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Three Dimensional Localization of Work Pieces in Assembly Lines with Radio Frequency Identification

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THREE DIMENSIONAL LOCALIZATION OF WORK PIECES IN ASSEMBLY LINES WITH RADIO FREQUENCY IDENTIFICATION

BY

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ABSTRACT

The knowledge of the location and the stock of work pieces are essential for companies to produce their products more effectively. Radio Frequency Identification (RFID) is becoming a widely used technology for this purpose. The goal of this thesis is to study the application of RFID for localization of work pieces in a manufacturing environment.

To achieve this goal, this report reviews different localization and identification systems. Then, requirements for an ideal system are establish. The system that best meets the requirements is determined to be an RFID system. The components of an RFID system are described, and since the antenna is a critical component of RFID systems, different antenna constructions and the important Friis formula are discussed.

After that, scenarios for localization of parts in an assembly line are listed. From these, the localization of work pieces in a warehouse is selected for further investigation. An experiment to determine the location of tags in this environment is designed. Data from multiple readings are recorded.

Then the recorded data for the described experiment are analyzed. The data indicate that the read range of the antenna is not symmetric and that every tag has a different response in the amount of counts. All recorded data imply that the amount of counts depends on the orientation and distance between tag and antenna, the antenna power and the number of read tags.

From the findings the localization of tags can be done by the following procedure. The first step is a scan with the maximum antenna power. The result of that scan is a list with all tags in the antenna read range. After this scan the antenna power has to

decrease and the next scan starts. The decreasing antenna power leads to a decreasing read range. Below a certain antenna power, the tags read with the full antenna power cannot be read anymore because the distance between tag and antenna is larger than the antenna read range. With the known shape of the read range for the lowest antenna power were a tag could be detected it can be assumed that the tag is at the border of this read range. When this procedure is carried out at multiple antenna positions, the tag location could be determined.

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CHAPTER 1

INTRODUCTION

Today, efficiency is a key factor for every company to stay competitive in the global market. To reach high efficiency, resources need to be used without any waste. These resources could be machines, employees, work pieces and raw material. The waste could be unused waiting time of a machine, the unused work capacity of human labor or a high inventory of work pieces and raw materials. Additionally, lost work pieces could result in multiple types for waste. First, lost work pieces might influence the working hours of a machine. In the case that the needed material is not distributed in time, the stock of the machine could run low which leads to idle processes. The idle process could also influence the entire system. Second, to find lost work pieces, employees are necessary, who search for the lost items. During that time the labor force of the employees cannot be used for processes with which the company would earn money. Finally, to compensate the lost material additional items may have to be manufactured, hence, more raw materials will be ordered and more machine hours and employees labor are necessary.

Therefore, the question which will be covered in this research study is how work pieces in an assembly line or factory can be localized to reduce the time to search for them if they are lost to prevent the company from wasting resources? The effects of the solution developed for the assembly line and the whole company could be an increase in the efficiency of the use of machines, labor and material by smarter distribution and logistics.

One possibility to find an answer to this research question is to focus on the development of a concept with a system which can localize the different targets. A issue is that just the positions of all work pieces would be known but not the identity of the items on these positions. To solve this issue, the information which might be transfer to the employees indicate, that a specific target is at a certain position. Therefore, the system has two tasks: localization and identification of objects.

The title “Three dimensional Localization of Work Pieces in Assembly lines with Radio Frequency Identification” could indicate that the technology was picked as the system to be used prior the beginning of the research. That was not the case. Therefore, in Chapter 2 different technologies for identification and localization are examined for how they fit the later identified requirements. Out of this process it turned out that the Radio Frequency Identification system is the technology to use. The reason why Radio Frequency Technology is specified in the title is to find it in a shorter amount of time when research will be done in the future in the field of Radio Frequency Identification or localization.

AIM OF THE THESIS

Therefore, it is the aim of this research study to develop a concept for a system to localize and identify work pieces in an industrial setting. This includes how the data will be recorded and how the target position can be determent or calculated out of this data.

RESEARCH OUTLINE

To achieve this goal this study covers in Chapter 2 different identification and localization technologies as well as their advantages and disadvantages for the scenario of localizing and identifying work pieces. Subsequently, requirements for the desired system will be established. With the established requirements one system will be picked for further investigation. This is the Radio Frequency Identification System. For this system the Friis formula, important parameter and possible designs will be discussed. Using this knowledge, an antenna will be designed, constructed and tested. The measurements of the manufactured antenna and a commercial (Invengo) antenna will be compared to come up with the best system for the experiment described in Chapter 3 Methodology. Finally, the patents of the last 18 years for Radio Frequency Identification will be described to find out the leading companies and persons in this field.

In Chapter 3 scenarios where the tracking system could be an improvement will be developed. One of these scenarios will be picked for further investigation. After that, the experimental setup and the procedure will be described to record the data.

After this, Chapter 4 analyzes the recorded data. Here the strategy or the formula to determine the antenna position will also be developed. To calculate the position of the tags additional experiments are necessary, which are described, processed and their results analyzed.

Finally, Chapter 5 will sum up the findings and will give a brief description for the future.

CHAPTER 2

REVIEW OF LITERATURE

For a system in a factory that can localize work pieces, it is also useful to identify these objects. With the information about the position and identity a computer system could calculate the most efficient way to retrieve these pieces, and give information to the employees where lost material or material for the next step can be found. First, this chapter will cover different identification technologies, and second, localization technologies. The technologies will be compared by their advantages and disadvantages for this scenario. With this information the ideal system will be picked. Finally, the latest innovations for this system discussed in patents will be given.

IDENTIFICATION SYSTEMS

Automated identification of an object is very important in our modern world. The automated identification technologies enable a machine or device to read, collect and transfer data. The interaction of humans in the identification process should be kept to a minimum, to prevent human errors (Williams, 2014). For example, without barcodes the checking out process at a register in a grocery store would more time consuming. Every single item would need to be identified by an employee and then the item number or price would be typed into the system. A system with no human interaction that can identify the object automatically would be much faster. In Kärkkäinen (2003) and Williams (2014) contact-less identification technologies like the Barcode and Radio Frequency Identification are described. These are the most used identification technologies. Other contact less identification technologies are Bluetooth, Optical Character Recognition and Vision Recognition.

Magnetic stripe, smart cards and Contact Memory Technology were described in Kärkkäinen (2003) as well, but these technologies need contact between object tag and reader for identification. Contact-less identification might be an advantage in the case of identification in an assembly line because the contact between the target tag and the reader cannot be ensured. Therefore, just contact-less identification systems are described in this section. At the end, the advantages and disadvantages of these technologies are listed in a table.

Barcode:

In a Barcode system the information is encoded by alternating printed areas of different colors called bars. A scanner detects the bar series and converts the information into machine compatible data. After Kärkkäinen, there are a lot of different ways to create these Barcode "symbologies." Out of this symbologies a few are used, which can be divided into one and two dimensional or composite barcodes. A one-dimensional Barcode can contain about nine characters per 2.54cm (complete code about 15 to 50 characters). Contrary to this a two-dimensional Barcode can contain about two kilobytes. In Figure 1 the different types of barcodes are displayed (Kärkkäinen, 2003; Williams, 2014).

The advantages of Barcodes are that they can be produced with a printer in large amount almost free. According to Williams (2014), a printed Barcode is cheap. In addition, the machine readability is good and the distance reading can be up to 50cm (Finkenzeller, 2010; Kärkkäinen, 2003).

A disadvantage of the identification with barcodes is that a so called “line of sight” between the tag and the scanner is needed to read the tag information. To read the two dimensions, more expensive readers are necessary. Additionally, the readability can be degraded by grease, grime and sunlight. Compared to other identification systems the data density is low and the reading time is slow at about 4 seconds (Finkenzeller, 2010; Kärkkäinen, 2003).

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a) b) c)

Figure 1 different Barcode styles: a) 1 dimensional Barcode, b) 2 dimensional Barcode, c) composite Barcode (BarCode Graphics, 2018)

Radio-Frequency Identification:

For the identification of an object with Radio-Frequency Identification (RFID), a tag, a reader and an antenna are used. The tag must be attached to the target. A tag contains an antenna and a chip where the data is saved. Tags can be passive, with no included power source, or active, with an included power source (in the Figure 2-4 below a passive tag is visualized). The difference of active and passive tags is that active tags just need a signal from the reader, which starts the transmission process for the active tag. Contrary to active tags, passive tags generate the necessary energy to power the chip and to send the information by induction from the reader signal. Therefore, the read range of active tags is larger because the signal for passive tags cannot be sent over the same distance as the signal for active tags.

In some cases, software is necessary to run the reader. The software on a computer runs the reader and might display the returned information. The reader, which must be connected to the antenna, will send the signal to the antenna and the antenna will send the signal out to the environment. For the RFID technology different frequencies of the signal can be used: Low Frequency with about 135 kilo Hertz, High Frequency with about 13.56 Mega Hertz, the Ultra High Frequency with about 860 to 960 Mega Hertz and finally, the Microwave with about 2.45 Giga Hertz. (Leong, Ng, & Cole, 2006).

