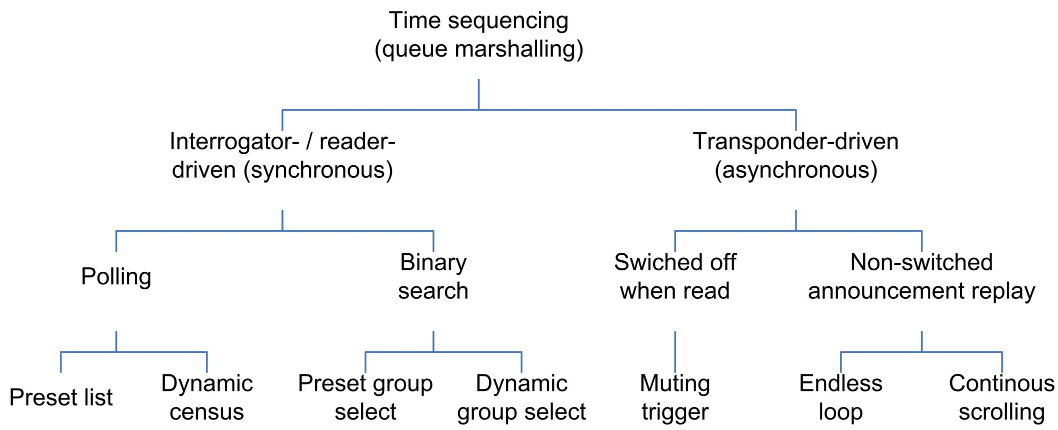

Figure 2.9: Time Domain Multiple Access consists of many different methods of sending many signals on a single channel by the means of scheduling. This classification was proposed by Hawkes (1997) [16] [10].

SDMA

SDMA means that the read area is small enough to only read one tag at the time. A directed antenna can use a narrow beam like a search light to activate only one tag at the time. However, this is a quite expensive solution and has few uses [10].

FDMA

FDMA uses different frequencies to separate communications from tags. Inductive or backscatter RFID tags could use different subcarrier signals to transmit their messages. However, this means that the reader needs to have receiver for all the different frequencies. Different UHF systems can use several different frequencies (frequency hopping) which can be considered as a form of FDMA. Otherwise, FDMA for tags, has few RFID applications because of the cost [10].

TDMA

TDMA is the most used procedure for RFID. Simply put TDMA consists of all techniques available for scheduling many broadcasts sequentially on the same channel. Distinct methods of TDMA can be seen in Fig 2.9. Procedures can either be interrogator-driven or transponder-driven. The latter

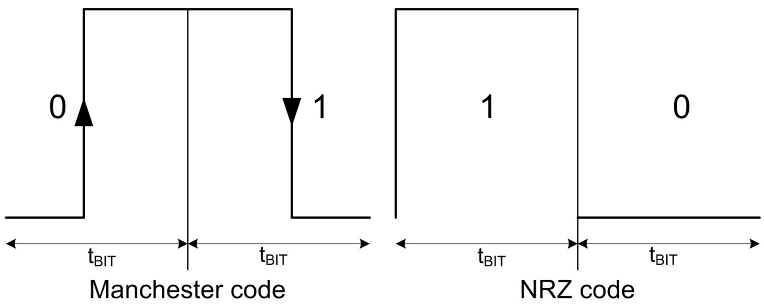

Figure 2.10: The Manchester signal includes more information than a standard digital signal (NRZ or No-Return-to-Zero). Because of this it is possible to reliably detect bit collisions in multiple simultaneous signals and thus implement binary search procedures for multiple access.[10]

is naturally slower and less flexible, because of the limited resources. However, some transponder-driven procedures are very successful, for example ALOHA-based procedures described in Sec. 2.5.2.

Interrogator-driven procedures are divided into polling procedures and binary search ones. The polling procedures require a list of all available tags, that are polled individually. This might be slow for larger amounts of available tags.

Binary search algorithms are very flexible and versatile and are therefore the most commonly used in RFID systems. Binary search procedures are much more effective than polling ones but the bit coding must include a way of detecting bit collisions. The Manchester code in Fig 2.10 is an example of such a coding.

The procedure first requests all tags to identify themselves by their unique serial number. The scanner then receives the simultaneously transmitted serial numbers and detects any bits that are both zero and one. If the third to fifth bits contain both ones and zeros, the algorithm builds a binary three to narrow down the possible candidates. The next step would then be to request all tags that have a zero in the third bit and so on. This is a very effective way of searching through the possible candidate serial numbers. [10]

CDMA

CDMA or code division multiple access does not divide up a channel by time. It rather superimposes multiple coded channels on a single frequency or channel. It is based on the mathematical properties of orthogonality. By coding a message using orthogonal vectors we can superimpose many messages on the same channel and decode them if the vectors are known. In practice, it is a somewhat more difficult because signals cannot be synchronised. This requires compensation by some additional advanced signal processing and filtering methods.

CDMA requires more advanced signal processing than TDMA and other procedures. This makes it an unlikely candidate for low-cost RFID tags. However, CDMA is widely used for mobile telephones and the new 3G UTMS network is based on a variant of a CDMA procedure (W-CDMA). The main advantage of CDMA procedures is the higher utilisation rate than what is possible for TDMA and FDMA. [50]

ALOHA-procedures

The ALOHA method was developed on Hawaii in the 1970s, hence the name. It is a transponder-driven stochastic TDMA procedure [10]. It is designed for systems where multiple transponders need to send only short bursts of data. Today it is exclusively used by read-only transponders.

The ingenious system is based on the ratio, between the short bursts and the available time, that is less than 20%. By using a random number generator the tags are idle for a random length of time and then transmits their message. As long as the number of tags competing for the same broadcasting time is low enough, a very quite effective and simple communication is achieved.

There are many refined ALOHA processes that are more effective than the original but they have the same principle. The slotted ALOHA, S-ALOHA, uses predefined time-slots used the synchronise the transmission. It increases the throughput considerably. The amount of slots can also be dynamical defined by the scanner, which improves the efficiency even further.

2.5.3 Data Security

Often RFID systems are used for access control, ticketing or other services. This requires the RFID tags so be securely identifiable and tamper proof. Finkelstein gives examples of three types of potential attacks on RFID systems [10].

- Unauthorised reading of a tag for duplicating or modifying purposes
- Using a foreign tag in order to gain access or services

- Mimicking a tag by recording and replaying radio transmissions (replay and fraud)

However, all RFID systems do not need to be secure. Different systems for industrial automation or tool recognition might not be worth equipping with expensive encrypting schemes.

2.6 Available frequencies, existing regulations and standards

2.6.1 RFID Frequencies

RFID system generate radio signals that can interfere with other radio applications. Therefore, they must comply to regulations that state which frequencies may be used and the maximum power of transmission. In Europe the European Radiocommunications Committee (ERC) [7] regulates the use of frequencies.

Most frequencies are already in use for navigation and positioning, radio, television and satellite television, communication or for military purposes. Certain bands or frequency ranges are reserved for unlicensed use. They are called ISM bands (Industrial-Scientific-Medical). RFID applications often use these unlicensed bands, see Figure 2.11.

The low frequency range including 134.2 kHz is often used for RFID applications. This range is often referred to as LF (low frequency). The data transmission rate is low because of the low frequency. This is usually used for access control, animal identification and asset tracking.

The range 13.553-13.567 MHz is part of the short wavelength range, often called HF or high frequency. This is commonly used by inductive RFID systems, because of the longer range of the near field. The data transmission rate is not very high, but better than the LF because of the higher frequency. RFID communication for proximity cards in this bandwidth is standardised by ISO 14443 [22].

The frequencies 868-870 MHz are used of RFID application in Europe only. Systems on this band use the backscatter method. Outside Europe the bands 888-889 MHz and 902-928 MHz are used instead. These frequency bands are commonly referred to as UHF or ultra high frequency.

The range 2.40-2.4835 GHz is also used in commercial RFID systems. This

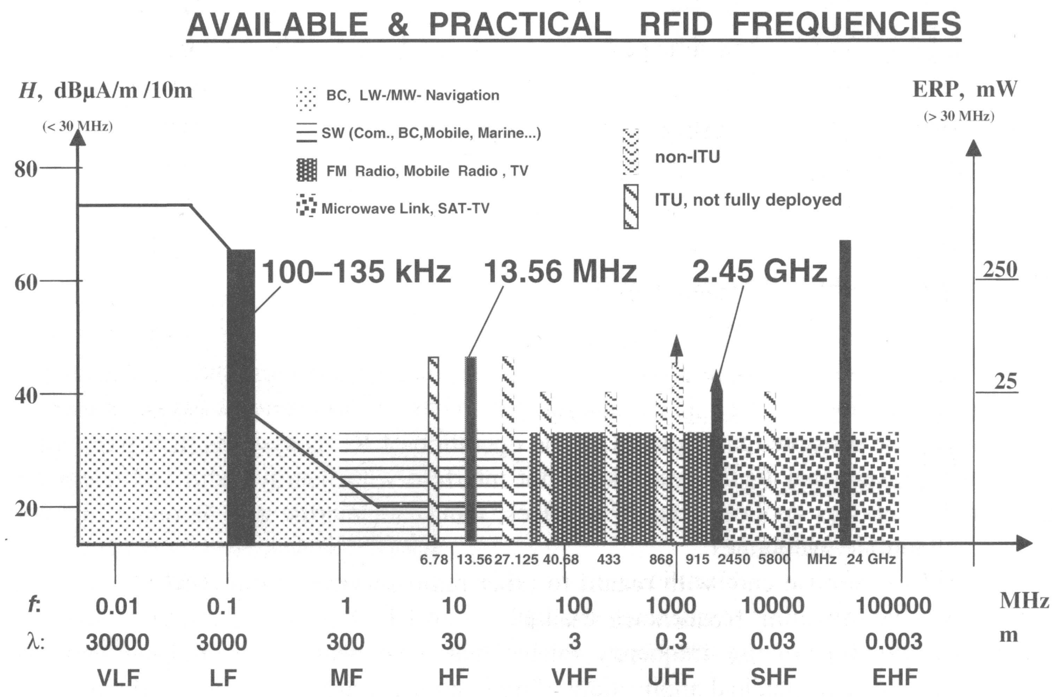

Figure 2.11: Most of the radio frequency bands are already reserved for different purposes. The frequencies used by RFID applications are therefore on the unlicensed frequency bands called ISM (Industrial, Scientific and Medical).[10]

is the same range as WLAN systems use.

2.6.2 Regulations

All the allowed frequency bands also have restrictions on the maximum power that can be transmitted and some other special restrictions designed to prevent the frequency from becoming overcrowded. For RFID systems in Europe the REC 70-03 for Short-Range Devices is central. Products, including RFID systems, that fulfil the relevant requirements can be marked "CE" (EC Declaration of Conformity) without further licensing. In addition to the REC 70-03 there are standards by ETSI (European Telecommunications Standards Institute) that further defines the requirements of transmissions. These are EN 300330, EN 300220 and EN 300440 that regulate 9 kHz - 25 MHz, 25 MHz - 1000 MHz and 1 GHz - 25 GHz respectively. In addition to these there is a new standard called EN 302-208 that enables higher transmitter powers in the UHF band. The EN 300330 mainly concerns inductively coupled devices. The maximum magnetic field H is measured at 10 m from the antenna with a non-modulated signal. The maximum value depends on the frequency allowing higher emissions on some frequencies, i.e. 13.56 MHz. Additionally the maximum fields strength also depends on the area of the antenna. Antennas less than $0.16m$ get a penalty of maximum 10 dB to the maximum field H. The EN 300220 deals with radio transmitters including UHF RFID. It specifies a maximum transmitting power instead of a maximum field strength. The maximum transmitted power is defined as the transmitted output power at 50 Ω or equivalent radiated power (ERP) using a dipole antenna. The EN 302-208 extends the UHF band and enables transmission powers of up to 2W ERP. It does not include any regulations of duty cycles but introduces the concept of listen before talk. This means that the scanner needs to listen for other transmissions before in transmits in order to avoid interference on a specific band. There must also be a break every 4 seconds of transmission, in order to let other transponders use the band as well.

The EN 300440 on the other hand specifies the maximum emitted power as effective isotropic radiated power (EIRP). This means the effect needed by an isotropic antenna (G = 0 dB) to reach the same flux density at the receiver location as the tested device. All these regulations [10], [8] for Europe can be summarised in the Table 2.2.

In the USA, radio devices have to comply to licensing regulations by the FCC. RFID systems are not separately regulated but they need to comply

Table 2.2: ETSI standards for maximum power and other regulation for ISM frequencies[10],[8].

Frequency Band	**Power**	**Comment**
119-135 kHz	≈ 37.7 dB μA/m @ 10 m	Increasing with 3 dB per octave
7400-8800 kHz	9 dB μA/m	EAS systems
13.553-13.567 MHz	42 dB μA/m @ 10 m	9 dB μA/m @ ± 150 kHz
865.000-865.600 MHz	100mW ERP	listen before talk
865.600-867.600 MHz	2 W ERP	listen before talk
867.600-868.600 MHz	500 mW ERP	listen before talk
868.000-868.600 MHz	25 mW ERP	$<$1% duty cycle
868.700-869.200 MHZ	25 mW ERP	$<$0.1% duty cycle
869.300-869.400 MHz	10 mW ERP	
869.400-869.650 MHz	500 mW ERP	$<$10% duty cycle
869.700-870.000 MHz	5 mW ERP	
2400-2483.5 MHz	10 mW EIRP	
5725-5875 MHz	25 mW EIRP	
24.00-24.25 GHz	100 mW EIRP	

to regulations based on the frequency used. The interesting frequencies can be viewed in Table 2.3. In opposite to European regulations, it must noted that the FCC specifies the maximum power in a different way. The electrical field strength E is measured at a distance, chosen to be in the far field region, and must be less than specified values. These restrictions can be converted to effective isotropic radiated power (EIRP) using 2.7. However, these transmission powers are quite low. The FCC part 15 section 15.247 enables higher powers of up to 4 W if a frequency hopping scheme is used. Roughly this means that the US regulations enables 4 W of transmission power for the UHF band whereas EU only permits 2 W, but due to the differences in how the power is measured the difference grows smaller.

$$P_{EIRP} = \epsilon_0 cE/4\pi r \tag{2.7}$$

The regulation of other countries often correspond to either the America or the European ones. One exception is Japan that has a different regulation system. However, it is often enough just to consider the FCC rules of the USA and the European ETSI standards.

Table 2.3: FCC regulations for maximum power and other regulation for ISM frequencies.[10]

Frequency Band	**Max E field**	**Measuring distance**
9 - 490 kHz	24000* μV/M	300 m
13.553-13.567 MHz	10 mV/m	30 m
902.0-928.0 MHz	50 mV/m**	3 m
2.435-2.465 GHz	50 mV/m**	3 m
5.785-5.815 GHz	50 mV/m**	3 m
24.075-24.175 GHz	250 mV/m**	3 m

*The maximum field E is divided by the frequency in kHz

**Using a frequency hopping scheme and an directional antenna up to 4 W EIRP is allowed

2.6.3 Standards

There is a quite broad spectrum of standards concerning RFID use. The most important body of standards is the ISO. They have issued standards for most RFID applications. There is also another body that is working with the standardisation of RFID technologies, the EPC Global [6]. EPC Global has among other things defined a unique electronic product code (EPC) that can be used to identify singular items.

There are standards for proximity and vicinity smart cards, the ISO 14443 and the ISO 15693.

More important and a bit controversial is the ISO 18000 standard [23] that defines the air interface for almost all RFID frequencies. This standard consists of different parts that each specify communications on a certain frequency. The sixth part deals with UHF, which is divided into 902-928 MHz in America and 888-889 MHz in Europe. In addition to this, there is a competing standard by EPC Global that also defines communications but it is not completely compatible.

There are also ISO standards for the purpose of animal identification, the ISO 11748/11785. Other relevant standards are those for supply chain monitoring including freight containers; ISO 17358, ISO 17363-17367 and ISO 10374.2.

In contrast to the ISO that mostly consists of scientists and academics the EPC is more represented by companies looking to use the technology. This can also be seen in the way EPC classifies RFID, it is classed in the standards according to the capabilities of reading versus writing and active versus passive. There are some different versions or generations of the EPC standard. The first one was called Gen-0 and the one widely in use today is Gen-1.

Gen-2 is currently replacing the older ones but still has some compatibility issues with the ISO-18000-6 in the UHF band.

2.7 Commercially Available RFID Systems

This section will review commercially available RFID solution today. It will give the reader examples of how RFID is used and for what purposes. Finally we will have a look at general drawbacks and risks of RFID, especially ethical and privacy issues.

RFID applications are in wide use nowadays. We use RFID technology almost every day without even thinking about it. Access control is almost completely dominated by RFID tags. You just show your card or key fob to a reader to open the door. Another common application we don't even think about is the electronic immobilisation of the car. If the right key isn't present the engine will not start even though the key is turned. Such a system is standard in most new cars. Ticketing for public transportation is also a good example of a successful RFID application. Many ski lifts have adopted the technology, too.

Other commercial applications are identifying shipping containers and keeping track of asset and stock. The next big step would be applying RFID tags to individual stock items. This would enable us to track items all the way through the supply chain, from the manufacturing batch to the customer buying them.

Some organisations have shown great interest in the implementation of RFID tracking throughout the supply chain. The pioneers within this field are, among others, Wal-Mart, Tesco (UK) and the US Department of Defence (DoD) [46].

2.7.1 Access Control

Access control using RFID is easy and quite well standardised today. RFID tags can be in cards, key rings, mounted on the windshield of a car or practically anywhere else. Passive inductive RFID is used in badges or key ring and usually have a range of less than 10 cm. Backscatter RFID can be used for access control for vehicles. A tag mounted on the wind shield can be read on a distance of up to 7 meters. The vehicle mounted RFID tags can be either passive or semi-passive.

2.7.2 Public Transportation Ticketing

Using smart cards for public transportation ticketing has been a success. It considerately speed up the ticketing process. Many cities have already adopted such systems. One example is the Helsinki region where the public transportation company YTV launched their RFID smart card "Matkakortti" in 2001. Passive inductive technology is used for ticketing. Because of the advanced security routines needed in the tag in order to avoid counterfeiting, more power is needed for the electronics than for example access control tags. This means that the range of ticketing RFID systems are limited to only a couple centimeters, often called close coupling.

2.7.3 Animal Identification

RFID for animal identification has been in use for quite some time. Pets can be marked with a small chip under the skin in the neck so that the owner can be traced if the animal gets lost. Systems used for animals is always passive inductive RFID.

Tags are also used to identify livestock. They can be used to identify an animal when it gets fed to track its health. It is also useful for tracing the origin of meat because the butchery can easily identify animals. Tags for domestic animal are manufactured in many different forms. It can be a standard ear tag or collar band, an implant under the skin in the neck or a bolus, i.e. a tag that is swallowed by the animal and stays in the digestive system [10]. Often hand held scanners are used for identifying tagged animals. Gates with large scanning antennas can also be used.

2.7.4 Anti-theft for Cars

Today many cars have an electronic device that inhibits the ignition in the engine if the right key is not in place. This is called electronic immobilisation. The mechanical key incorporates a RFID tag that is checked by the sensor in the car independently from the mechanical lock. Passive inductive technology is used for this purpose. Electronic immobilisation devices have been fitted on almost every new car since 1995 [10]. However, keys can still be counterfeited or stolen.

2.7.5 Sporting Events

RFID systems can also be used in sporting events to automatically time participants. It is especially useful in mass events as marathons and cross-country skiing events. Participants only need to fasten a small transponder to their shoe or to their bike. Rubber mats with integrated antennas are then used register the passive inductive RFID tags as they pass over. These large rubber mats can, for example, be placed at the starting line, mid timing lines and at the finish line. This allows fast and easy timing and real-time results during the event at a low cost. Systems like this have been used in major marathons for almost 10 years [3].

2.7.6 ID to Remove Human Error

One interesting application of RFID technology is aiding people in avoiding mistakes. *Errare humanum est* is a well known fact. By building smart system that can cross-check things we do, we could reduce errors in processes where mistakes are expensive, for example in health care and some critical industrial processes.

Double-checking can be done by tagging objects and having an automatic sensor that checks the object when it is applied somewhere. The system would recognise the object and could give a warning if it is not correct. For example chemical containers and gas bottles could have transponders that contain information about their contents, size and maximum pressure. Before containers are refilled they can be checked automatically to ensure that they are compatible.

Other uses that have been suggested is drug administration in hospitals [18], see Section 3.2.2, and cross-checking of blood transfusions [53] with bar codes.

2.7.7 Logistics

The word logistics has many definitions, basically it is the art of managing the flow of material. One definition

> *"Logistics is the function responsible for the flow of materials from suppliers into an organisation, through operation within the organisation, and then out to customers."*

is given by Waters in his book [47]. Would it not be revolutionary to the discipline to be able to track all items in real-time?

Logistics was first used for military purposes. It was the managing of supplies for troops. Today logistics is mainly used in business context.

Simply one can say that logistics or the more holistic term supply chain management means all the functions that deals with having the right stuff at the right place at the right moment. The term supply chain management visualises that in order to optimise your logistics you need to take the whole chain of suppliers in consideration, it cannot be done focusing only on your own little part.

The automatic detection of products with RFID provides a new powerful tool for managing logistics, as Wal-Mart and DoD have predicted. They are among the first organisation that have tried to incorporate source tagging of all products in their supply chain, i.e. adding transponders to product during manufacturing in order to track them later. DoD, for example, already requires all suppliers to add RFID tags to the their products.

Asset Tracking

One of the more obvious uses for RFID is asset tracking. One can pinpoint the location of RFID transponders within a network of sensors. This can basically be done is two ways. Large shelves can be fitted with inductive readers that continuously scan the objects on the shelves. This way it is every object that is removed or added to the shelf is automatically updated into a database. The other method is to keep track of inventories inside a large building. Active tags, i.e. tags sending out a signal, can be positioned based on which antennas can read the signal. This way the piece of equipment can be positioned to a certain room. By attaching such transponders to inventories you can prevent them from ”wandering” away. Localisation would also allow you to use your resources more effectively by minimising waste, i.e. both the need to replace misplaced items and reducing the time staff spend looking for missing items [9], [35]. Personnel can be tracked as well, to allow colleagues to get hold of each other quickly.

Shipping Containers

The ISO 10374 standard defines the RFID identification of shipping containers. Active microwave backscatter transponders are used for this purpose. They work at several frequencies because of differences in regional legislation, see Section 2.6.3, and employ a modified FSK subcarrier procedure [10].

Cellular phone as universal RFID reader

Some cellular phones today have a inductive RFID scanner feature. Such integrated RFID scanners can make RFID technology more popular and widespread.

2.7.8 Personal Identification

One use of RFID is personal identification. Access control systems are one kind of personal identification. RFID technology will also be used in the new Finnish biometric passports. The passports will be readable only when opened, according to official statements.

Implants can also be used for identification. On the market there is an implantable RFID chip that can contain data, [44]. It is called Verichip and is implanted under the skin. It has been approved by the FDA in the USA, which means it is quite safe to use. One night club in Barcelona even uses these implants to identify their VIP customers. This is perhaps more for the publicity of it than for the convenience and practicality.

Other Applications

In the USA, Chase Bank is advertising their new contact-less pay card called Blink [4]. This is a pay card that you only need to show to the reader at the till in order to pay. This is perhaps a bit alarming because somebody could walk close by the reader and pay somebody else's bill. If somebody got hold of a modified reader this could be a new tool for pick pockets.

2.8 RFID tag sales today

In Table 2.4 we can see the global cumulative tag sales by the end of 2005 [20]. The most important category is passanger/automotive that includes both car clickers, i.e. car keys, and public transportation ticket smart cards. The second most important category is access cards and third come tags for tracking pallets and cases. These three main categories made up close to 80% of the tag sales by the end of 2005. The RFID consultancy com-

Table 2.4: Global cumulative sales of RFID tags by 2005 [20].

Category	Sales (M$)	Comment
Retail / customer goods	230	UHF/HF pallets and cases
Logistics / postal	15	containers, postal testing
Airlines / airports	25	LF / UHF baggage and vehicles
Health care	40	staff and patients
Animals / farming	65	LF
Libraries/archiving	70	HF
Manufacturing	50	LF / HF
Leisure	100	LF / HF Toys & sports
Laundry	75	Hospital, hotel & military
Financial / Security	670	Access cards
Military	2	LF/HF/433MHz assets&vehicles
Passager/automotive	1000	car clickers, ticketing
Other	80	LF/HF
Total	2422	

pany IDTechEx predicts that the sales of 2006 alone will be greater than the cumulative sales up to 2005. By 2010 the tag sales will be 12.35 G$.

If item level consumer goods tagging will be taken into use, then the potential market for tags will be enormous. IDTEchEx estimates that the market value by 2020 is as high as 10,000 G$. This would be by far more valuable than estimates for any other field of use. Widespread use of RFID tags by postal offices does also show great potential, 650 G$. The RFID tagging of drugs and pallets/cases have a large potential, 70 G$, too, but it is only marginal to the tagging of consumer goods.

2.9 Health risks of RFID

Today there are hundred of thousands of RFID scanners and EAS systems in use. All of these systems utilise EM fields to detect and scan tags. According to some sources RFID systems pose no threat to the health of ordinary people [39], this might be true but prolonged occupational exposure may occur.

The report by The International Commission on Non-Ionizing Radiation Protection (ICNIRP) [42] examines the effects of EM radiation on humans. The report describes mechanisms of thermal and non-thermal interaction between EM fields and biological systems. Thermal interaction is the heating of tissue which can cause damage. The most notable non-thermal interaction is membrane stimulation, this means that the membrane potentials may be altered at a cellular level and might have effects on the nervous system. The report states that the high frequencies of EAS/RFID system produce no heating or thermoregulatory stress [42]. However, EAS and RFID devices may interact with medical devices such as pacemakers, which can cause dangerous situations. The report recommends that further studies should be made on this area and that device manufacturers should provide information needed for health risk assessments. There is also a need to continue to collect exposure data, especially for occupational groups. If possible low-frequency and high-frequency exposure should be differentiated.

2.10 Suitability for Hospital Environment

We know that strong electro-magnetic fields can interfere with electronics. Hospitals contain many devices that are critical, e.g. life supporting equipment that must not be disrupted.

Today many hospitals have banned the use of cellular phones because of the risks of interference. How are RFID application compared to this? Are they a potential source of interference, too?

Since 1993 there has existed an electromagnetic compatibility (EMC) standard for medical devices (MD), the IEC 60601-1-2. It was, however, only specified for frequencies lower than 1 GHz. In 2001 it was updated to cover frequencies up to 2.5 GHz. In the standard it is specified that life-supporting equipment must be able to handle field strengths up to 10 V/m and non-life-supporting up to 3 V/m.

RFID transmitters and similar short range radio devices are regulated separately in Europe and in the USA. In Europe regulations are country specific but replaced based on the European Conference of Postal and Telecommunications Administrations (CEPT). In the USA radio devices have to conform to the Federal Communications Commission (FCC).

A study conducted in Sweden [45] has tested the compatibility of different cellular phone technologies and WLAN (802.11b) with medical devices. Both laboratory test according to ANSI standards and clinical test have been performed. The study showed minimal interference between medical devices and WLAN communications. Some rare pieces of old equipment were affected by cellular phones broadcasting at full strength.

2.11 Summary

RFID systems consist of transponders and scanners. Transponders can contain a certain amount of data, much like an advanced bar code. The can remotely be scanned or read by a RFID scanner even without a direct line of sight.

The two main types of passive RFID is inductive and microwave backscatter RFID. Inductive RFID uses the inductive coupling between two coils. The magnetic or near field is spatially restricted, which means that the range is limited. The rule of thumb is that the range of the system is less than the diameter of the antenna. Inductive RFID often function on either LF, about 130 kHz, or HF at 13,56 KHz.

Backscatter RFID, the other type of RFID, uses EM waves. This gives the backscatter systems a much longer range compared to inductive systems. Backscatter RFID usually use the UHF frequency of ca 900 MHz. Often the power, needed for the electronics in the tag, is the limiting factor for the range. In order to acquire longer ranges semi-passive systems are used. This means that the transponder has an integrated battery for powering the microchip.

All RFID systems are to some degree affected by their surrounding materials. The microwaves of backscatter RFID is very susceptible to metal because they are easily reflected. Aqueous materials absorb frequencies close to 900 MHz very effectively. Inductive RFID is less susceptible, but metallic object may still alter the resonating frequencies.

RFID is used in our daily life even though we do not always notice it. We use key cards to unlock doors and we start our car with electronic immobilisation. We use smart cards for public transportation and perhaps for ski lifts. Similar technology is also used for identifying shipping containers and at farms to identify livestock. RFID is also taking its first steps into hospitals.

Chapter 3

Tracking and Monitoring Systems

In this Chapter we review different methods of implementing a tracking or monitoring system. We will also take a brief look at previous applications including tracking of materials and monitoring of anaesthetic drugs.