In the following paragraphs, the procedure is illustrated and explained. To read the tag information, first, a reader is necessary which generates the alternating radio frequency signal. The signal will be transmitted to the antenna and from there to the environment, as seen in Figure 2.

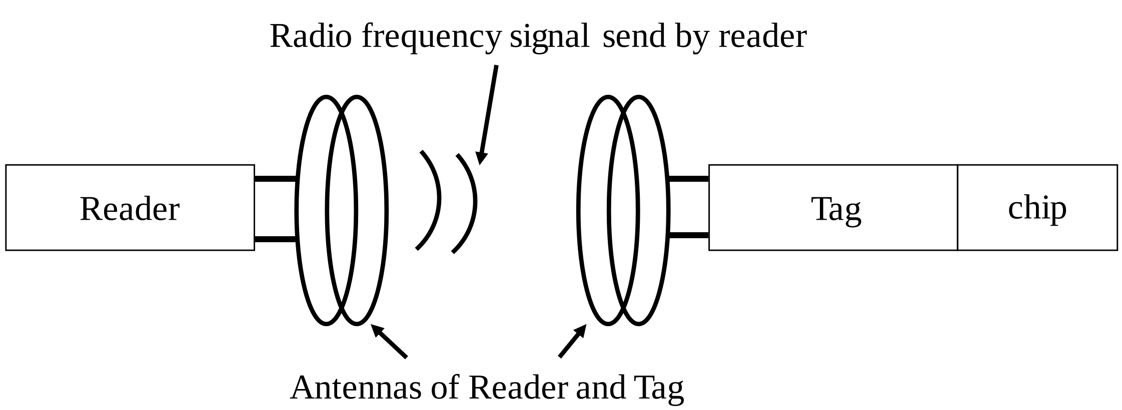

Figure 2 RFID reader sending radio frequency signal; visualized from the information in the text

The alternating radio frequency signal creates a current in the tag by induction in the tag's antenna (Figure 3). In case of active tags, this current is the trigger to send the tag information, or in case of passive tags, the current has to power the process of sending the information.

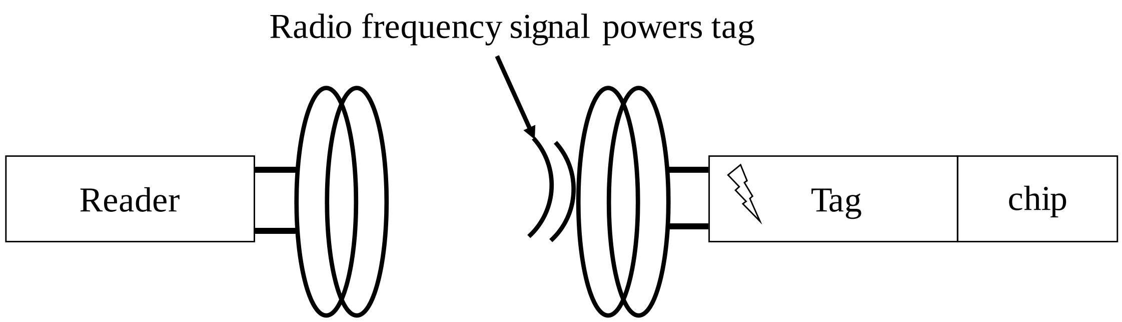

Figure 3 RF-signal powers tag by induction in tag antenna: visualized from the information in the text

With this energy, the tag can send the saved data on the chip back to the reader. The antenna of the reader receives the signal, transmit it to the reader and the reader decodes the antenna signal to machine-readable information, Figure 4. This information could be displayed on a monitor with a Graphical User Interface.

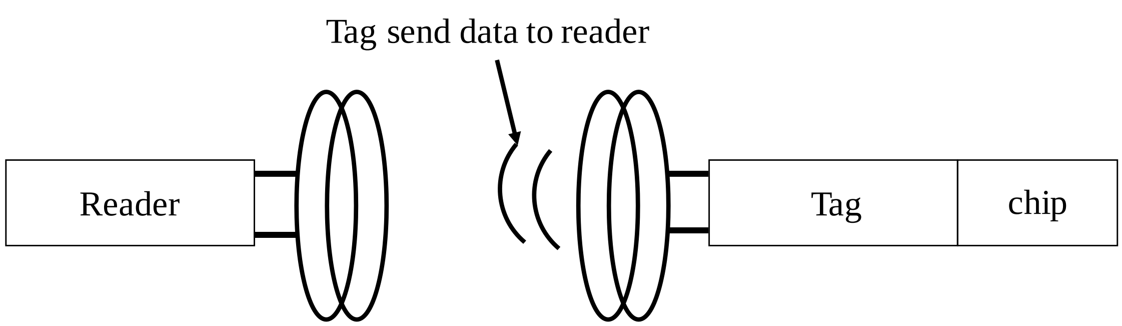

Figure 4 Tag is sending information back to reader; visualized from the information in the text

The advantages of using a RFID system compared to a barcode system are that the line of sight is not required for the RFID system and the tags do not have to be oriented carefully. A RFID code can save up to eight kilobits and multiple tags can be read by one antenna. Additionally, grease, grime and sunlight affect the readability of a barcode, but the RFID system is not affected by these (Finkenzeller, 2010).

The disadvantage of RFID compared to the barcode is that the barcode is almost free, while the RFID tags cost about 12 cents per tag in units of one million. Additionally, the batteries for active tags may have to be replaced after their life time (Want, 2006).

Due to these advantages, RFID system can be used in a lot of fields today, such as security, tracking, authenticity and electronic payments. In the security field RFID is used for access control in factories. Every employee receives a RFID tag in the form of a card or chip. A reader in front of every secure area can read the employees' tag number. This tag number can be compared on a computer with the numbers that have access. If the access data contains the employee number, the computer will send a signal and the door opens. Another security field is anti-theft. To prevent shop lifting tags are attached to the products. For this system the reader is installed at the entrances and exits of a building. If a product is purchased, the tag has to be removed from the product. If the tag is not removed, the readers will read the tag number and sound an alarm, preventing shop lifting. It is also possible to embed the tag inside of the product, say between the material layers of clothing. In this case the tag cannot be removed, so during the purchasing process the tag numbers of the purchased item have to be removed from the list of non-purchased products, otherwise the gate readers at the exits start the alarm. This system is also used in libraries, where a tag is inserted in the books (Want, 2006).

In the field of tracking, RFID tags are used at sports events like marathons to track the participants. With a tag attached to every participant and a reader at certain check points along the route, the system adds information like starting times when the tag passes the checkpoint. With this list of tag numbers and time coded reads, the lap time can be calculated for every participant. With RFID tags, tracking of pets and animals is also possible. A tag is often placed under the skin of the animal. If the animal is found after it runs away, the tag number is read and searched in the system to find the owner (Want, 2006).

For some things like money, government documents, certificates or pharmaceutical drugs it is important to know the authenticity. With a small chip inserted into these, it would be much harder to create counterfeits or unsafe drugs and the user would have the certainty that the product can be used safely. For this field Hitatchi (2003) developed a tag with dimensions of about 0.4mm by 0.4mm. Due to the dimensions the tag can be embed between paper layers (Want, 2006; Hitatchi, 2003).

RFID tags can also be used to make electronic payments. A car equipped with a tag could be read by readers at toll roads. With a list where the tag numbers are related to the information of the car owner’s credit card, the billing can be done automatically. A similar system is already being used in the United States called E-ZPass. Another example is electronic tickets like ski passes. The tag number can be read at the entrance of the slope. The information will be compared with the numbers of the purchased tickets for that day or event (Want, 2006; RITBA, 213).

Bluetooth:

Objects can also be identified using Bluetooth technology. Bluetooth is a short-range identification and communication technology between computers or mobile devices with radio links. Items in a factory can also be identified with Bluetooth chips. The chip has to be attached to the item. The identification occurs by receiving the individual identification number from the chip at a reading device (Kärkkäinen, 2003).

The advantage of Bluetooth identification is that all mobile phones and computers, which can operate with Bluetooth, can identify the different chips. A conventional reader might not necessary (Kärkkäinen, 2003).

The disadvantages of Bluetooth are the necessary power supply for the chips. Passive chips like passive RFID tags are not possible. The price of these chips in comparison to other systems is more expensive. One reason for the higher price is the underdevelopment of the Bluetooth standard and advances in mass production of the chips (Kärkkäinen, 2003).

Optical Character Recognition (OCR):

The OCR system was developed to read the human readable information on labels on the item. The readers for this system are much more complicated than readers of other identification systems (Finkenzeller, 2010), (Kärkkäinen, 2003).

The advantages of OCR identification are that the characters can be read by employees, so that the information read by the system can be supervised. Additionally, the density of the data can be very high and the labels can be cheaply produced with a printer (Finkenzeller, 2010).

The disadvantages of an OCR, system is that the systems are expensive and complicated. The reading speed is also slow and the maximum reading distance is very short. As with the barcode system, grime can influence the reading process (Finkenzeller, 2010).