3.1 Available Technologies

The goal of a tracking system is to measure flows of materials and people. This can be done in two ways. We can either have a larger system that can pin point transponders anywhere, by the means of network of antennas covering the controlled area. The other method would be to only scan all items going through some gates or doorways. This can give us enough information to pin-point the transponders at room level depending on the number of control gates.

We will examine technologies that are available on the market and give some price estimates. We limit ourselves to tracking systems capable of either registering items going through a gate or locating a transponder by multiple antennas. During the evaluation of the different techniques we will assess their the suitability for our hand hygiene monitoring project described in Chapter 4. For this we need detection with high temporal and spatial resolution at certain key locations, e.g. for detecting and identifying someone using a wall mounted device. The fundamental requirement for the detection system could be translated into a detection range or accuracy of a half metre.

Table 3.1: Passive inductive RFID

	Scanner	Antenna	Tag
Price	1000-2500€	Custom loop	200€ / 100 pcs.
Size	Large	Large	Credit card

3.1.1 Inductive passive RFID

As a first passive solution, we consider traditional passive inductive RFID technology. This is based on the induction coupling of two coils through magnetic flux, see Section 2.4.2. The inductive coupling supplies energy for the tag and functions as an up-link information channel through load modulation. Passive inductive RFID technology is used in many everyday applications. For example, access control devices often use 132 kHz magnetic fields and public transport fare systems use 13.56 MHz magnetic fields to identify and charge passengers.

This technology is great for access control but it is designed to require the user to the show the card / tag to a scanner. Gate antenna configurations as wide as 1-1.5 meters are also possible.

This kind of technology is used for the identification of cattle and other animals. However, the tags used need to be scanned by hand. Alternatively, cattle can be driven through a narrow gate with large loop antennas for scanning.

The problem with this solution is the range or the lack of it. Most inductive RFID systems are designed for less than 10 cm, because the inductive coupling gets much weaker over longer distances. A range of over 50 cm is achievable but it requires large currents and an antenna that is of the same size as the distance. Still reliability is a serious issue because of the orientation sensitivity of the inductive coupling. If the receiving coil is parallel to the magnetic flux fields no flux will be detected through the coil and thus no coupling will be present. The advantage is that the magnetic fields can penetrate most materials quite well. Water does not constitute a problem, nor do smaller metallic objects.

The price information in Table 3.1 is obtained from TopTunniste Oy[1].

[1] ToP Tunniste Oy is a Tampere based company that focuses on RFID solutions for identification and data collection. It has a web store for RFID hardware. www.toptunniste.fi

Table 3.2: UHF backscatter passive RFID

	Scanner	Antenna	Tag
Price	≈ 1000€	Integrated	100€ / 100 pcs.
Size	Medium	N/A	10 cm

Suitability

This is a technically feasible solution but not very practical because of the large gate antennas.

3.1.2 Passive backscatter UHF RFID

The RFID technology that shows most potential is the passive backscatter UHF. It works like radar, by detecting tags by their reflected electromagnetic power. It supports high reading speeds enabling many tags to be read in a short period of time. Communications take place through modulating the reflective properties of the tag antenna. UHF RFID systems have a range of over 5 m. Systems like these have been proposed for improving logistics through their ability to detect goods automatically. An array of scanning antennas can rapidly scan a whole pallet of consumer goods and acknowledge them as arrived without any human intervention.

The drawback of UHF RFIDs is reliability. The detection is quite sensitive to the orientation of the tag, thus requiring several readers or restricted orientation of the tags. Even more important is that the frequency close to 900 MHz is very effectively absorbed by water. This means that a tagged bottle of water or a tag enclosed in a hand are virtually invisible to scanners. Because of this high absorbance of the body, UHF RFID is not used for identifying persons.

In our application UHF RFID could be an alternative because we only need to detect users from the front. A person must use both his hands to use a gel dispenser and must thus be facing the dispenser and the scanner. A UHF tag, integrated in the name tag of personnel, can be detected, as long as no arms or any other body parts block the line of sight. Expert estimates of the reliability of the proposed system would be between 80% and 90% which is not good enough for us. The price information in Table 3.2 is obtained from Vilant Systems Oy[2].

[2] Vilant Systems Oy is a Espoo based RFID consulting and systems integrator company. www.vilant.com

Table 3.3: Semi-passive Transponders

	Scanner	Antenna	Tag
Price	2800-4000€	Integrated	25-45€
Size	Small	N/A	Thick credit card

Suitability

Passive backscatter RFID is not suitable for identifying persons, because of the high absorbance of the human body.

3.1.3 Semi-passive Transponders

Semi-passive or battery-assisted transponders utilise a battery to power the electronics. However, all communications remain passive. Information is sent by modulating the reflected signal, exactly in the same way as UHF passive RFID.

By using a higher frequency like 2.45 GHz we can scan through many materials, including water. Elcoplast[3] in Tampere offers a solution for hands-free identification, see Table 3.3 for price details. Their Confident system consist of credit card sized, semi-passive, battery assisted tags that can be read by scanners from up to 8 meters away. The readers are directed, so by placing one suitably, for example in the ceiling, we can obtain a reading area that corresponds to our needs.

This system is used for identifying cars at gates, but it can also be used for personal identification. It is used at paper mills for access control for both cars and personnel. The system is not very orientation dependent because of the on-board energy source. It is designed for hands-free use, which can be needed in clean-rooms. The system has not been used in hospital environments in Finland. The transmitting power is only 50mW, which is less than standard UHF readers.

Suitability

This solution suits our needs, however, it is more expensive than passive systems.

[3] Elcoplast is a Tampere based family company that specialises in remote identification, data collection and electronics development. www.elcoplast.com

3.1.4 Active Transponders

Active RFID transponders are radio beacons that transmit a signal with the aid of an internal power source. These transponders become more expensive than the passive counterparts because of their on-board power source. Here we can separate two different types, one is UHF tags communicating with WLAN stations that can be used for localisation. The other type is a simple active beacon that is detected by a custom scanner. Sometimes infrared diodes and sensors can be used as an indoor positioning system. A simple system much like the remote control for the television can position an emitter to a certain room, because IR light is easily reflected by walls. IR positioning is not suitable in more open areas.

Tracking System

There are many commercial systems offering localisation within buildings. These systems consist of a tuned network of antennas on the premises that detect active tags. Tags detected by several antennas can be located by the strength of signal or the delay of it. Range is not a problem but the spatial accuracy is not very good. An optimised network of readers can pinpoint beacons by less than a metre. This might be good enough for our purpose, but setting up such a network is not cheap. GE Healthcare[4] offers solutions like this, so does Exavera Technologies[5]. Ekahau[6] also supplies both technology and solutions for various tracking purposes.

Suitability

A tracking/positioning system would supply us with the information needed. Costs are higher than in the semi-passive system but the tracking capabilities of the positioning system are much more versatile. It can include monitoring of several processes.

[4]GE Healthcare, a part of General Electric that bought Instrumentarium in 2003. www.gehealthcare.com

[5]Exavera Technologies Inc. is a US company that specialises in advanced wireless networks for identification of both assets and people. www.exavera.com

[6]EkaHau is a Finnish/American company that supplies Wi-Fi tracking technology. www.ekahau.com

Table 3.4: ActiveTagTM

	Scanner	Antenna	Tag
Price	$ 1800 + taxes	Included	$ 18 + taxes
Size	Medium	Large	Thick credit card

3.1.5 Combinations of Active and Passive

A combination of the earlier mentioned techniques could be employed to solve our problem in a better way. By combining the specificity of induction coupling with the range and reliability of active tags we could meet the specifications.

A product called ActiveTagTM[7], see Table 3.4, offers a solution for hands-free access control. The system consists of active tags that communicate with scanners resembling WLAN stations. This gives the system a good range and read reliability. The specificity comes from separate activators that create a LF magnetic field. When a tag enters / detects such a field it sends a signal through the scanners notifying the central information system of its location close to the activator.

Suitability

The system is capable of suiting our needs regarding both specificity and range. However, the only supplier is in the USA.

3.1.6 Summary of Technologies

As we can see there are many ways to accomplish tracking. The passive inductive RFID solution seems to have too short range for tracking in a busy environment. The passive backscatter has serious issues with metals, water and human tissues. A semi-passive solution could be reliable and practical enough for a tracking system. On the active side we can conclude that the Wi-Fi network seems quite practical. The precision, however, is not necessarily very good.

[7]ActiveTagTM is a product by Axcess Inc. that is a US company that delivers RFID tracking and video survaillance solutions. www.axcess.com

3.2 Published Proposals of Tracking / Monitoring Devices

The following examples of RFID tracking or monitoring devices have been found using different search engines. Some are found through PubMed (MedLine) and some through Google.

3.2.1 Asset tracking

Tracking assets has become a popular way of improving performance of organisations. Tracking assets will in theory reduce the time personnel spends looking for equipment they need, will improve the utilisation rate of equipment and reduce lost equipment. Today there are many solutions on the market that offer asset tracking through tagging key assets and setting up receivers at the premises they are used in. Some have tracking systems especially design for hospital use [14].

Østby et Al [35] have conducted a study to find out if tracking assets with RFID and IR really help improving the utilisation rates. The study was carried out in 2002. Østby wanted to know the accuracy of the tracking system, its effects on the utilisation rates and how it is perceived by personnel. One potential use of the system would be charge capture, i.e. focusing the costs of the equipment used to the right ward. The experiment was carried out at the Duke University Medical Center in North Carolina, US. Two almost identical wards were selected, one for intervention and the other for control. Control studies were performed both before and after the intervention period. Both wards had 32 beds, about 40 nurses, about 30 patients and a average patient stay of six days.

The system selected was delivered by Hill-Rom Inc. and used RF and IR signals to locate electronic tags. Signals were sent every 10 seconds and a central computer kept track of the equipment. The location of equipment was then graphically shown on a monitor that staff uses.

Three key equipment types in both wards were tagged, infusion pumps, sequential compression devices and beds. In the intervention ward sensors were installed and dummy ones at the control ward. Direct observations by surveyors were used to monitor the accuracy of the system.

Østby found that the accuracy of the system was about 80 %, and that the accuracy of locating equipment to a specific room was a little less than 80 %. The results showed that only the utilisation rates of the infusion pumps increased significantly. Staff also reported that the pumps were easier to find with the new system.

If the scale of the experiment had been larger, i.e. the whole hospital, the result would have probably been better. Not all the equipment was tagged because of the limited scope of the study. However, the technical part of tracking is straight-forward but implementing it in a heterogeneous hospital environment with multiple administrative units is not an easy task.

3.2.2 Avoiding mistakes

Intervention to avoid mistakes is one of the key applications for RFID. Some experiments have already been carried out in several places to reduce errors.

The Food and Drug Administration (FDA) mandates that drugs and blood delivered to US hospitals must be bar coded so that they are machine identifiable [12]. This is the first step towards machine prevention of errors; the next step would be to incorporate RFID tags to items.

Error prevention is more than just having a machine that double-checks medication. It is just a minor part of a greater quality assurance strategy.

Drug administration

Errors in medication and administration of drugs are very costly for the health care sector. Studies say that about 7 % of the patients [2] in the USA experience an adverse drug experience (ADE) and that the costs of these are about 80 billion US$ annually [25]. Much has been proposed to address this, Bar Code Medication Administration (BCMA) is one method. It is basically a system that requires drugs and patient to be identified electronically before administering medication. There is clinical studies suggesting that BCMA systems might prevent ADEs significantly, even up to 58 % [24]. However, negative effect like confusion and reductions in flexibility among staff have been detected as well [36].

In Auckland many hospitals are using integrated drug administration system (IDAS) to support drug administration in the operating room (OR). The system is a set of procedures and tools for keeping the anaesthetic drug administration area in order. It includes a piece of software that confirms drugs before administration and keeps records.

During operation an anaesthetist usually works within a small area, see Figure 3.1. All the drugs, whether in ampoule or pre-filled syringes are bar coded

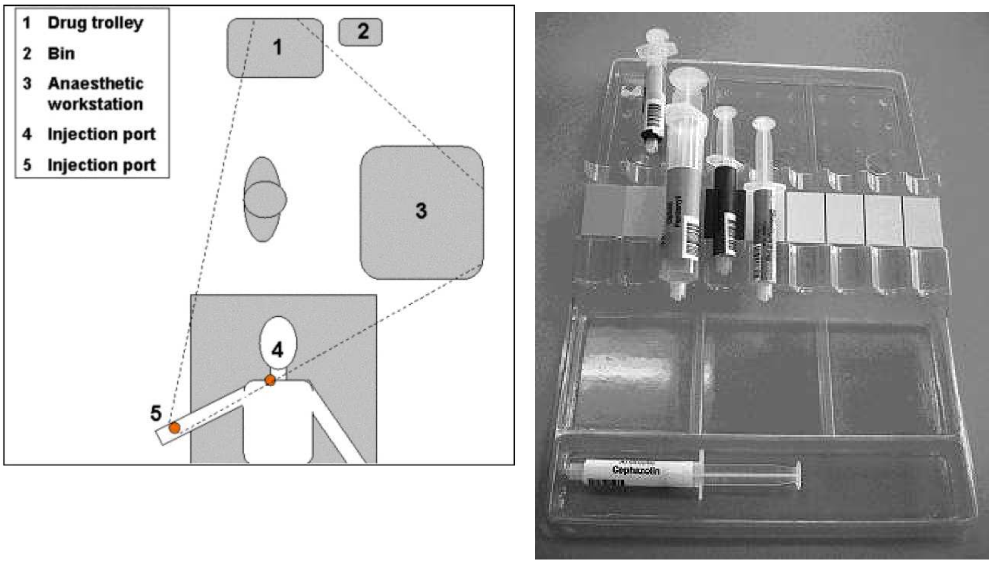

Figure 3.1: The area, in which a anaesthetist mostly works, is called the anaesthetic triangle. (left) The drugs to be used are drawn up into syringes and placed on a special tray for easy access and avoiding mix-ups. (right) [18]

according to international standards. Before operation drugs are prepared and drawn up into syringes that also have bar codes. All the syringes are placed in special trays to keep the work surface organised, see Figure 3.1.

The anaesthetist has one monitor for the patient's condition and a separate for the IDAS software. On the monitor, details on the operation and the patient can be seen, as well as all the drugs injected and other anaesthetic details. Before administering any drug, the bar code of the syringe is scanned and the amount is entered to the system. At the same time the system reads out aloud the name of the drug in order to confirm it with the anaesthetist.