Vision Recognition (VR):

All of the previous presented technologies require that a tag has to be attached to the object being identified. The Vision Recognition system creates an image from the compiled. The dimensions and shape of the object are used for identification by a software (Kärkkäinen, 2003).

The advantage of a VR system is that no labels or tags are necessary for the identification of the object (Kärkkäinen, 2003).

The disadvantage of a VR system is that an image is taken from the object. To take that image, the illumination conditions have to be very good for an errorless process. Due to these arguments VR is used in quality control and surveillance at assembly plants (Kärkkäinen, 2003).

Table 1 advantages and disadvantages of identification technologies (Kärkkäinen, 2003)

Identification method	Advantages	Disadvantages
Barcode	-cheap -easy to produce	-line of sight is needed -arrange exact to read -no multi code reading
Radio Frequency Identification	-no line of sight needed -multiple tags readable	-more expensive than barcode

	-no effects of grease grim	
Bluetooth	-Conventional reader is not needed	-Energy supply for chips -Mass production is advancing -higher price compared to other systems
Optical Character Recognition	-employees can read tags/labels to check or in emergency	-High price -Complicated readers -slow reading -short reading distance -universally not applicable
Vision Recognition	-No labels/tags necessary	-Illuminative conditions

LOCALIZATION SYSTEMS

To localize an object, different technologies with different techniques and metrics are possible. In Deak (2012) active and passive systems are described.

The defining characteristic for a passive system is that the target is not marked by a tag or other device, whereas an active system contains a tag or device attached to the target (Deak, 2012).

The localization of the target can follow the following procedure. The localization technology in use to send out a signal through all sources. These sources can be antennas or other transmitting devices. The targeted object will respond to the signal or the object tag will send the stored information back to the source. The sources receive the signals and transmit the information to a server. With the signal information, an algorithm on a computer can calculate the target's position using predefined metrics. These metrics are the Received Signal Strength Indicator (RSSI), the signal running time (Time of Arrival (TOA); Time Difference of Arrival (TDOA)), and the angle in which the antenna receives the signal (Angle of Arrival (AOA)) (Deak, 2012).

At RSSI a signal source transmits an outgoing signal. The target reflects the signal or sends information back. The received signal strength from the target at the signal source can be assigned to a specific distance between the systems signal source and the target. Due to the missing orientation information, the target can be anywhere around the source within the measured distance. Therefore, all possible target positions form a sphere with the signal source in the center (Bolic, Simplot-Ryl, & Stojmenovic, 2010).

Like the RSSI system the TOA and TDOA calculate the distance between the antenna and the target tag, but in this case the time which the signal needs to travel the distance is recorded. With the known travel speed of the signal in a medium and the travel time, the distance can be calculated. Similar to the RSSI system the information of the orientation from the target to the signal source cannot be calculated from the signal information, so the target tag can be located on a sphere around the signal source.

In contrast to the prior three metrics, an AOA does not calculate the distance between the signal source and the tag. A system using AOA metrics returns the orientation of the direct line between tag and signal source related to an initial coordinate system. The tag can be anywhere on this line (Deak, 2012).

With the information of the metrics two different localization techniques can be used by the algorithm to calculate the target position.

First, is called trilateration. For this technique the distance information between target and signal source is used. Due to the unknown orientation of the target around the signal source, the distance information creates a sphere around the signal source. Therefore, for the localization in a three-dimensional space, four signal sources are necessary; in a two dimensional space, three are needed. The positions of the signal sources need to be known. The advantage of this method is the fact that the target has to be on the spheres of all the signal sources which detected the tag. All of the spheres have to intersect at one point. Two intersecting spheres have a circular contact. In the case that they intersect at just one point, the target will be on the line of the shortest distance between these signal sources. The third sphere intersects this circle at two points and the last sphere is only intersecting with one of these two points. This point is the position of the target (Ko, 2010).

Trilateration for a two-dimensional case is displayed in Figure 5. In this case all possible target spots form a circle around the signal source. The calculation of the target location is similar to the three dimensional case. The circles of two signal sources intersect at two points. With the distance information of the third source, only one of these two points can be the target location. The trilateration can be used for RSSI-, TOA- and TDOA-systems (Ko, 2010).

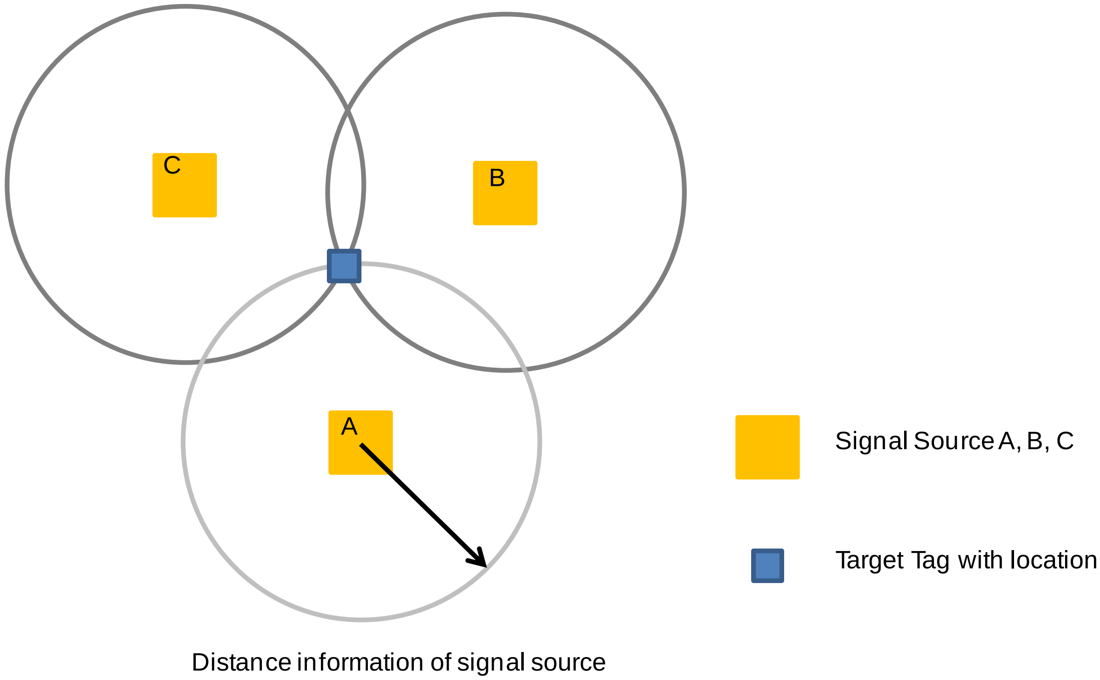

Figure 5 Trilateration of a target tag in two-dimensional space after (Ko, 2010)

The second localization technique is called triangulation. The technique of triangulation is displayed in Figure 6 for the two-dimensional space. Similar to trilateration the positions of the signal sources (at least two) have to be known. For triangulation the orientation of the line between target and signal source is used. Therefore, one angle per source is necessary in a two-dimensional case, and two angles per source in a three-dimensional localization case. With the known angles α and β, the unknown angle γ can be calculated because the sum of all angles in a triangle is always 180 degrees ((Eq. 1) (Ko, 2010).

$$\gamma = 180 - \alpha - \beta \qquad \textbf{(Eq. 1)}$$

Where

α is one of the returned orientation information β is one of the returned orientation information

γ is the missing angle in the triangle

180 is the sum of all angles in a triangle

With the known degrees of the angles and the positions of the signal sources, the missing edges of the triangle and the distances between signal source and target, can be calculated using the law of sines ((Eq. 2).

$$\frac{a}{\sin\alpha} = \frac{b}{\sin\beta} = \frac{c}{\sin\gamma} \qquad \textbf{(Eq. 2)}$$

With all known angles, edge lengths and the coordinates of A and B, the target position can be calculated (Figure 6). The triangulation can be used with the information of an AOA-system.