In simulated environments the IDAS system seems to reduce the numbers of ADE's compared to traditional methods [48], but the usefulness might be limited due to usability issues. Reading bar codes requires that the syringes are held in an particular way and they are taken close to the reader.

Houliston [18] has tried to implement a RFID extension to an existing IDAS system. RFID could overcome many of the usability issues of the bar code system because RFID does not need a direct line of sight. A RFID system at 13.56 MHz was used with transponders wrapped around the syringes for optimal usability. The system is only an extension to the bar code interface,

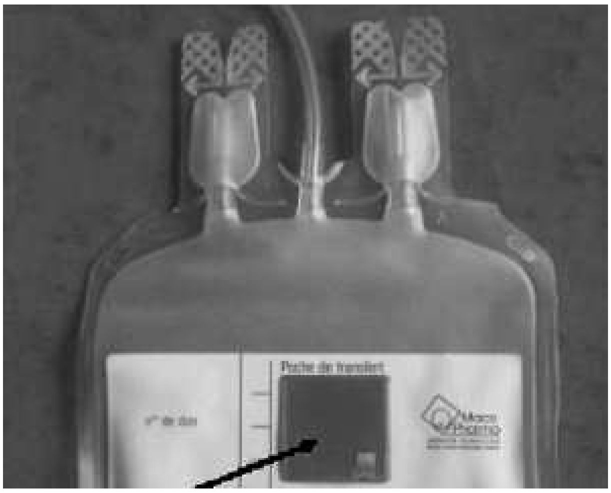

Figure 3.2: All blood bags are fitted with RFID tags. Before transfusion these are scanned and compared with patient wrist bands to ensure that the patients are given the correct blood. [33]

which means that the RFID system simulated a bar code being read.

The reader would need be as practical as possible, allow a maximum of time of intervention and minimize the exposure to the patient. Therefore the RFID reader was placed under the drug tray so it could detect any syringes being removed.

The trials were promising but further work is still needed. Undetected syringes and advert reads are problems in certain situations, due to the range of detection of the tags. No tests were made to check interference by medical equipment in the OR.

Blood transfusions

A pilot study in Massachusetts General Hospital tried the RFID technology to reduce blood transfusion errors [33]. As in many studies, patients were fitted with RFID bracelets that contain patient information, including blood type. Every blood bag was also equipped with a tag. The system has RFID readers built into the blood transfusion apparatus, see Picture 3.2. When preparing to administer blood to the patient, the system cross-checks that the blood really is suitable for the patient. If not, the apparatus gives a warning signal.

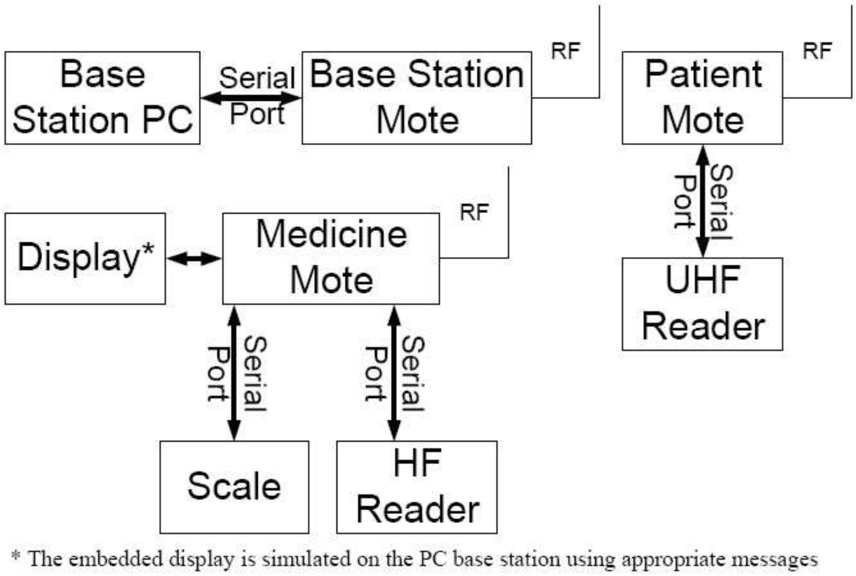

Figure 3.3: A schematic figure of a RFID and sensor mote system. The system consisting of HF and UHF RFID scanners and a pair of scales can follow up medication intake and reminding patients to take their medicines.[17]

Elder health care - Drug reminder

RFID systems can be combined with sensor networks to create intelligent systems. There is some published research about a medication reminder for elder health care [17]. The proposed medication reminder involves a small network of RFID sensors that both follow-up medicines and patients. The system, see Fig. 3.3 and Fig. 3.4, includes a HF RFID reader that monitors a tray of medicine bottles placed on a scale. The RFID component offers a way of knowing what bottle is removed and when it is replaced. The scales, on the other hand, can tell the total weight of all the bottles. By combining the information from these two components the exact amount medicine extracted from any of the bottles can be determined.

An additional node of the system contains an UHF RFID sensor that detects the patients. The patient is wearing an UHF tag (or several to ensure correct detection) that is detected when the patient is in the proximity of the medicines. This way the system knows the patient and can remind him or her of the medicines to be taken. Communication with the patient can be carried out by an embedded display by the medicine tray.

Figure 3.4: The implementation of a system consisting of HF and UHF RFID scanners for reminding patients of taking their medication.[17]

Tracking / Information systems of Dental Prosthetics

Radio frequency identification offers a monitoring tool for manufacturing processes of highly individualised products. The dental prosthetics, i.e. crowns or bridges, are highly individual and customised to fit the receiver. In addition they need to meet very high standards of quality because of their field of use.

A French company is offering a RFID solution for tracking and assuring quality of dental prosthetics [21]. The process begins with a RFID tag being inserted into the prosthetic when it is moulded. Because of this, the prosthetic can be correctly identified during all the phases of manufacturing to ensure the right work is being done to the right prosthetic. In addition to this, all the materials, operations performed and operators are recorded to the tag with a time stamp for later tracing. When the dentist receives the prosthetic and installs it to the patient, the information is moved to some other medium for future storage while the tag itself is deleted to ensure confidentiality.

Complete Tracking Systems

Today there are complete tracking systems available for hospitals. There are many suppliers of such, Exavera, GE Healthcare and Ekohau to mention a few. These tracking or indoor positioning systems are often called real time location systems (RTLS).

These systems provide the tracking of almost all materials in the hospital worth tagging. Patients, staff members and visitors are provided with a ID tag that enables the system to pin-point their location at any time. A very fun animation of how the Exavera eShepard system works can be seen at http://www.exavera.com/healthcare. The advantages of a tracking system would be increased utility rate of materials like, more effective staff, less mistakes with mixed up patients and more efficient work flow.

Tracking systems can be based on standard Wi-Fi 802.11a/b/g access point or they can use modified Wi-Fi access point with RFID readers included.

The Töölö study of time accuracy of RFID data entry

A study at Töölö Hospital investigated the accuracy of an automated patient tracking system at an operation room [31]. Traditional entry of data into information systems is subject to delays and human errors, which prevents the system from being effective at detecting inefficiency and bottlenecks. Novel RFID and wireless detection systems could provide means of automatic patient tracking. The tracking system was the indoor positioning solution (IPS) provided by Radianse Inc[8]. The patients were equipped with transmitters that are detected and pin-pointed at a room level accuracy. The information provided by this tracking system was used to time-stamp certain key events such as "Patient ready for OR", "Patient in OR" and "Patient out of OR". The same information was also gathered traditionally by staff and by a dedicated, independent person for reference. The results suggested that the automatically obtained time-stamps were considerably more accurate than the traditional ones. Traditional time-stamps are usually first recorded on paper and later entered into the information system. This also suggested that the old system could not be used for real-time monitoring of the patient flow. An automated system, on the other hand, could give alerts or reminders if a patient is taken to the wrong OR or has been waiting too long. Automated tracking also reduces the time nurses need to manually enter data into information systems and frees them for more important patient work.

However, the trial of the patient tracking system was not without difficulties. The reusable tags must be disinfected between use, which is quite costly. They can also easily be detached from the patient. New disposable wristband

[8] Radianse Inc. is a American company that specialises in active RFID technology for health care.

transmitters could solve these difficulties [31].

3.2.3 FinnWell projects

FinnWell is a Tekes programme to promote health care technology in Finland. The program aims both at improving quality and profitability of health care and promoting health care-related business and export. There are three different kinds of projects funded, diagnostic technologies, care related IT products and the development of operational processes. [11]

The ”Wireless technology in hospital operation management“ project is carried out by the University of Oulu at various hospitals. This project aims at developing technology and concepts for a wireless hospital, that systematically can collect data on process using time, location, identification and measurement data. Optimisation can be performed when it is known how both people and materials move. In the beginning mostly WLAN technology will be used but development work is also done on Ultra Wide Band (UWB) technology.

FinnWell also involves the private sector in its projects. The ”Wireless transmission and location in hospital[9]“ project, where ODL Terveys Oy develops and tests WLAN and UWB based medical and logistical processes, where location data is utilised. In the ”Wireless monitoring and data collection for nursing[10]“ project a company called Incode Oy developed data transmission systems for hospitals to improve the accuracy of treatment data. [11]

3.3 Summary

In the beginning of this chapter we took a look at different technologies or techniques for implementing a tracking or monitoring system. We found several ones that had varying strengths and weaknesses. The technique to be used depends much on the exact purpose of the system. If we only need to know when someone or something is at a exact location we use gate antennas with passive inductive RFID. If we need to recognise non-aqueous and non-metallic objects we can successfully use passive backscatter RFID. In case we only need to roughly know the location of something or someone inside a building we can use an existing WLAN network or special antennas for triangulation.

[9] Langaton tiedonsiirto ja paikannus sairaalassa
[10] Langaton hoitotyön seuranta- ja tiedonkeruujärjestelmä

We have reviewed many applications of RFID systems for monitoring or tracking purposes. RFID systems can be used to safeguard against mistakes by cross-checking blood bags with patients automatically. The same can be done to avoid ADE by electronic drug ordinations and the scanning of both medicines and patients to ensure they are the right ones. Intelligent system can also be built to aid anaesthetists during operations or elder citizens to take their prescriptions.

RFID tags and scanner offers a whole new tool for automatically collecting information about complex systems and for designing intelligent systems that are limited only by our imagination. The problem is to find suitable uses where we can gain some added value by applying a monitoring system. Finding such an application is not easy but requires thorough knowledge of the problem and professional skills to realise the system in a productive manner. If the system mainly consists of people working together, as often is the case in health care, it is very important to take this factor into consideration. A tracking system meant for monitoring people is much more demanding than a system meant for tracking cattle at a farm or luggage at an airport.

Chapter 4

Case: Hand Hygiene Monitoring

The previous chapter reviewed different technologies for monitoring and tracking and presented different applications of RFID system for health care. This chapter will focus on a special problem and the application of RFID technology to solve it. We will try to improve the hand hygiene at hospitals by constructing an electronic monitoring system that ensures the use of alcoholic hand rub.

4.1 Nosocomial Infections

Nosocomial infections or care-related infections are all infections that are acquired during care at any health care unit. It is roughly estimated that about 1 in 10 patients admitted to hospitals are affected by a nosocomial infection [26]. A patient with an infection is hospitalised for much longer than otherwise needed, which causes additional cost for the health care system. It is estimated that in Finland, nosocomial infections cost about 200 M€ [28]

In Finland, the nosocomial infections have to fulfil three requirements [28]. First, they can be caused by any micro-organism (virus, bacteria, fungi or parasite) or its toxins. Secondly, the infection must not be present during the admission to care, except when it originates from an earlier care period. Third, the infection is detected during the care period or after it.

The ageing population, new treatments that impair the immune system and the increasing use of proteases and other foreign objects increase the risk of nosocomial infections. These factors increase the amount of patient susceptible to infections. Other factors like the continuous cuts of care places and the understaffing of health care units also increase the risks of infections.

For an infection to spread, three conditions must be fulfilled. A source of infection must be present; this can be a human, animal or an inanimate object. Secondly some means of transmission is needed. The transmission can, for example, be direct contact by the source or indirectly via some other temporary object. Finally, for a infection to spread, a susceptible host is needed. Usually this means someone with an impaired immune system, due to medical treatments, illnesses or some kind of trauma. To stop infections we need to stop only one of these conditions from fulfilling. However, since hospitals always will have both susceptible hosts and ill people functioning as sources, minimising the possible means of transmission is the most important way of reducing infections.

Infectious diseases have in general five routes of transmission. The first and most important is (1) contact transmission. It requires contact between the source and a potential host to spread. Usually contact transmission is subdivided into direct- and indirect-contact transmission. The former needs direct contact between the source and the host, while the latter can take advantage of intermediate objects. These can be inanimate objects or contaminated hands that are not disinfected. (2) Droplet transmission is similar to contact transmission. Coughing or sneezing creates and propels small droplets that contain infectious materials. These small droplets do not remain in the air but fall down quite rapidly because of their relatively large size. However, while airborne these droplets can be absorbed by susceptible hosts and thus spread the infection without contact between the hosts.

The third route of transmission that is important for nosocomial infections is (3) airborne transmission. Airborne transmission must not be confused with droplet transmission. Small airborne particles, tiny droplets or dust particles contain the infectious agent. These particles remain suspended in the air for longer times and can infect over longer distances. This requires some special measures for isolation. The most common one is under-pressurisation of the patient room, which ensures that air only flows into the room and not out. One common example of airborne transmission is tuberculosis. Other routes for spreading infections are (4) common vector infections, meaning that water or food are contaminated and (5) vector-borne transmission. The latter describes the situation where vectors such as flies, lice, mosquitoes or rats carry a disease.

Discussing care related infections, we need to clarify the difference between endemic and epidemic infections. Endemic infections arise from ordinary treatment; they originate from the patient himself and are expected to a certain degree. Epidemic infections, on the other hand, are caused by something

Table 4.1: Categories and distribution of nosocomial infections. [32]

	Endemic	Epidemic
Urinary tract infection	27%	5%
Surgical wound infection	17%	10%
Pneumonia	16%	12%
Sepsis	11%	20%
Intestinal infection	3%	18%
Skin infection	2%	13%
Other infections	14%	22%

foreign. Epidemics infections occur unexpectedly and can usually spread. About 2-4 % of all nosocomial infections are part of an epidemic. The usual types of epidemic infections are sepsis and intestinal infections, but they can also be cause by contaminated equipment or medicines. However, the epidemic infections are important because they are the easiest to prevent.

In Table 4.1, we see the most common categories of care related infections. Urinal tract infections are very common and surgical sites are easily infected too. However, these infections are mainly endemic and are rarely caused by epidemics. The mortality of nosocomial infections is almost entirely caused by pneumonia and sepsis [32].