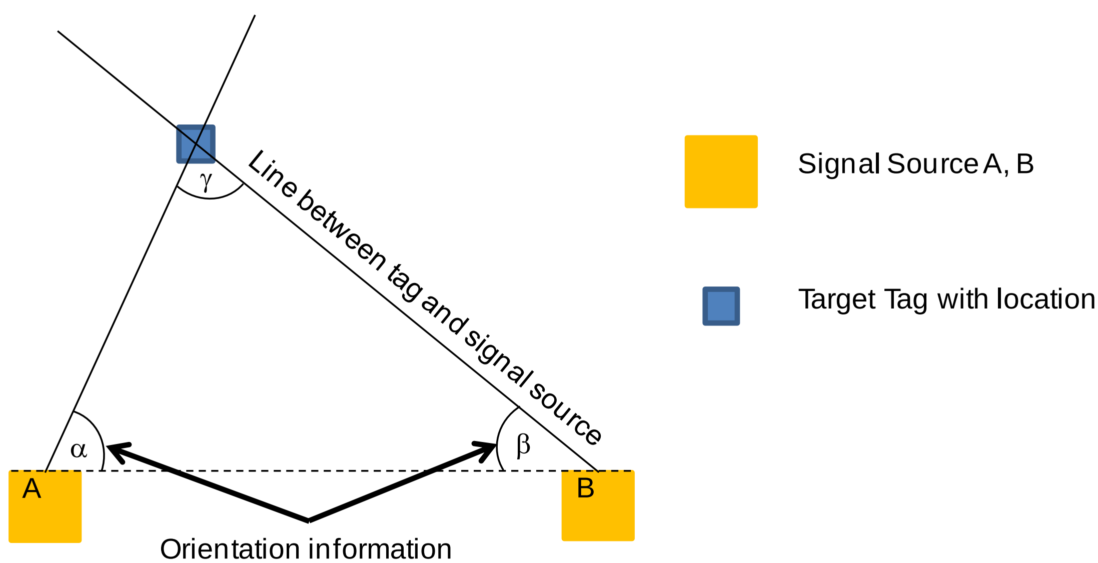

Figure 6 Triangulation of a target in a two-dimensional space after (Ko, 2010)

In the previous paragraphs the procedure to calculate the target position from the returned information from the localization technology was described. However, in the real-world, obstacles can be inbetween the reader and the target. These obstacles can lead to wrong information returns to the system. Therefore, the tracking of an indoor object is more challenging than the tracking of an outdoor object. The line of sight is not always possible in many cases. So, a requirement for an indoor localizing system is that the system has to be independent of the line of sight. Due to this requirement the Global Positioning System, for example, is not useful in the case of indoor localization because the line of sight is required (Deak, 2012). In the following paragraphs the hardware technologies used for indoor localization will be described, which metrics they use and their advantages and disadvantages for localization in an indoor assembly line.

Wireless Local Area Network (WLAN)

For device tracking with WLAN the target has to be equipped with a WLAN receiver. The receiver receives the strengths of the WLAN signal sent from the access point(s). The information of the signal strength can be assigned to the distance from receiver to a specific access point. The next step can be to send the information about the signal strength back to the access point. The calculation can be done through additional software running on a server or on a mobile phone or laptop using the locating software. Because of the described received signal strength for localization, the system is using RSSI with trilateration. Additionally, it is most suitable for tracking mobile devices like mobile phones or laptops because they are already using WLAN networks (Deak, 2012).

One of the advantages of localization with WLAN is the use of existing infrastructure. The access points are already installed, their positions are known and to add software to a mobile device or laptop is possible (Deak, 2012).

One disadvantage of the system might be that not significant access points are installed next to the assembly lines. Therefore, the position might not be exact enough for successful tracking (Deak, 2012).

Some examples of technologies which uses WLAN for localization is the Ekahau Real Time Location System, the Microsoft RADAR or the Skyhook WLAN Positioning System (Deak, 2012).

Ultra-wideband (UWB)

Ultra-wideband (UWB) is not a localization system like WLAN or the other introduced systems. UWB is the technique to transmit radio waves with a high bandwith. The bandwith is the difference between the maximum and minimum used frequency. The difference is usually greater than 500 Megahertz (Mhz). A commercial system which uses an ultra-wideband signal is Ubisense. Ubisense uses their unique software, sensors and tags to run the system. The sensors return the TDOA and AOA, so the algorithm can triangulate the target position (Gezici, et al., 2005) (Deak, 2012).

The advantage of using an UWB signal is the bandwith. The different frequencies increase the chance that the signal can pass or transmit around obstacles. Another advantage of systems using UWB like Ubisense is that triangulation is possible, so just two signal sources are necessary to provide information about orientation.

The disadvantage of UWB systems is that they are under developed. A disadvantage for the Ubisense system specifically is that the price compared to other systems is high (López, Gómez, & Andrés, 2017).

RFID

Tracking with an RFID system works similar to localization with WLAN. In place of WLAN routers, RFID antennas have to be installed in the area where targets should be tracked. The targets have to be equipped with a RFID tag, which can send the identification number when the antennas send the trigger signal. The RFID antennas return the received tag identification numbers to the reader. The reader will transmit the information to the server with the calculation software to run the localization algorithm.

The basic idea behind tracking with RFID is that multiple antennas are mounted (for example on the ceiling) in the area where targets will be tracked. The position of every antenna is important because the read ranges should overlap (Figure 8). Due to the overlapping read ranges different zones can be identified. For example, in Figure 8 Target Tag 1 is in a zone where just Antennas B, C and E receive the tag identification number. This leads to a tag position, where all read ranges of the three antennas overlap. The same can be done for Target Tag 2, where just Antenna E can receive the tag identification signal, and Target Tag 3, which can be triggered by Antennas D and F (Figure 8). It can be seen from this example that every zone can be read by different antennas. The ID of the different antennas can form a unique code for the zones. In

Table 2 the tag ID's are listed for the corresponding antenna code in the case of Figure 8 (Seol, Lee, & Wooseong, 2017).

Table 2 antennas related to the tag identification numbers after (Seol, Lee, & Wooseong, 2017)

Tag ID	Antennas
1	B,C,E
2	E
3	D,F

The relation between tag ID and antenna can also be established the other way around, where the antennas are listed with the corresponding tag ID's Table 3.

Table 3 Tag identification number scanned by antenna

Antennas	Tag ID
B	1
C	1
D	3
E	1,2
F	3

Both tables above contain the same information but display it in a different way. The advantage of doing this is that one to one relations between antenna and Tag ID can be identified easier. In Chapter 4 this advantage will be discussed in relation to the chosen scenario.

The RFID antennas return the tag identification numbers they receive. With this information and the known read range of the antennas, the location of an object can be calculated. To calculate a more precise location, the signal strength could be related to a certain distance (RSSI). With the RSSI trilateration can be done.

Some RFID systems, like the Invengo system used later in Chapter 3, are able to return the RSSI. In Figure 7 the Graphical User Interface is displayed with the column for the RSSI (Invengo, 2015).

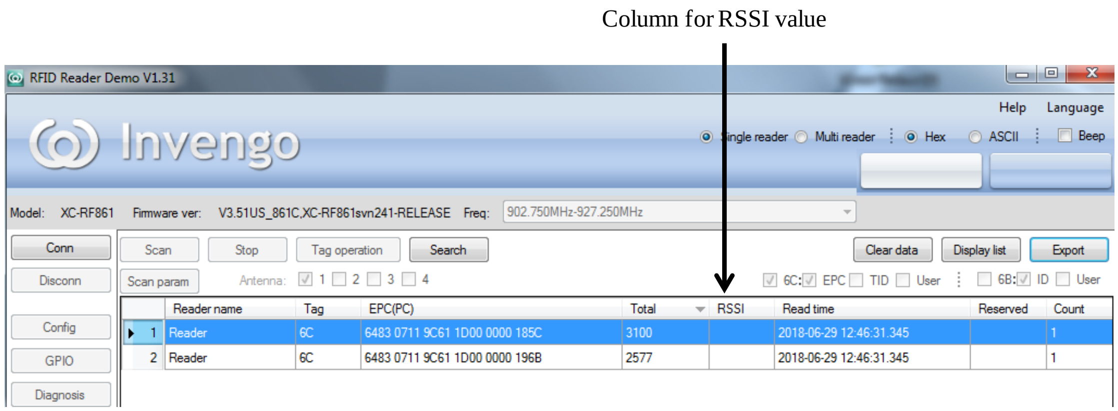

Figure 7 Column for RSSI in the Invengo Graphical User Interface

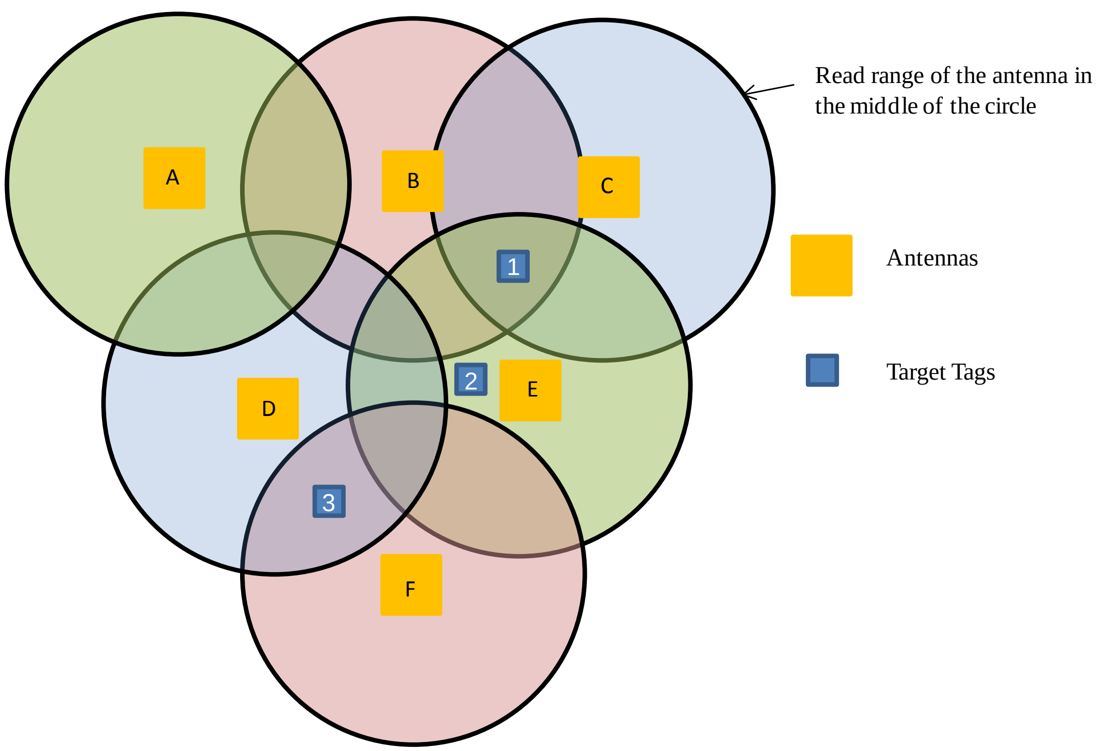

Figure 8 Tracking with RFID antennas after (Seol, Lee, & Wooseong, 2017)