Infections are caused by some microbe, but microbes are a common name for many small life forms. Microbes can be bacteria, viruses, fungi or other parasites. What we usually refer to as care related infections are usually caused by *Staphylococcus aureus* and *Escherichia coli*. MRSA, which has almost become a synonym to care-related infections in the media, is short for *methicillin resistant Staphylococcus aureus*. This means that the bacteria have developed resistance to a certain type of antibiotics. If a strain of *Staph. aureus* bacteria develop resistance to other antibiotics such as vancomycin, they are called VISA or VRSA. However, these are thankfully not very common. The *E. coli* bacteria are often associated with urinary tract infections. Other bacteria that are important for preventing infections in hospitals are for example *Legionella pnemophilia* that live in fresh water. However, in fresh water the bacteria are not enough to infect but in water piping systems they can be enriched and cause infections.

Fungi can also cause infections. *Candida* is a genus of yeast that can infect patients. The most common is *Candida albicans*, but it does seldom cause serious infections for patients with a normal immune system. It can be a problem for patient suffering from severe burns or to drug addicts using dirty needles. Another kind of fungi that may cause problems for patients is the *Aspergillus* that is a type of mould. It exists practically everywhere in the nature and its spores are often present in the air. However, the mould does only pose a threat to patients with an already weakened immune system. Such patients may need to be isolated in slightly over-pressurised rooms with filtered air intake, in order to prevent the *Aspergillus* spores from infecting the patient. Viruses also cause some of the typical hospital acquired infections. Intestinal infections epidemics caused by rotaviruses are common at paediatric units. [28]

4.2 Hand Hygiene

One of the single most important measures to reduce nosocomial infections is proper hand hygiene. This was already proved by Ignaz Semmelweis in the 1840s, when he reduced the neonatal mortality rate considerably. He did this simply by instructing physicians to wash their hands with a solution of chlorine and lime between autopsy work and patient examinations. It must be pointed out that this was long before any theory had been proposed that illnesses are caused by germs. Although the importance of hand hygiene has been known for over 150 years, many studies conclude that the hands are not cleaned or disinfected often enough. Rates of 40% are mentioned in literature [34], [41].

Hand hygiene consists of all measures for preventing microbes from spreading through the hands of health care workers. Usually hand hygiene is (1) hand washing with soap and water, (2) hygienic hand rub, (3) surgical hand rub or (4) the use of gloves. Taking proper care of the skin with lotions is also important, because healthy skin is less susceptible to infections [28].

Hands are populated by both a resident flora and a transient flora of microbes. The resident flora usually resides deeper inside the skin and does not cause infections. On the contrary, it protects the skin because foreign microbes cannot replace them easily. The transient flora is microbes that are acquired from contact with sources, such as patients or contaminated surfaces. This flora resides on the surface on the skin and will thus easily spread with the next contact. However, the transient flora can easily be eradicated by proper hand hygiene measures. The objective of most hand hygiene procedures at hospitals is to destroy this transient flora.

Earlier hand washing was recommended to minimise the transient microbe flora, but nowadays hygienic hand rub is used instead. Frequent hand washing with soap and water makes the skin dry which makes it more susceptible to infections. Hand washing only reduces the microbes by half but using an alcoholic hand rub (alcoholic gel) the microbes can be reduced by several logarithms. The hand rub usually contains 80% ethanol that rapidly kills both most bacteria and viruses. The dose of about 3 ml of alcohol gel evaporates from the hand quite quickly which means that there is no need to rinse it off. The alcohol hand rub is much friendlier to the skin and does not harm the skin even during frequent use.

Nowadays it is recommended that soap and water is only used to remove visible dirt from the hands. Hand rub on the other hand should be used both before and after every patient contact. It should also be used after removing protective gloves or when moving from a dirty area of the patient to a cleaner area. It has been proved that even small improvements in hand hygiene at hospitals can positive effects on the rate of nosocomial infections. In Geneva a effective campaign to increase hand rub compliance resulted in a decrease of nosocomial infections from 16.9% to 9.9% [37].

4.3 Review of Previous Work

The idea of hand hygiene monitoring is not unique. Many companies in the US have already done research and development work. A Google search and a patent database search yielded many interesting projects. Many of these are intended for ensuring proper hygiene in the food industry, as well as in hospitals. A system by Amron Corporation is tested and the results are published in a medical journal [41]. This research is described in the section 4.4 , whereas the unpublished hand hygiene projects are described in the next subsections.

4.3.1 iHygiene - Woodward Laboratories

Woodwards Laboratories are currently developing a hygiene monitoring device that employs RFID to identify users. It claims to be capable of monitoring that company hand hygiene policies are followed. The iHygiene system is designed for both the food industry and health care. Woodward Laboratories claims to have patents pending for their product.

The system consists of RFID badges, gel dispensers equipped with RFID readers and wireless communication modules and a computer with software. Detailed information on the exact principles of the system is not available, but broadly speaking the system would collect information about the user each time he washed his hands. A substantial part of the system is the software that generates reports of the hygiene. The system would check that proper hand hygiene is maintained and could even give real time alerts to management of non-compliant events.

www: http://www.woodwardlabs.com/pdfs/iHygiene_Press_Release.pdf (3.5.2006)

4.3.2 I-Hygiene - Cognos Systems

Cognos Systems' I-Hygiene product measures hand hygiene performance without identifying users. The I-Hygiene system consist of small wireless modules to be fitted in soap or gel dispensers and software that generates reports and trends of the hand wash performance. No users are personally identified which means that no one is personally implicated for slips in hygiene. This makes it much easier to adopt opposed to similar systems using identifying personnel. Cognos claims to have patents pending for their product and that it is available for manufacturers of dispensers.

www: http://www.cognos-systems.com (3.5.2006)

4.3.3 Hill-Rom Services

Hill-Rom Services has a broad patent [51] for a hand hygiene monitoring system, capable of tracking and identifying users. The system would track personnel and determine their need of disinfection based on location data. In this manner, it can track both personnel and visitors and ensure that they maintain proper hand hygiene. The patent also describes that the system is capable of monitoring the hygiene and use of equipment and other materials. However, on the web site of Hill-Rom Services no information of this system can be found.

www: http://www.hill-rom.com 20.5.2006

4.3.4 Other patents

The search of patents on hand hygiene monitoring devices turned up a few interesting patent applications submitted in the USA.

Patent Application US2005/0134465 A1 [40] is for a hand cleaning device capable of ensuring that the hands really are cleaned. The device would provide a means of managing and ensuring proper hand hygiene. However, this patent application does not really describe any good method of detecting the hygiene.

There is also patent a application, US2004/0150527 A1 [15], for a gel dispenser

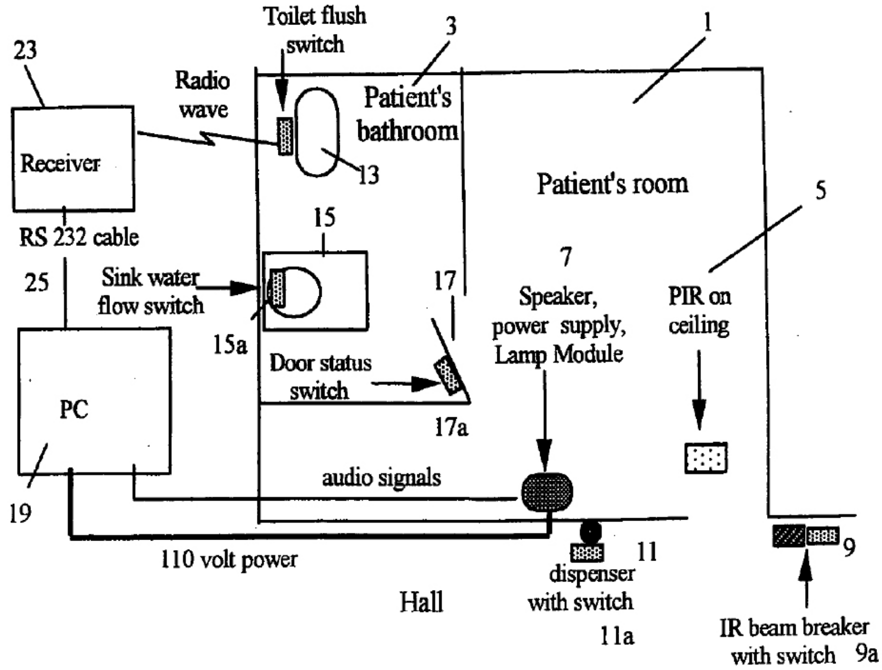

Figure 4.1: Doors are monitored by (5) and beam breakers (9). Hand gel dispensers (11) and washbasin (15) are monitored by switches. All of the sensors are connected to a computer that follows-up the compliance with hand hygiene recommendations. In case of non-compliance the system reminded the user by a recorded voice signal (7). [30]

attached to the wrist. This gel dispenser would also be capable of determining how often hand disinfection is performed.

4.4 The John Hopkins/Amron Hand Hygiene Study

4.4.1 Description of the system used

The monitoring system used in the study [41] is similar to the one described in the patent application [30]of Amron Corporation. The purpose of this monitoring system is to ensure that proper hand hygiene routines are maintained.

The system consists of the electronic monitoring of the doors of the patient rooms, the monitoring of hygiene stations (washbasins and gel dispensers) and a computer, see Fig. 4.1 The doors are monitored by a combination of motion detectors (5) inside the door and beam breakers at the doorway. This combination can determine the direction of anyone walking through the door. The switches at the hygiene stations are connected to the computer and tell whether they are used or not.

The system checks that the required hand hygiene, disinfection or washing, is carried out whenever somebody leaves a patient room, see Fig. 4.2. The system notices when a person leaves the patient room and checks its records if any of the hygiene stations (washbasins or gel dispensers) have been used in the patent room in a certain time window. If they have been used, the system registers a compliant hand hygiene event. However, if no hand washing is detected within the patient room, the system also checks for hand washing events outside the room. If no hand hygiene measures are detected outside the room either, a warning signal is given, and the event is registered as either a compliant or a non-compliant hand hygiene event.

The system by Amron Corporation is also capable of monitoring personal hand hygiene at toilets, using the same principles as monitoring patient rooms.

4.4.2 Results of the monitoring system

The study [41] was carried out to determine the effects of the hand hygiene monitoring system on the overall compliance rate of the hand hygiene recommendation. The secondary objective was to study the effects on the rate of hospital infections. The study was carried out at the JHH, in an intermediate care unit with 14 beds in nine rooms, during a total of 420 days. During this time about a quarter of a million events were recorded, where hand washing or disinfection were recommended.

The study consisted of three phases, (1) determination of the initial rate of compliance or baseline, (2) intervention phase and (3) determination of any long term effects. During the first phase the system was already installed, but it did not intervene or give any reminders. It only gathered information to be used for calculating the baseline compliance rate of hand hygiene. This figure tells the probability of proper hand hygiene measures being taken in the any of the measured events. This rate, measured by the system, did differ somewhat from a rate based on observations. However, this difference was a consequence of slightly different ways of counting.

The second phase, on the other hand, was the intervention phase. Information was gathered in the same way as during the first phase, but in addition to this, the system also reminded people of hand hygiene. It gave a voice prompt, whenever people forgot to wash or disinfect their hands when leaving a patent room. In the third phase the system was passive again. It did not give any reminders; instead it only gathered information for determining the compliance rate. The long term effects of the system on the hand hygiene routines were studied in this way. The results can be seen in Table 4.2. We can see that the reminders of the system

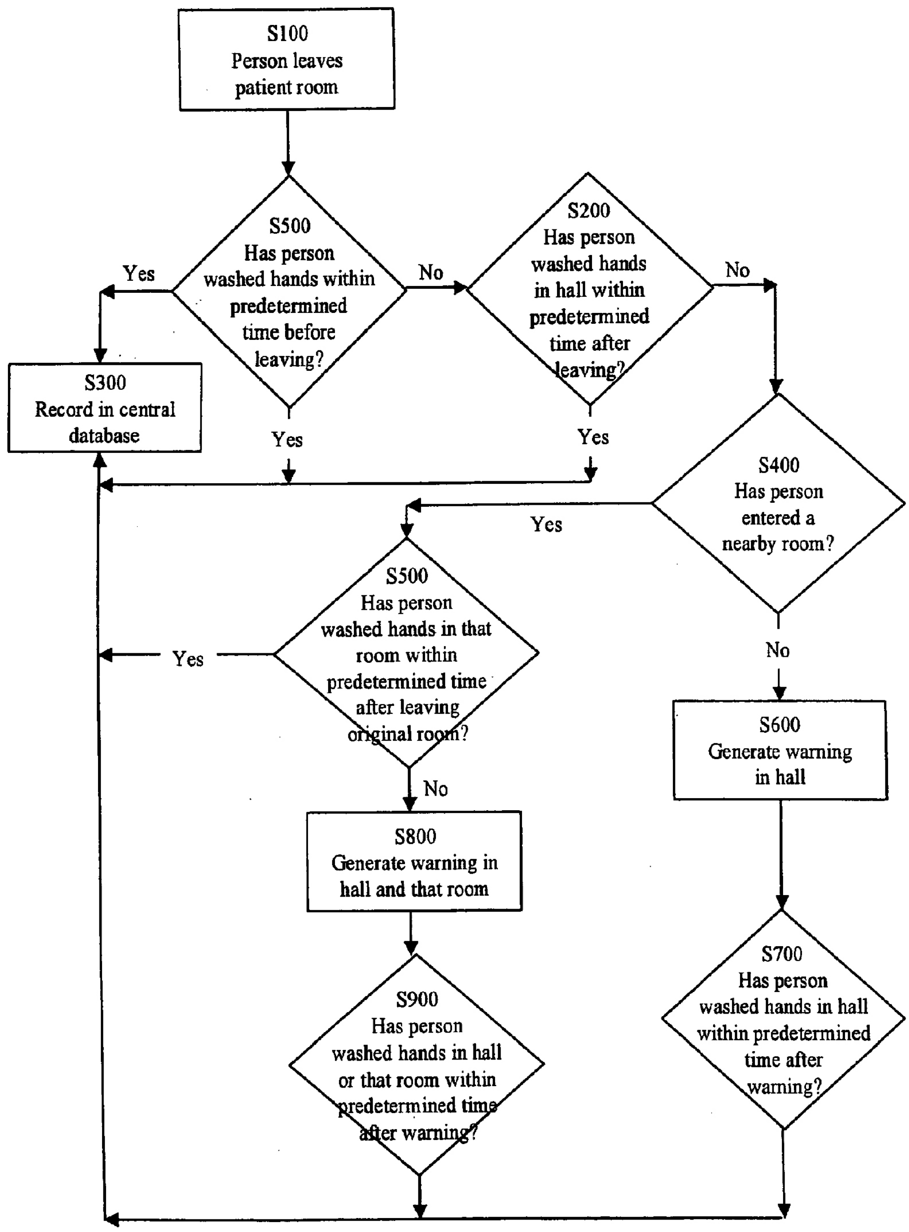

Figure 4.2: An example of the logics of the system monitoring hand hygiene (Amron Corporation). [30]

Table 4.2: The hand hygiene compliance rate during the study [41].

	Hand Hygiene at Exit	Improved Compliance
	%	Odds ratio
Phase I	19.1	
Phase II	27.3	1.38
Phase III	24.4	1.41

clearly improved the compliance rate.

A decreasing trend in nosocomial infections both per patient days and patients were observed. Considering infections per patients, decreases of 22% during phase II and 48% during phase III were observed. However, the patient samples were rather small and because of this, no decreases in either phase could be observed using a confidence level of 95%. Still, if both phases II and III are considered as one single longer time interval, a significant decrease of nosocomial infections can be detected.

Considering these results one must bear in mind that the compliance rate given by the system is not the same as one based on observations. The reason for this is that the system counted every person leaving the patient room, while the observers only counted people that had actually been in contact with the patient. The compliance rate based on the observations was about 20 percentage units higher than the system's compliance rate. In all other respects, the information gathered by the system was quite reliable and did not differ much from day to day.

The study clearly implies that an electronic hand hygiene monitoring system has positive effects on the compliance with hand hygiene recommendations both on a short and long term.

4.4.3 Assessment of the system

The monitoring system used in the study was only capable of detecting hand hygiene compliance of people leaving patient rooms. This is an important part of hand hygiene if the patient is already infected. However, more important would be to prevent an otherwise healthy patient from acquiring an infection, i.e. it would be better to monitor compliance with hand hygiene recommendation of people entering patient rooms. The best solution would, of course, be to monitor the hygiene at both entries and exits at the patient rooms.

The hand hygiene monitoring system did not identify any users. The advantages of this are that there are no ethical problems with personal integrity or singling out of individuals. Nobody is personally implicated for neglecting hand hygiene recommendations. On the other hand, if we only get an average of everybody at a ward, no personal feedback can be given to individuals, which at least seems to be required for reaching very high rates of compliance. The effects on the hand hygiene recommendations compliance rate of a monitoring system could be significantly greater if identification was used.

The feedback to the users was only a voice prompt reminding them of hand hygiene. It was good that the feedback was immediate after a failure to disinfect hands. However, in order to reach better results, the system should be more imperative. The results of such a system could be used in combination with incentives or sanctions that really motivate personnel to achieve better results. E.g. a hand hygiene bonus based on the compliance rate could be used to encourage improvement.

The technical reliability of the monitoring system could be improved. During the 420 days of the study about 283,000 entries were recorded but only 25200 exits. The difference is over 10%. This is explained by the restricted capability of the system to separate people walking out at the same time; two people leaving simultaneously can easily be registered as only one exit. It must be noted that the study was carried out during 2000-2001. Wireless identification systems have evolved since then, which could improve the technical implementation of a similar system today.

4.4.4 Assessment of the study

During the first phase of the study the baseline or the initial compliance rate was determined. However, during this phase the whole system had already been installed and although it was entirely passive, the mere presence of devices reminded staff members of the importance of hand hygiene. Thus the measured initial compliance rate could have been higher than it really was. This was noted in the study.

The compliance rate determined by the system differed from the compliance rate based on observations. The electronic sensors counted everyone leaving the patient rooms, while observers only counted the people having been in contact with the patients. Because of this, the observed compliance rate was about 20 percentage units higher than the measured one. Even though the study was 420 days long, the sample was too small to predict any decrease in nosocomial infections. If the time had been longer or the amount of patients greater, the study could perhaps have yielded better results on the rate of infections.

It could also be possible that a significant reduction of nosocomial infections requires considerable improvements of the hand hygiene compliance rate. The explanation of this would be that the number of infection is not proportional to the amount of missed hand hygiene events. This could be investigated through an epidemiological study [38].

4.5 A Potential System for Hand Hygiene Monitoring

In the following we will present a hand hygiene system that we have designed based upon the American systems described earlier. We think the proposed system is well suited for testing at a ward in a hospital in the Helsinki metropolitan area [38]. The system consists of (A) ID badges, for identifying persons when they disinfect their hands, (B) alcohol gel dispensers that are fitted with a device that can detect and identify the ID badges and communicate with the WLAN stations, (C) WLAN network for easy wireless networking and (D) a computer that collects all events in a database, see Fig. 4.3.

In the future, monitoring systems of health care routines will be integrated into the broad computer systems. This must be taken in consideration in a potential hygiene routines trial by choosing system interfaces, the badges worn by personnel and visitors and all the solutions for networking and storing information, that are based on well-known standards.

4.5.1 Function of the system

Whenever an alcohol gel dispenser is used, the RFID scanner of the dispenser identifies the ID badge of the user. The information about the event, such as user and time, is then transmitted over the WLAN network to a database for statistics. If no user can be associated with a event the event is still recorded. Data collection of the use of alcohol gel is thus fully automated, and required no extra effort from the personnel.

In a more advanced version of the system we also measure the need for hand hygiene, much like in the Amron system in section 4.4. In this case the system would use information from an existing tracking system. From the location data, we could acquire information on when a person is with a patient. Knowing when patient contact occurs, we could easily cross-check with our hygiene database to ensure that proper hand hygiene is maintained. A system, using these principles, could identify the situation, when a physician enters a patient's room without disinfecting his hands. If no hand hygiene actions are taken within the room, the system could remind the physician.

The described system monitors the hand hygiene in real time and the results can be used both to improve routines and to encourage personnel to reach even better results

The components used in the described system can also be used for other purposes, such as access control, automatic entry of information, tracking material and identifying people (patients) to avoid treatment errors.

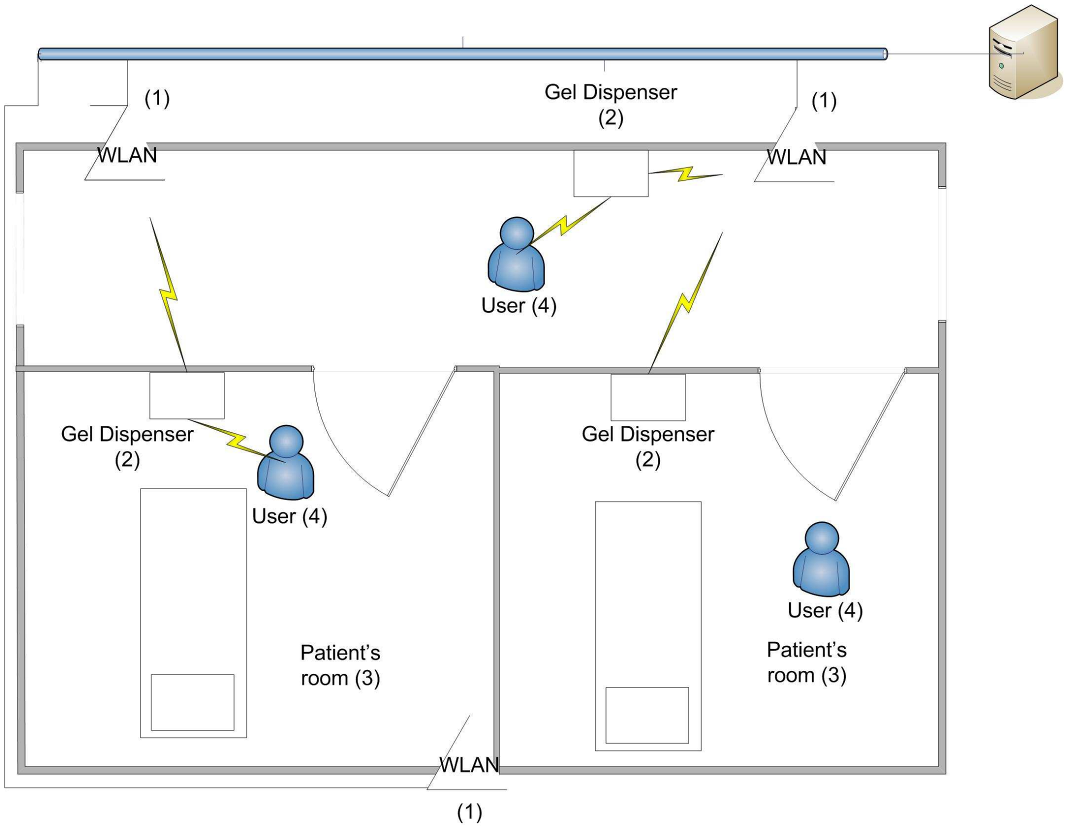

Figure 4.3: Scheme of the proposed system. The users wear a ID badge (A) that can be remotely identified. The alcohol rub dispensers (B) have a WLAN (WI-FI) capability and a RFID scanner that identifies the user and sends information about the alcohol rub use through the WLAN base stations (C) to a server (D) for storage.

4.5.2 Technical implementation

The simpler version of the described monitoring system does only register the use of alcohol hand rub on a user based level. This would give us statistics on the compliance to hand hygiene recommendations on a individual level.

The more advanced version of the system requires monitoring the need of hand hygiene. This can be implemented by monitoring the doorways for movement as in the Amron solution or, alternatively by a positioning system, as is also suggested in an American patent [51].

ID badge

The ID badge is a personal identification card that is always worn by both personnel and visitors. It must be possible to locate, track and scan the ID badge. Various RFID cards are suitable, but an on-board battery is needed to reach the needed operating ranges. Such RFID cards are called semi-passive. The badge should remain functional for long periods of time without battery changes, several years is possible nowadays. The same badge can also be used for access control, which would also ensure that the badge is worn at all times.

Registering the use of dispensers

The person (ID badge) is scanned and identified when using the alcohol rub dispenser. This can be implemented in different manners, e.g. by a RFID scanner installed on the dispenser or above in the ceiling. The identification process must not require any extra efforts or movements for personnel since their busy job must not be interrupted. It would be beneficial to indicate a successful identification, e.g. by a LED-light. The information about the user is sent wirelessly, e.g. by WLAN, to a server.

Monitoring the need of hand disinfection

In the more advanced system, the need of hand disinfection is monitored. It is recommended that hands are disinfected both before and after every patent contact. These situations can be detected in several ways. A clinician walking into a patient's room can be detected by a RFID badge scanner at the doorway. Another way would be to analyse information from a positioning or real time location system (RTLS). Then, a patient interaction requiring hand disinfection could be defined as staying in the patient's room for a certain period of time or standing close enough to the patient.

Server

All the information gathered by the system would be saved by a server in a, i.e. SQL-database. The server would regularly create reports both on the use of the dispensers and on the staff's individual use. The reports would be available for the ones concerned using a ordinary web browser. Regular reports could also be sent to both management and to the users. The database should be implemented in such an way that makes it possible to link it to future integrated health care information systems.

Network connections

Only standardised network connections are needed to implement the hand hygiene system. The WLAN (WI-FI) base stations make up a wireless link between the alcohol gel dispensers and the wired network. This also enables easy addition of other wireless devices for monitoring purposes. The network for collecting process data that is not mission critical could be physically separate from the critical network to avoid any disturbances.

A standard WLAN network can also be used for tracking purposes using software or specially designed WLAN hardware clients [5].

Cost estimation

A rough cost estimation for the system: 100 € / ID badge and 1000-1500 € / dispenser, half a man-year for software development. It is assumed that a WLAN network is part of the infrastructure.

4.5.3 Benefits

There are many potential benefits of a tracking and monitoring system. However, the benefits can only be reaped if the system is properly used and exploited in decision processes. The main idea of the proposed system is to collect data and information on hand hygiene and on the routines associated with it. In order for any information system to be of use, the information must be exploited for some purpose.

The hand hygiene information is to be used for improving the overall hand hygiene and thus reducing nosocomial infections. The system gives us a tool for rapidly determining the level of hand hygiene. This tool can be used by management to evaluate both the current trend of hygiene and measures taken to improve it. In addition, the system would give individual feedback to users allowing them to see their weekly hygiene performance. This would make it much easier for them to improve their hand hygiene routines. By associating this hand hygiene performance with some kind of monetary or other reward or bonus, the effects of this self improvement could be multiplied. The connection between improved hand hygiene and reduced nosocomial infections rates is already considered proven [37]. This ambition to improve hygiene and thus reduce infection rates should solely justify the development and implementation costs of the systems, because of all the potential savings of health care costs associated with the reduced infection rates.

The proposed system will collect vast amounts of data of the flows of staff and patient interactions. This information can be analysed and used to model processes at the hospital. Such models could then perhaps help to gain new knowledge and improve existing routines to improve the overall efficiency of the hospital.

The same components that are developed for the proposed system could also be used for many other monitoring purposes. With similar components we could monitor the flow of key resources and supplies. We could monitor the flow of patients and acquire position data them. This way we can monitor many other routines than hand hygiene. In the future, personal identification system could identify users at computer workstation, removing the need for passwords, or for identifying the people, removing key medicines from a medicine cabinet.

4.6 Alternative Solution: No RFID

The original project scope was to record the use of hand gel by allocating each consumed lot of gel to a person. This poses many problems, both social and ethical ones, regarding the monitoring of individual workers. In addition there are technical issues, such as realising a RFID system that is reliable enough, see section 5.3.1.

An option that solves all of these problems is to skip the RFID identification of personnel. Instead, we would only use a sensor that reliably counts the times the gel dispenser is used. This information would then be sent to a central server for storage. By monitoring several gel dispensers in this way at a ward, we will get real-time information on the consumption of the gel, see Figure 4.4. This information would then both work as a measure of hand hygiene at a ward and as a motivational factor for the staff. The advantage of this, in comparison to measuring the consumption by the refilled bottles, is that we get much faster feedback. If the consumption decreases several weeks in a row measures can be taken by management to raise the awareness of gel use at the ward.