The localization can also be done the other way around. In that case the tags are usually embedded in the floor. The antenna is attached to the object to be tracked. By the tag identification numbers received from the antenna, an algorithm can calculate the position. Due to the physical size of the antenna and the necessary power supply, this configuration is suitable for larger objects like robots. This method has one disadvantage. If the tags are active and embedded in the floor, they have to be removed at the end of their lifetime. Another point is when the floor is built with reinforced concrete. The steel in the concrete can interfere with the RFID signal, so that the tags may not be triggered by the antennas (Condas, Devey, & Lemaire, 2010).

An advantage of tracking with RFID is the price for the tags. The price for large amount orders is about 13cents, when the tags are ordered in quantities of one million. Additionally, RFID tags are smaller than Bluetooth or WLAN receivers (Want, 2006; López, Gómez, & Andrés, 2017).

A disadvantage of tracking with RFID is that the orientation of the tag can have an influence of the tag detection. That leads to the issue that a tag can be in the read range of the antenna but is not triggered by the antenna signal. A solution to avoid this problem is to attach multiple tags at different orientations to the target (Condas, Devey, & Lemaire, 2010).

Infrared

Various systems have been developed which use infrared light for localization. Some of the systems have the accuracy of a few centimeters, because they use TOA and AOA metrics, while others have room-level accuracy (Deak, 2012).

An advantage of localizing with infrared is that the technology is inexpensive (Deak, 2012).

The disadvantages of tracking with infrared are that the infrared signal does not travel through obstacles like walls. Therefore, the line of sight is necessary between reader and tag. In addition to this, the infrared signal can also be disturbed by direct sunlight and fluorescent lighting (Deak, 2012; Satyanarayanan, 2008).

Ultrasonic sound

Ultrasonic sound is also possible to use as the signal to transfer information to locate an object. The Active Bats system, developed by AT&T Cambridge, uses Ultrasonic sound. For this system, a badge is attached to the target. The badge sends the stored information about its identity. A receiver, usually installed every square meter in the ceiling, receives the signal and transmits the information to a computer which operates the localization information (Deak, 2012).

The advantage of the Active Bats system is that the calculated position is very precise. This precision is within just a few centimeters for over 94% of the readings (Deak, 2012).

One disadvantage of using Ultrasonic sound systems for localization like the Active Bats system is that that objects can reflect the signal. This reflection can cause errors in the received data. To eliminate these errors and achieve the aforementioned accuracy, a statistical rejection algorithm is used. Another disadvantage is that the timeslots to transmit the signal are limited (Deak, 2012).

Bluetooth

Object tracing with Bluetooth works similarly to tracking with WLAN. A Bluetooth receiver detects the signal strength. For example, the BilpNet system uses the WLAN signal, which is transferred by Bluetooth to the mobile device. Then a program on the device can run the localization algorithm or the received signal strength is sent back and a server does the calculation (Deak, 2012).

The advantages of tracking with Bluetooth is that an already installed device is used. Additionally, the read range of the Bluetooth signal can be extended when additional antennas and amplifiers are installed (Deak, 2012).

The disadvantage is that the installation of additional antennas increases the costs of the whole system. Furthermore, every item, which does not have a Bluetooth receiver, needs to be equipped with one. As previously discussed in the introduction of the Identification Systems section, these receivers or tags are very expensive and underdeveloped (Deak, 2012).

REQUIREMENTS FOR THE SYSTEM

In this section, requirements will be established for an ideal identification and localization system in assembly lines. There are three issues which the system must deal with. First, obstacles like large objects in the line may reflect the signal. Second, a signal strength decreases when it passes walls or obstacles. Third, other signals could interfere with the target signal. Out of these three issues the requirements will be established for a system which will be used for tracking and identification of work pieces in assembly lines. In Chapter 3 this system and its potential for use in different assembly line scenarios will be discussed (López, Gómez, & Andrés, 2017; Mehdipour, Trueman, Sebak, & Hoa, 2009).

The desired system should not only be used in developing assembly lines, but it should also be used as an improvement for existing assembly lines. In the case of an existing assembly line, the machines and their positions as well as the positions of the employees' work places might not be easily moved. The desired tracking system should not interfere with the machines or harm the employees. Another issue with the fixed machine positions and the framework of the hall is that the line of sight between the reader and the tag might not be clear.

In contrast to the unchanging machine positions, the workplace conditions can change. While some areas are clean, in some areas there are conditions like airborne dirt and vaporized grease or water. The dirt and vapors can form a layer on an identification tag. This layer could make the readability of the system worse, so the ideal system should not be affected by it.

The distribution of the items needs a quick and reliable distribution. Due to the mobility of the items, the use of an external power supply to power the tags via cable is not possible, but a battery included with the tag is an option. In this case, the amount of energy is limited. If a battery is attached to a tag, it should work for at least several months. Changing the batteries should not occur often.

For a suitable identification and localization technology, the read range should be in a specifically sized range. On the one hand, a small read range might not detect the tags for a successful localization. On the other hand, a large antenna read range might receive all tag identification numbers in the monitored area. When all tags are readable from every possible antenna position, it is not possible to calculate the target location because every scanning antenna would give the same list of received tag identification numbers. This leads to that the dimension in the scenario influence the read range.

All requirements are listed below again:

- Line of sight is not required.
- Machines are not interfered, employees are not harmed.
- No effect of dirty layers on tag or item.
- No external power supply for tags.
- Artificial conditions like illumination is not necessary.
- Read range depends on the situation, should be larger than 1m.

SELECTION OF IDENTIFICATION AND LOCALIZATION SYSTEM

In this section an identification and localization technique will be picked for further investigation. Therefore, Table 4 is first established, which summarizes the requirements for an ideal system fulfilled by the identification technologies given at the beginning of the chapter. If a technology fulfills the requirement, it is marked with a checkmark (✓), if doesn't it is marked with an X. After that, Table 5 is established where all possible combinations of localization and identification systems are given. The aim is to identify the best combination of identification and localization systems because most systems cannot do both. Finally, one combination of systems will be picked for further investigation.

In Table 4 the identification systems and the requirements they fulfill are presented. Only RFID fulfills all requirements, while Bluetooth fulfills four out of the five requirements. Barcode and OCR have the same weaknesses in that the line of sight is required and unclean tags might not be readable. Additionally, OCR has a limited read range. Finally, Vision Recognition has the weakness that the item to be identified needs special lighting conditions and a line of sight.

Table 4 Fulfillment for the requirements of the identification techniques

Identification System\requirement	No line of sight needed	no dirt effects	no power supply	no artificial conditions	read range
Barcode	x	x	✓	✓	✓
RFID	✓	✓	✓	✓	✓
Bluetooth	✓	✓	x	✓	✓
OCR	x	x	✓	✓	x
Vision Recognition	x	✓	✓	x	✓

Finally, the VR technology will not be used because the identification process with VR is problematic when the targets are stored in paper boxes or when the item is not illuminated appropriately.

lists all possible combinations of identification and localization techniques in a matrix. If a combination is feasible, the field is marked with a checkmark (✓), if it is not, it is marked with an X. Two techniques, RFID and Bluetooth, can do both identification and localization. Therefore, a combination of Bluetooth or RFID with another technique is not required, so the rows and columns of RFID and Bluetooth are marked with an X, accept the fields where the row and column of the two systems intersect.

First, the Barcode system is not suitable to be used for the desired system. One issue with the barcode system is that the line of sight between tag and scanner is necessary, but in an assembly line this might not be possible. Another issue is that the barcode scanner may need to be aligned to face the barcode before scanning. This means that the position of the barcode is essential to know before scanning. This requires another system to locate the barcode.

Second, the use of an OCR system is not suitable as well because of the same issues the barcode system has (line of sight needed, effect of dirt). In addition, the OCR system has a short read range.

Finally, the VR technology will not be used because the identification process with VR is problematic when the targets are stored in paper boxes or when the item is not illuminated appropriately.