A system measuring gel use at all the gel dispensers in a ward gives us the total consumption and the exact time of use. If we know the amount of patients at the wards we get the gel consumption per patient, which probably describes the

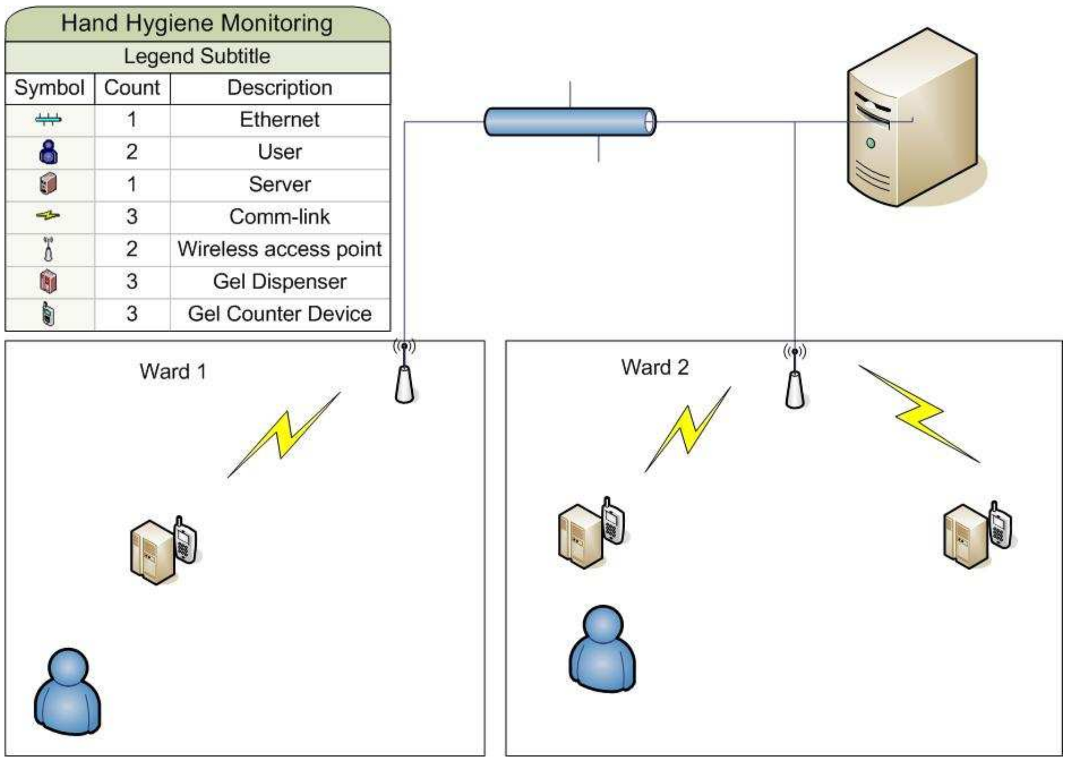

Figure 4.4: The wards would be connected to a main server that collects data from all the gel dispensers

total hand hygiene even better. If we know when a member of the staff works, we could calculate an individual comparison number for him that represents his consumption. This way we achieve the same goal as our prior system.

The requirement of this model is that we have a network, preferably having wireless access points to simplify data collections. The data collection units would consist of minimal sensors running on batteries that are coupled to a WLAN unit. It would wirelessly broadcast a signal representing the location and the use of one unit of gel. The server would collect all data in a data base and construct useful information in the form of web-based statistics on the internal web site and e-mail notifying key managers if the average use slips too far. It could also send weekly e-mails to all personnel at the wards bench-marking their performance (e.g. weekly consumption / per patient) in comparison to other wards.

I suggest that we develop a system like the described one because it yields the same information at the fracture of cost and effort of the earlier one. The only downside is that we don't develop a personal tracking system for future use. However, during the project it was discovered that Cognos Systems already offers a product much like the one described here, see section 4.3.2.

4.7 Summary

Nosocomial infections are a major issue in modern health care and improved hand hygiene seems to be the key to this problem. Many studies have shown that, although the importance of hand hygiene has been known for over 150 years, proper hand hygiene measures are only taken in 40% of the situations. We hope to be able to significantly increase this rate of hand hygiene by introducing electronic monitoring devices. These monitoring devices can either give feedback on the performance in terms of hand hygiene or actually enforce proper hand hygiene by reminding personnel in realtime if the hand hygiene measures are neglected. In the USA, work has already been done on similar systems and one study of the effects of a hand hygiene reminder system has been published.

Systems for ensuring proper hand hygiene might have a positive effect on the overall hygiene but there are several issues that must be solved. There are several technical problems that need to be solved before such a system is possible. One of the proposed solutions includes a RFID scanner that recognises the user of a hand gel dispenser, however, identifying a person is not very easy or cheap. When we solve the technical problems we still need to address the ethical problems that such an system presents. The system would monitor and collect information about the user continuously. Is it right to monitor people doing their job like this? Would these people like to be monitored, would we like to be monitored in the office every day to ensure that we work efficiently? One way to go is to continuously monitor the use of hand gel but not use any sort of personal identifications as in the Amron system or as in the system proposed in Section 4.4.

However, a small scale hand hygiene monitoring system could easily be built and can be tested at a local hospital. This would not cost very much and it could give us valuable knowledge about hand hygiene routines and perhaps decrease nosocomial infections. If the system proves to be useful during the initial tests , it could very well be developed further and commercialised. If the study, carried out during the testing phase, shows that the hand hygiene monitor really improves the hygiene and reduces the rate of nosocomial infections, it would become a valuable future sales argument.

Chapter 5

Evaluation

5.1 RFID technology

It has been said that RFID is the most hyped technology today. This might be because RFID consists of many different techniques with different abilities. In media, RFID is often regarded as only one technology that enables collecting of almost total information about real world systems. What is usually regarded as RFID in media is passive UHF technology that can be used for identifying pallets and items for logistical purposes. These UHF systems can identify tags remotely and is effective at scanning large amounts of tags simultaneously. It is this kind of RFID that grows the most and is considered to have the most potential. However, this system has serious issues regarding aqueous materials and metallic sheets. Water based materials absorb and metallic surfaces reflect the electromagnetic waves and renders scanning difficult or impossible through such materials.

Inductive RFID that is used in key cards and smart cards for i.e. ticketing in public transport is not that often mentioned in the media. It has quite different capabilities than the UHF RFID, the range is very limited but this also means that less energy is needed. This technology is used to replace the physical contact needed for reading a card or a key. By inductive coupling, a completely encapsulated and passive electronic device can interact with other electronic systems.

The third technology often referred to as RFID is active RFID used for indoor positioning. These RFID systems have little in common with the passive systems. Active RFID tags can more be considered as an electronic chip with an on-board radio transceiver, compared to the passive ones that only reflect or modulate the incoming energy. Active RFID systems have several advantages because of the constant supply of energy. It can enables much higher detection rates and longer range. Active transponders can be positioned within a network of antennas. The transponders can also have other functions such as sensors or alert buttons. Alert buttons can change the state of the tag in a database simply by pushing it or it can attract attention to itself for security reasons.

5.1.1 Future item level tagging

It is said that in the future we could very well have RFID tags on all articles in the supermarket [43]. We could then easily add items to our shopping trolley that registers them automatically and shows us the total price in real-time. At the check-out we would then pay for our purchases without scanning them, perhaps even with a contact-less pay card.

Let's take a closer look at the tags on the individual articles. They would be attached to the products during manufacturing. They are not necessarily a external tag but can be incorporated in the product, sewn into a jacket or included in the plastic casing of electronics. This means they can be tracked throughout the supply chain, a particular product can be located or its last scanning can be pinpointed. When the article arrives in the supermarket it would both be added to the data base and marked as unsold. When customers buy the product, the tag just gets marked as sold. By marking the tag as sold or not sold, the same RFID tag can work as an EAS system, too. If somebody tries to take a unsold product out from the store an alarm would go off. However, the tag is never removed from the product, it remains active even while the product is used or worn.

The scenario described above cannot be realised in the near future. Tag prices are still high compared to superstore goods. UHF scanners cannot read tags in the proximity of water or metals. This rules out a large proportion of all goods in a store and makes it impossible to identify all products by remotely scanning the shopping cart at checkout.

However, RFID tagging is presently used for identifying boxes of goods arriving on pallets into warehouses and department stores. A array of UHF scanners can easily identify tens of boxes of goods packed on a pallet when it is moved through a doorway. This saves lots of time because bar codes on the pallets and boxes do not need to be scanned by hand. The advantage over bar codes is also that the RFID tags may contain much more information.

5.1.2 Social and ethical acceptance of RFID technology in general

RFID offers new methods of collecting information on tracking items and also people. Item-level tagging of consumer products involves RFID tags that are incorporated in products. The unique serial number in the products, in conjunction with a worldwide data bank of serial codes, enables companies to track individual products all the way from the factory to the end-user. This has many advantages, because stolen goods cannot be resold and unauthentic products can be identified. This is not entirely novel, conventional serial codes on products have offered the same functionality earlier. The advantage of the RFID serial codes is the easy reading and checking of them. A RFID scanner can in seconds authenticate pallets of consumer goods by cross checking their serial numbers with databases. Reading and cross-check serial codes by conventional means would take hours and would not be economical. Through maintaining a database over the products it would be possible to know the entire history of each product, it would be know when and where it were produced, in which exact batch and for which market. Information would be available on when the product was shipped, when it got through the customs and where it was sold.

The problem that arises here is that the tag does not necessarily get destroyed when it is bought by an end user. The tag in a jacket that the customer has bought can still identify the jacket and reveal information about that particular product. The tag can also be scanned remotely. Suddenly, the user of the jacket has lost some of his privacy because his clothes and other possessions reveal much his shopping habits and much more. It is of course not that easy to acquire all the information about products but since the serial numbers are revealed the rest is not up to the user any more.

RFID just offers a way of collecting this data, conventional computers and databases store this information and enable any potential misuse. As long as a tag only contains a serial number, it is useless unless it can be associated with other information on this serial number.

Loyalty card systems used by most shops today can be compared to the RFID issue. The loyalty card systems are used for collecting extensive information on the shopping habits of individuals. However, the use of loyalty cards is completely voluntary, cash payments are untraceable. RFID tags are different because individual customers cannot choose if they want RFID tagged products or not. We must decide whether we want RFID tagging and the potential benefits it brings.

In order for our society to accept and reap all the benefits of RFID technology we need to be ensure that it is not misused. A three phased solution is proposed for this [13]. First the technology must be designed in a privacy-enhanced way. This includes the disabling of RFID chips.

Secondly, legislation is needed to define rights and responsibilities for all parties or at least set principles for these. Third and last, companies using RFID technology must engage in self-regulation. This would allow companies to develop industry-wide policies for RFID, but still maintain some responsiveness to evolving business environments and new privacy problems.

Another RFID issue is the deliberate tracking and monitoring of certain professional groups. RFID technology also offers methods of collecting information about

S Identify tags remotely Easy information collection Passive, long life Easy use Invisible to user Mature technology	W Range / inteference problems Cost Many different technologies
O Intelligent systems can be built Gather information -avoid mistakes -optimise processes -track materials -reduce costs	T Bad design -> not usable Technical failure vulnerabilities Privacy of user Everything can/will be monitored Social and ethical acceptability not guaranteed

Figure 5.1: SWOT analysis of RFID for tracking and monitoring.

routines and processes at work places. This issue will be described in section 5.3.1

5.1.3 Security

Wireless security is always an issue. If information is radiated from a antenna it can always be read by others than the intended receiver. If the nature of the information is such that it needs protection it should be encoded or encrypted. Even if a particular device has a certain maximum working range, sensitive enough equipment can receive the transmissions at a much longer range.

RFID is still considered to have security issues. The new Finnish passports that include biometric information have a RFID interface because they can be read wirelessly. Still RFID is not mentioned in any public document describing the new passports. This seems very much like an intentional attempt to avoid negative publicity on behalf of RFID security.

5.2 Tracking and Monitoring

RFID can be used for tracking and monitoring purposes. However, since RFID is such a broad definition of technologies, it is hard to summarise it. We will try to visualise the potentials of RFID for tracking and monitoring by performing a SWOT analysis, Fig 5.1.

The strength of RFID is fundamentally the ability to identify tags remotely. This enables easy collection of data. Most RFID tags are passive which means they are cheap and remain functional for a long time. A well designed system is very easy to use and almost invisible to the user. To some extent RFID technology can be regarded as mature.

The weaknesses include the high cost of RFID systems. The limited range may become an issue for some technologies and interference by various materials for others. RFID consists of several different technologies, which is a source of problems since they all have different advantages and drawbacks.

The main opportunity that RFID offers for tracking and monitoring is the construction of intelligent systems. These systems can collect information on real systems and enables improvements of the performance of these systems. The collected information can be used for avoiding mistakes by RFID verification, optimising systems based on the information obtained or simply for tracking and positioning materials. The purpose of all these systems is ultimately to reduce costs.

The threats for such RFID applications is bad design that can lead to usability problems or systems that do not work as intended. RFID monitoring systems are also vulnerable to technical failures. Privacy of the user is important and it must be ensured that RFID tracking is not misused. RFID monitoring is a two-edged sword, it can be used for improving performance but also for spying and collecting too much private information on people. Social and ethical acceptability is not guaranteed.

5.2.1 Modular Design

Our vision of the tracking and monitoring system is that it is modular. It consists of independent subsystems, performing certain tasks. The subsystems would share the same components, but the functionalities can be chosen as wanted. Examples of the subsystems could be the tracking systems for different purposes, access control, hygiene monitoring, medication or blood type cross checking system. In order to design the subsystems inter-operable we need to use open standards and as much standardised parts and technology as possible.

Patients, staff and visitors would wear RFID ID cards that can be used to identify and track them. All subsystems would use the same ID cards. Materials such as IV-pumps and beds would be marked with some standard transponders, too. They would be read by both some tracking system and perhaps by some other module.

In principle the only needed infrastructure is a LAN network. A standard computer network works well for sharing information. Upon this wired network, a wireless one can easily be built. A standard Wi-Fi (WLAN) network can be used for tracking Wi-Fi tags, for example the systems by Ekahau Inc.

5.3 Hand Hygiene Monitoring

5.3.1 Challenges and open issues

There are many problems and open issues associated with the hand hygiene monitoring system. First there are some technical difficulties with constructing a device with the specifications needed. In addition, we need to address the ethical and social issues that are associated with tracking of employees. Legal problems may also arise in the later stages of the projects, because of the many American patents and patent application on the subject.

Technical issues

It is fully possible to realise a personal tracking and identification system as described earlier. However, there are some issues that make it more difficult and expensive. Our first idea was to use passive RFID technology for tracking and identification. However, this turned out to be much more problematic than anticipated. Passive inductive RFID technology has a limited range. It is suitable for applications where the user can show card to a scanner or where a tag is taken through a narrow gate. It is not suitable for hands-free identification of persons at an arm's length from a hygiene station.