Table 5 System options

localizatio\identification	Barcode	RFID	Bluetooth	Optical Character Reading	Vision recognition
WLAN	x	x	x	x	x
RFID	x	✓	x	x	x
Infraread	x	x	x	x	x
Ultrasonic	x	x	x	x	x
Bluetooth	x	x	✓	x	x

Table 5 leads to two possible systems for localization and identification, RFID and Bluetooth because both systems can do identification and localization. Due to the disadvantages of Bluetooth, described at the beginning of this chapter (more expensive, underdeveloped), the RFID technology will be picked for further investigations.

ANTENNA CALCULATION AND DESIGN

One key element of an RFID system is the antenna because the antenna must transmit the reader signal to the environment as well as to receive the tag answer.

Therefore, this chapter covers the most important antenna forms. After that the metrics gain, bandwidth, directivity and impedance were described. Finally, the Friis formula will be given, which calculates the antenna read range.

Dipole Antenna

First, is the dipole antenna. A dipole antenna can be build with two in line wires of the same length, displayed in Figure 9. In the middle of the two wires is an AC source, which can be the signal from the reader. The length λ of the antenna is based on one wavelength of the frequency which the antenna should send. The wavelength can be calculated with (eq. 3). It is also possible to build an antenna with a shorter length. In this case the λ can be divided by a nonnegative integer (Bevelacqua, 2009; Deavours, 2010).

$$\lambda = \frac{c}{f} \quad \textbf{(eq. 3)}$$

Where

λ Wavelength

c speed of light (3*10^8 m/s)

f signal frequency

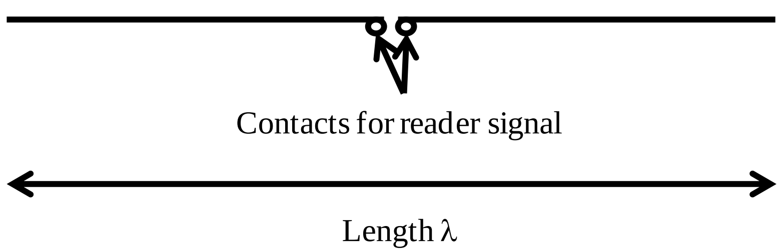

Figure 9 Dipole Antenna after (Bevelacqua, 2009)

Another way of designing a dipole antenna is the so called meandering dipole, shown in Figure 10. Here, the wire meanders, which leads to a more compact style of the antenna. The compact style can be important for the antenna to fit under labels (Deavours, 2010).

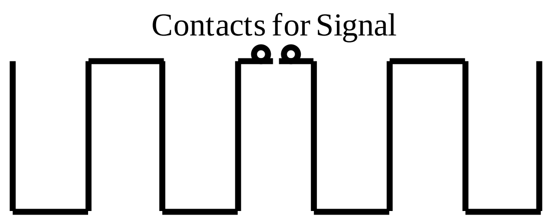

Figure 10 Meandering Dipole Antenna after (Deavours, 2010; Galehdar, Thiel, & O`Keefe, 2007)

The antenna will send electromagnetic waves when it is connected to an alternating current. The alternating current will charge the wires like capacitors positive or negative with the frequency to be sent. The moving electrons lead to an electromagnetic field around the wire. The electromagnetic field expend to the environment (Deavours, 2010).

It is also possible to build monopole antennas. A monopole antenna containing just one of the wires to send out the radio waves, displayed in Figure 11 (Bevelacqua, 2009)

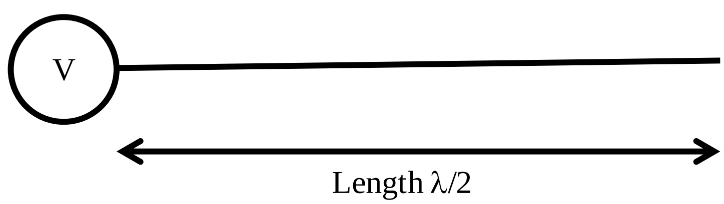

Figure 11 Monopole antenna after (Bevelacqua, 2009)

There are multiple ways to build an antenna. Additional antenna shapes are presented at Bevelacqua (2009). In the next paragraphs some important antenna measurements and the Friis formula will be discribed.

Bandwidth:

The bandwidth of an antenna is the difference between the highest and lowest frequency which the antenna can send (Bevelacqua, 2009).

Impedance:

The impedance is the relation of the current and the voltage. It can be a complex number, if current and voltage are not in phase (Bevelacqua, 2009).

Radiation Pattern:

The radiation pattern is the information how much power is transmitted by into ever direction around the antenna. Therefore, the shape is three dimensional. For a better visualization a two dimensional charts present layers of the shape of the three dimensional one. The chart layers are the so called E- and H-plane (Bevelacqua, 2009).

On the chart of the radiation pattern, the half power beam bandwidth is the angle between the two lines which can be drawn between the center of the antenna and the points at the main lobe where the power of the main lobe decreased by 50% or 3 dB (Bevelacqua, 2009).

Gain:

The gain describes how much power of the antenna is transmitted in the peak direction compared to an isotropic antenna.

With the Friis formula the power which a tag receives can be calculate (Equation 4) (Bolic, Simplot-Ryl, & Stojmenovic, 2010).

$$P_{tag} = P_{antenna}\left(\frac{\lambda}{4\pi r}\right)^2 \psi_{antenna}\psi_{tag} \qquad \textbf{(eq. 4)}$$

Where

P_{tag}	signal power that tag receives
$P_{antenna}$	power of the antenna
λ	wavelength of the signal
r	distance between antenna and tag
$\psi_{antenna}$	gain of the antenna
ψ_{tag}	gain of the tag

The formula indicates that the power which the tag receives depends on, the distance between antenna and tag, the antenna gain of antenna and tag, the wavelength of the signal and on the power which was sent out by the antenna. With the known minimal power to operate the tag, the formula could be converted to calculate the read range of the system (Bevelacqua, 2009).

Antenna manufacturing

With the knowledge of the last paragraphs a monopole antenna will be developed and tested in this section.

For the monopole antenna the cupper strips from an electric cable were used. The isolation was removed and the wires were interweaved together. This copper wire was then cut to the length of 16.5 cm, which is the half of the wavelength of the UHF signal. For the connection to the Invengo reader signal (is described in Chapter 3), the plastic cover from the antenna was removed. Then the metal antenna in Figure 12 was replaced by the copper string (Figure 13). The electric connection to the signal was ensured by drilling the screw through the one end of the copper string.

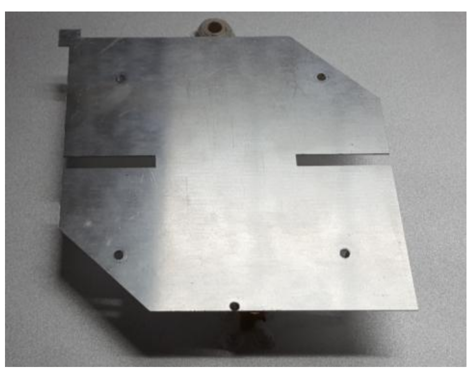

Figure 12 Metal Plate from Invengo Antenna

Figure 13 Copper Monopole Antenna

With this new antenna the read range for a tag with an antenna power of 30 dB was taken. To determine the read range the antenna was placed at one edge of a table. Then the tag was moved from a point outside of the read range into the read range. The result is that the antenna has a maximum read range of less than one meter.

With a read range of less than one meter the maximum possible reading distance of the manufactured antenna is below the read range of the Invengo antenna which is about 6 meters (data in Chapter 4).

Reasons for this result might be that the wire is maybe not cut at the best length which could have an effect on the signal frequency. Another reason might be that the Invengo antenna has a larger surface and contains more material, which is maybe optimized for the reader signal, than the copper wire.

PATENT RESEARCH

To get an overview about the leading companies which provide RFID localization systems, this section will sum up patents from 1st, January 2000 to 31st , May 2018. The aim is to get an idea which companies or persons are leading the market. The claim of the patents is not being described. The patents were found on Google Patents by searching for “localization RFID” and “RFID localization”.

When using “localization RFID” 16 patents were found while for “RFID localization” 54 patents occurred. Out of these 70 patents 21 patents were selected because these patents covered the localization of a target like robots or to build up a warehouse management system. The list with the selected patents is given in Table 6. Some inventors are written in Mandarin or Korean letters

Most of the patents from Table 6 were invented by different persons. Just two times the inventor of patents were the same. These were the patent US7619532B2 and US20090027170A1 which were invented by Israel Amir from Remote Play Inc. These patents cover the flow of the directional information for real time location RFID networks and the use of a dual antenna base station. This base stations can improve the RFID localization after the patent.

The other persons were: Mario Schühler, Lars Weisgerber, Johannes Arendt, Rainer Wansch, Heinrich Milosiu and Frank Oehler from the Fraunhofer-Gesellschaft who invented WO2017137624A1 and WO2017137524A1. The first patent covers a device to determine a transmitter location and the method, while the second patent covers the device to determine a transmitter location.

Table 6 Patent numbers

Patentnumber	Title	Date	Inventor (s)	Assignee
EP1898341A1	Automated system for drawing up localised inventories	31.08.2006	Bruno Fabre, Nathalie Chateau, Adrien Vallet,Guy Venture	Neopost Technologies NBG ID
US20090267741A1	RFID Floor Tags for Machine Localization and Delivery of Visual Information	27.04.2009	Eric Chun-Yip Li, Peter A. Swenson	Tennant Co
US9324053B1	RFID tag cylinder inventory control method	07.10.2014	Joshua Lavra, Giuseppe Liberati	Air Liquide Advanced Technologies US LLC
CN106249198A	Indoor robot positioning method based on combination of multipoint RFID and ultrasonic waves	15.07.2016	mandarin written	mandarin written
US8860611B1	RFID-based mobile vehicle localization	15.05.2012	Roger J. Anderson, Jeremy E Hatcher	US Secretary of Navy
US20150186693A1	Systems and Methods for Radio Frequency Identification (RFID) Localization	31.12.2013	Bryan Michael Blair, John Thomas Fessler, Julie Ann Gordon Whitney	Lexmark International Inc
US7619532B2	Dual antenna base station for improved RFID localization	27.07.2007	Israel Amir	Remote Play Inc

Patentnumber	Title	Date	Inventor (s)	Assignee
US20140375429A1	Systems and methods for object localization and path identification based on rfid sensing	27.07.2007	Lucian Cristache	LUCOMM TECHNOLOGIES Inc
WO2014203041A1	System and method for rfid indoor localization	20.06.2013	Abdelmoula BEKKALI, Abdullah Kadri	Qatar University Qstp-B
US20160146934A1	Real-time rfid localization using uniform, high-performance tags and related method thereof	26.06.2013	Kirti Chawla, Gabriel Robins	University of Virginia Licensing and Ventures Group
WO2016115713A1	Rfid-based localization and mapping method and device thereof	22.01.2015	mandarin written	mandarin written
KR20100023552A	Optimization of rfid localization system exploiting building plans	22.08.2008	korean written	korean written
CN104899617A	3D localization method of Chipless RFID (Radio Frequency Identification) on the basis of printing electronic technology	24.04.2015	mandarin written	mandarin written
US20140197926A1	Utilization of motion and spatial identification in rfid systems	14.02.2008	Pavel V. Nikitin, Gary Neal Spiess, Hunter Martin Leland, Lynn Carl Hingst, John Howland Sherman	Intermec IP Corp

Patentnumber Title Date Inventor (s) Assignee
US20150286849A1 Apparatus and method for identifying and localizing objects 02.04.2014 Christian STIMMING, Christian RAPP Sick AG
US20150186694A1 System and Method for Locating Objects and Determining In-Use Status Thereof 31.12.2013 John Thomas Fessler, Keith Bryan Hardin, Julie Ann Gordon Whitney Lexmark International Inc
CN103995250A Method for tracking radio frequency tag track 29.05.2014 mandarin written mandarin written
WO2017137524A1 Device and method for determining a position of a transmitter 12.02.2016 Mario Schühler, Lars Weisgerber, Johannes ARENDT, Rainer Wansch, Heinrich Milosiu, Frank Oehler Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.
WO2017137624A1 Device for determining a position of a transmitter and corresponding method 12.02.2016 Mario Schühler, Lars Weisgerber, Johannes ARENDT, Rainer Wansch, Heinrich Milosiu, Frank Oehler Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.
US20090027170A1 Two directional information flow in real time location sensing RFID networks 27.07.2007 Israel Amir Remote Play Inc
CN104535960B Based on the fast indoor positioning method of rfid 29.12.2014 mandarin written mandarin written

CHAPTER 3

METHODOLOGY

In this chapter scenarios will be described, where localization with RFID can be useful for an assembly line. For each scenario, obstacles and how the RFID system can be used to avoid them are described. Subsequently, one scenario will be selected for further investigation. The chosen scenario will be set up in an experiment and the data will be recorded.

SCENARIOS

Before localization scenarios can be named, the flux of the work pieces or the raw material is important to identify. The steps of the process to transform the raw material into a finished product are shown in Figure 14. A process may start with the delivery of raw material, like steel coils. The raw material could be stored before it is delivered to the machines to produce work pieces. The work pieces produced could be stored again or delivered to the assembly lines. The assembled products can be stored or dispatched immediately to the customer.

From this material process description, the following stages can be identified: delivery, processing, assembly, storage and dispatch. At the delivery and dispatch stages, localization with RFID can help to scan the incoming or outgoing material and products. With this information the stock software could be updated immediately and alert the employees if a dispatch is incomplete. In the processing and assembly lines, RFID localization can help find the necessary products for the next step more quickly, and it can check if the necessary products are already at the desired location. For the storage step, localization with RFID could help keep track of the large amount of items, so that the employees do not lose inventory.

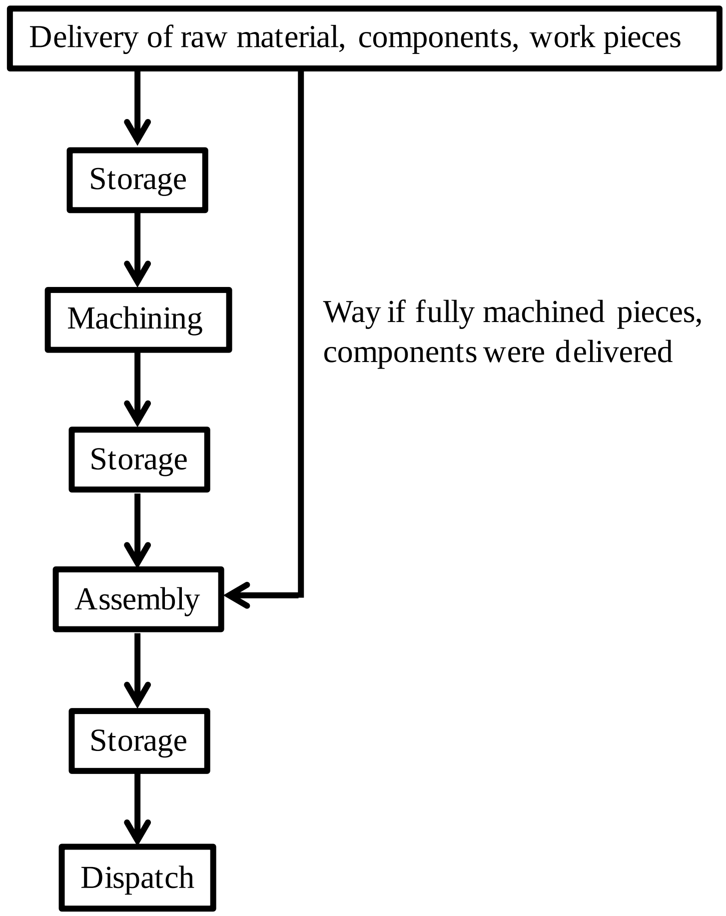

Figure 14 Potential Material Flux

In the following paragraphs, scenarios are described for the identified stages. The aim is to describe the obstacles in each step and how they could be solved with an RFID localization system.

Scenario for Delivery/Dispatch:

Delivery is the entrance of the raw material or components into the factory and dispatch is the exit where the products leave the company. During delivery situations, a lot of material may arrive at the same time. Even though this may be a hectic moment for the employees where errors can happen easily, all information about the received items need to be inserted into the inventory system without error. Dispatch is the stage of the process where the company has possession of the products for the last time and where the company can make sure that the outgoing dispatch is correct. At both stages, automatic scanning of the items could be done by RFID readers and antennas with tags attached to the items.

All processes described for the delivery and dispatch stages involve humans. Therefore, a system which does not need employees will help to reduce human errors. Despite to the automatic process, some human oversight might be necessary for monitoring.

A sketch of a possible solution is displayed in Figure 15. RFID tags are attached to all the boxes which contain the products. When the boxes pass a gate (checkpoint at the delivery/dispatch, were tags are recorded) with antennas, the antennas will read the tag numbers. These tag numbers could be compared with the tag numbers of the products which must be delivered or dispatched. With this information the stock system could automatically be updated, and the system could confirm if a deliver or dispatch is complete. The company Zebra displays this solution at their internet webpage and in their brochures for RFID antennas (Zebra, 2016).