Passive UHF RFID, that has a range of up to seven meters, is not very usable for personal identification purposes. UHF radio waves are effectively attenuated by water. Human tissue is virtually impenetrable to the UHF waves, which means that a RFID scanner must have a direct line of sight to the badge. This renders it very difficult to successfully scan badges carried by people.

Active tags and badges send out a signal of their own. This makes them much more usable and easier to scan or locate, but this feature need a constant supply of energy in the form of a battery. The battery life is, however, limited and a large system consisting of badges needing new batteries regularly s very expensive to administer. WLAN based tracking is an example of active tracking.

Semi-passive RFID systems might be best suited for the needs of the hand hygiene system. They combine the long lifetime of passive systems with the extended range and reliability of active ones. However, there are no systems on the market today that would suit our needs directly.

Implementing a device that communicates over WLAN and scans RFID tags is not entirely simple. A solution for a prototype would be to use an ordinary PC for this purpose. Broader testing will require a more practical solution that is easier to install. This would most probably result in a small control board with a WLAN chip and an attached RFID scanner. This requires some planning and skills to implement.

Indoor positioning systems are quite inaccurate in practice. The positioning is often based on time averages of the signals, hence the acquired position includes inaccuracies in both position and time. The resolution of standard WLAN positioning systems is at best 1 meter.

Recording all the hand hygiene events will produce vast amounts of data that needs to be stored for later use. This requires the system to be well planned and dimensioned to avoid bottlenecks or overloading. This experimental information gathering system should perhaps be separate from critical networks, in order to avoid disruptions of critical systems.

The hand hygiene monitoring system needs to be quite reliable before it can be tested in a hospital environment. The needed reliability or accuracy of the system depends on the purpose of the system. If we only want indicative information on the trend of hand hygiene, the system does not need to be very reliable. On the other hand, if we want to use the information for rewarding or sanctioning personnel, the reliability must be on a higher level and beyond doubt accurate. This is not an easy engineering feat, as we saw in the Amron study where the number of exits and entries differed by over 10%, see Sect. 4.4. A potential source of errors would be the scanning of by-passers close to the gel dispenser. If several persons are in the vicinity of the dispenser, it might be very difficult to allocate the use of gel to the actual user.

A monitoring system of the hand rub dispensers might have negative effects on the availability of hand rub. It might get more difficult to add new gel dispensers because the monitoring systems probably are more expensive than the dispenser themselves. It has also been suggested that small dispensers could be attached to every patient bed and that personnel could carry around pocket bottles of alcoholic gel [37]. These ideas do not agree very well with our proposed monitoring system, while it will render it very difficult to register the use of hygienic hand rub.

Social and ethical acceptability of monitoring hand hygiene

Many ethical and psychological elements are associated with personal monitoring of work routines. This kind of monitoring can be seen as a violation of the integrity of individuals and as a prelude to an Orwellian society. Other may just view it as a natural safeguard against nosocomial infections and as protection of the patients.

The fact is that a monitoring system collects data of both the whereabouts and activities of individuals and that the information can be tracked back to them. Even though the purpose of the system is solely to improve the conditions for patients, we need to consider the staff at the hospital. The employees will be forced to wear tags, much like cattle, that can be scanned at any time by the employer. Employees will feel monitored constantly and it will most probably induce some kind of feeling of lack of trust between the employer and employee. Therefore, it is vital that the introduction of such a monitoring system is done in close collaboration with the staff. It must be stressed that the purpose of the system is not to monitor the employees because of lack of trust but to help staff reach better results and to reach perfection beyond the marginal of human errors.

In addition to what can be gained by a tracking or monitoring system, we also need to consider what can be lost by it. The basic operations of health care consist of the professional skills of the medical doctors and the caring nursing staff. Everything else is just auxiliary functions. If we introduce a new system that might provide slight improvements to the auxiliary functions, we need to consider its effects on the basic operations, as well. In order to develop and implement a monitoring system for hand hygiene or any routine, it must be carried out together with clinicians and nurses to ensure that it is acceptable and suitable. Before introducing one to any ward it must openly be discussed by both staff and management. If a monitoring system in introduced against the will of the staff or without it understanding the purpose, the system may decrease the overall morale and add hostilities against management. On the other hand, if introduced in a positive manner, the external interest in their daily routines may actually be motivating for staff members.

Chapter 6

Conclusions

RFID consists of three different types that are very different technically and has very different uses. First, there is inductive technology that is used for access control. This technology just offers a way of remotely accessing a microchip and supplying it with energy at the same time. The range is very limited because of the nature of inductive coupling, but it is also almost independent of the medium between the scanner and the tag. The second kind of RFID is passive UHF that is used by the EPC standard. These are cheap passive tags that contain a unique serial number that can be read at distances up to seven meters. These tags, if they become cheap enough, can be fitted on consumer items in order to identify and track them from manufacturing to the consumer. When speaking of RFID ethical and security issues, it is usually this type of RFID that is meant. The third kind of RFID is active RFID. Active RFID means virtually any electronic device that can independently send a radio signal to identify itself. Such devices are becoming available and miniaturised when more energy efficient electronics and smaller energy sources are developed.

RFID technology shows much potential, however, there are still some technical issues that needs sorting out before it can be taken into mainstream use. RFID shows great potential for health care use. It can be used to identify patients, medicines and blood bags in order to avoid mistakes due to mix-ups.

The RFID technology also enables efficient recording and gathering of information on routines and processes by suitably placed readers that record tags passing by. This way new and more detailed information can be obtained on the streams of materials, patients and personnel. More detailed information can lead to better optimisation and planning and help making our health care system more efficient. However, monitoring and collecting too much information might give rise to new problems. Monitoring systems may feel intrusive to some people and the information collected may be misused to gather detailed information on individuals. Similar issues are also raised by the proposed item level tagging of consumer goods.

The problem is that such a system can be used to collect extensive information on individuals without their permission and thus violate their privacy. These issues need to be carefully addressed and discussed publicly. Work place monitoring needs to be negotiated by all stakeholders.

A practical example of a RFID monitoring application is hand hygiene monitoring. Research in the USA has already suggested that such systems have an impact an the overall hygiene and on the frequency of nosocomial infections. It is fully possible to build a system that monitors and registers hand washing and hand disinfection. It can be implemented with or without the capability of identifying the user. If RFID is used to identify the users, then the privacy issues and the social acceptability must be properly addressed.

Future research and development work should be carried out to build and test different hand hygiene monitoring devices. If monitoring proves to be effective and socially accepted then these devices may provide very interesting business opportunities in the future.

Bibliography

[1] Electronic Article Surveillance (EAS) - An Overview of the Major Technologies. http://www.aimglobal.org/technologies/eas/easoverview.asp, 13.2.2006.

[2] Bates, D., Cullen, D., and Laird, N. Incidence of adverse drug events and potential adverse drug events. *J Am Med Assoc*, 274 (1995), 29–34.

[3] ChampionChip. www.championchip.com, 15.3.2006.

[4] Chase Blink card. www.chaseblink.com, 1.2.2006.

[5] Ekahau. www.ekahau.com, 7.7.2006.

[6] EPC global. www.epcglobalinc.org/about/about_epc_network.html, 31.2.2006.

[7] European table of frequency allocations and utilisations covering the frequency range 9 kHz to 275 GHz, 2004. www.ero.dk/eca-change, 31.1.2006.

[8] European Telecommunications Standards Institute. www.etsi.org, 4.4.2006.

[9] Exavera Technologies, ”eShepherd Overview”. www.exavera.com/healthcare/eShepherd.php, 23.3.2006.

[10] Finkenzeller, K. *RFID Handbook - Fundamentals and Applications in Contactless Smart Cards and Identification*, 2nd ed. John Wiley & Sons Ltd, Sept 2004.

[11] FinnWell. www.tekes.fi/ohjelmat/finnwell, 7.7.2006.

[12] Food and Drug Administration, Department of Health and Human Services, USA. FDA Rule Requires Bar Codes on Drugs and Blood to Help Reduce Errors. http://www.fda.gov/oc/initiatives/barcode-sadr/.

[13] Garfinkel, S., and Rosenberg, B. *RFID Applications, Security and Privacy.* Addison-Wesley Professional, 2005.

[14] GE Brochure, www.gehealthcare.com/usen/service/healthcare_services_msolution/docs/svd_0121_1005_en_us.pdf, 6.2.2006.

[15] Harper et al. Method for monitoring hand hygiene compliance. U.S. Patent Application No. 2004/0150527 A1, Aug. 5, 2004.

[16] Hawkes, P. Singing in Concert - Some of possible methods of orchestrating the operation of multiple RFID-Tags enabling fast, efficient reading without singulation. Amsterdam, February 1997.

[17] Ho, L., Moh, M., Walker, Z., Hamada, T., and Su, C.-F. A Prototype on RFID and Sensor Newtworks for Elder Healthcare: Progress Report. SIGCOMM'05 Workshops.

[18] Houliston, B. Integrating rfid technology into a drug administration system. *Health Care & Informatics Review Online* (Dec 2005).

[19] How stuff works. http://electronics.howstuffworks.com/anti-shoplifting-device5.htm, 30.1.2005.

[20] IDTechEx. http://www.idtechex.com, 27.7.2006.

[21] Using tags to make teeth, RFID Journal. www.rfidjournal/article/articleview/1206/1/1/, 23.3.2006.

[22] ISO-14443. www.iso.org, 1.2.2006.

[23] ISO-18000. www.iso.org, 1.2.2006.

[24] Jensen, L. S., Merry, A., Webster, C., Weller, J., and Larsson, L. Evidence-based strategies for preventing drug administration errors during anaesthesia. *Anaesthesia*, 59 (2004), 493–504.

[25] Johnson, J., and Bootman, J. Drug-related morbidity and mortality: A cost-of-illness model. *Arch Intern Med*, 155 (1995), 1949–1956.

[26] Ken Inweregbu, Jayshree Dave, A. P. Nosocomial infections. *British Journal of Anaesthesisia:CEACCP 5*, 1 (2005), 14–17.

[27] KSW Microtec. www.ksw-microtec.de, 15.5.2006.

[28] Kuntaliitto, S., Ed. *Infektioden torjunta sairaalassa*, 5. uudistettu painos ed. WS Bookwell Oy, 2005. ISBN 951-755-977-1.

[29] Landt, J. Shrouds of Time - The history of RFID, 2001. AIM.

[30] Lane et al. U.S. Patent Application No. 2005/0248461 A1. Systems and methods for measuring hand hygiene compliance, Nov. 10, 2005.

[31] Marjamaa, R. A., Torkki, P. M., Torkki, M. I., and Kirvilä, O. A. Time accuracy of a radio frequency identification patient tracking system for recording operating room timestamps. *Anesth. Analg. 4*, 102 (Apr 2006), 1183–1186.

[32] Martone, W. J., Jarvis, W. R., Edwards, J. R., Culver, D. H., and Haley, R. W. *Incidence and nature of endemic and epidemic nosocomial infections In: Hospital Infections 4th ed.* Lippincott-Raven Publishers, Philadelphia, 1998, pp. 461–476.

[33] RFID knowledgebase. Massachusets General Hospital blood, USA, 2005. http://rfid.idtechex.com/knowledgebase/en/casestudy.asp?freefromsection=115, 2.2.2006.

[34] Centers for disease control and prevention. guideline for hand hygiene in health-care settings: Recommendations of healthcare infection control practices advisory committee and the hicpac/shea/apic/idsa hand hygiene task force. MMWR 2002;51(No. RR-16).

[35] Ostbye, T., Lobach, D., Cheesborough, D., Lee, A., Krause, K., Hasselblad, V., and Bright, D. Evaluation of an infrared/radiofrequency equipment-tracking system in a tertiary care hospital. *J. Med. Syst. 27*, 4 (Aug 2003), 367–80.

[36] Patterson, E., Cook, R., and Render, M. Improving patient safety by identifying side effects from introducing bar coding in medication administration. *J Am Med Inform Assoc 5*, 9 (2002), 540–553.

[37] Pittet, D., Hugonnet, S., and et al,, S. H. Effectiveness of a hospital-wide programme to imrovw compliance with hand hygiene. *Lancet*, 356 (2000), 1307–1312.

[38] Prof. Jukka Tulkki. Private communication.

[39] RFID Center. http://www.rfidjournal.com/faq/30/25, 20.7.2006.

[40] Rice et al. Hand cleansing device with monitoring capability. U.S. Patent Application No. 2005/0134465 A1, Jun. 23, 2005.

[41] Swoboda, S. M., Earsing, K., Strauss, K., Lane, S., and Lipset, P. A. Electronic monitoring and voice prompts improve hand hygiene and decrease nosocomial infections in an intermediate care unit. *Crit. Care Med. 2*, 32 (Feb 2004), 358–363.

[42] The International Comission on Non-Ionizing Radiation Protection. ICNIRP Statement Related to the Use of Security and Similar Devices Utilizing Electromagnetic Fields. *Health Physics 87*, 2 (Aug 2004), 187–196.

[43] Rfid tunnus kertoo kaiken. *Tekniikka ja Talous* (2002). 4.12.

[44] VeriChip. www.verichipcorp.com, 1.2.2006.

[45] WALLIN, M., MARVE, T., AND HAKANSSON, P. Modern wireless communication technologies and their electromagnetic compatibility with life-supporting equipment. *Anest Analg.* (Nov 2005), 1394–400.

[46] WANT, R. The Magic of RFID. www.intel.com/technology/itj/2005/volume09issue01/publishe
Oct 2004. Intel Research.

[47] WATERS, D. *Logistics; An Introduction to Supply Chain Management.* Palgrave Macmillan, 2003. ISBN 0-333-96369-5.

[48] WEBSTER, C. S., MERRY, A. F., GANDER, P. H., AND MANN, N. A prospective, randomized clinical evaluation of a new safety-oriented injectable drug administration system in comparison with conventional systems. *Anaesthesia*, 59 (2004), 80–87.

[49] WIKIPEDIA. Wikipedia, the Free Encyclopedia, 2006. http://en.wikipedia.org/wiki/Near_and_far_field, 29.5.2006.

[50] WIKIPEDIA. Wikipedia, the Free Encyclopedia, 2006. http://en.wikipedia.org/wiki/CDMA, 15.5.2006.

[51] WILDMAN ET AL. Hygiene monitoring system. U.S. Patent No. 6,727,818 B1, Apr. 27 2004.

[52] YOUNG, H., AND FREEDMAN, R. *University Physics, extended version with modern physcs*, 9th edition ed. Addison Wesley Publishing Company, Inc, 1996. ISBN 0-201-31132-1.

[53] Patient safety applications of bar code and rfid technologies. white paper, 2005. Zebra Technologies.