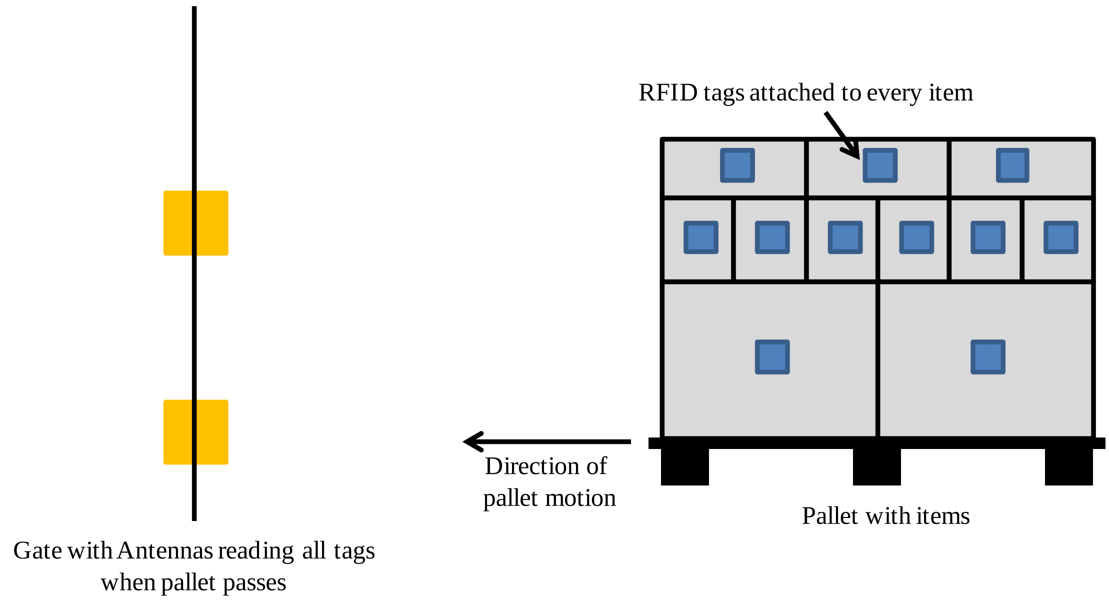

Figure 15 Product scanning at delivery or dispatch after (Zebra, 2016)

Scenario for Machine line up

A machine which does not work due to a lack of material stock does not earn money for the company. A system which notices low stock of materials may prevent this situation. To obtain the necessary information for the system in this scenario, an antenna could be installed in a position where it is able to scan the whole input line of the machine as shown in Figure 16. With the information about the items in the input line, it could also be ensured that the right items were delivered.

An advantage, of such a system might be that the system could order the necessary work pieces in advance before they run low. With all the antennas in the factory, the track of the products could be recorded.

The scenario could also be done for the machine’s output. With an antenna scanning the machine output, information could be sent about the finished work pieces.

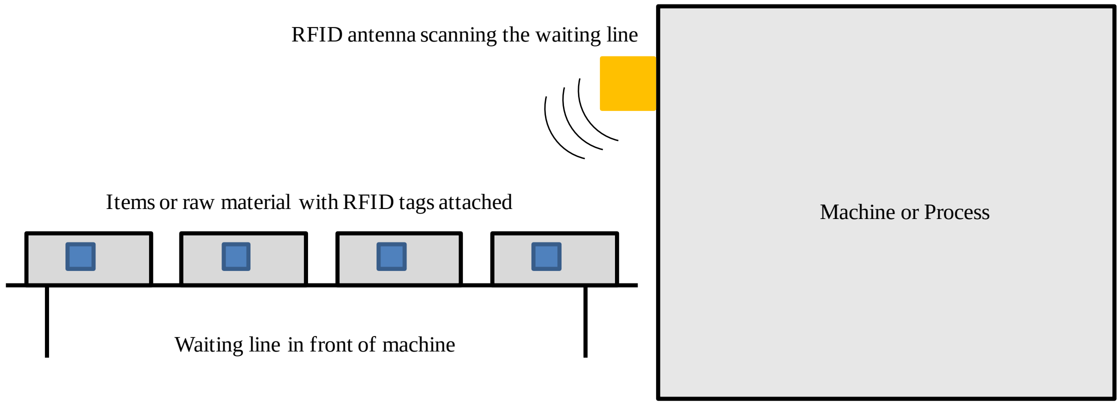

Figure 16 Waiting line in front of machine

Scenario for Area Localization

Another scenario occurs when items must be located in a production facility. In this case antennas mounted on the ceiling could create different reading zones, like those displayed in Figure 8. With information about the zone where the item is located the product could be found faster. If the RFID system in use can record the RSSI, the location of the target might be calculated more precisely.

Scenario Storage

In storage a lot of products could be placed in a very small amount of space. To lose track of inventory would cost employees time to find them again and cost the company money. This issue can lead to products which are not delivered on time because their location is unknown.

In this scenario it is assumed that the items are stored on pallets, because these pallets make the logistics of moving the items easy by using devices like forklifts.

In this scenario, it can be assumed that a beam can move between storage shelves, Figure 17. On the beam a movable antenna could be mounted. The beam would move from left to right and the antenna would move from the bottom to the top of the shelf. Hence, the antenna could scan at every possible tag position. Another way to scan all tags might be the installation of an antenna in front of every possible tag position. Each option has an advantage and a disadvantage over the other. The solution with the movable antenna would decreases the cost because just one antenna would be needed, while the option with multiple antennas could decrease the reading time (Son, Joung, Lee, Kwon, & Song, 2017).

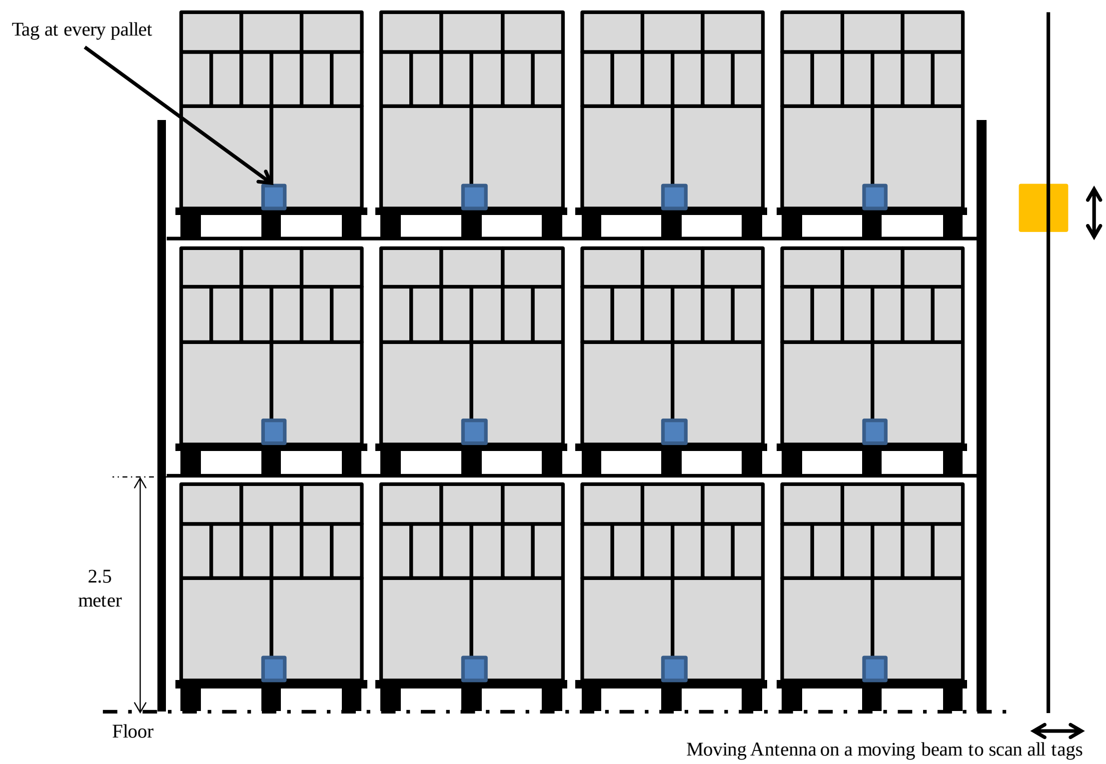

Figure 17 Scenario Storage with moveable antenna after (Son, Joung, Lee, Kwon, & Song, 2017)

Due to the large number of stored work pieces per area, this scenario will be chosen to investigate the advantages of RFID to minimize human error by an experiment.

EXPERIMENT

In the following paragraphs the experiment will be explained. The experimental setup will be described, as well as the process of data recording. The data will be analyzed in Chapter 4.

Setup of the Experiment

The experimental setup must reproduce the conditions corresponding to the situation shown in Figure 17. In Figure 17 all the tags are in one plane. For the case that all tags are in a vertical plane (that is the case in the Figure 17), a frame on which the tags would be mounted, might be necessary for the experiment. This vertical plane could be changed to a horizontal orientation for the experiment, the advantage being that no frames would be needed. Another advantage for this case is that using tags in a horizontal plane is much more easily accessible because they could be laid on the ground. Therefore, the position of the tags for the experiment will be on a horizontal plane.

Before the experiment was set up, the readability of tags laying on the ground was tested. The result was that tags on the ground could not be read by the antenna. An explanation for this result could be that the concrete floor contained steel, which affected the signal. However, this hypothesis could not be proved. A solution to evade this obstacle could be to put them on a table with a wooden tabletop. The thickness of the wooden tabletops used in the experiment (see an image of the tables in Figure 19) was large enough that the steel in the floor and of the table’s frame did not influence the tag’s readability.

To transform the situation of Figure 17 from hypothetical to real, first, the dimensions of the pallets are important to determine because they influence where the tables must be positioned to place the tags. Pallets are available in different sizes. For the purpose of this experiment, it is assumed that the tags are attached at the long side of a Europallet with the measurements of 1.2 meter by 0.8 meter (Figure 18) (Returnable Packaging Services, 2018). The maximum height of a pallet with items depends on the shortest dimension of the inner height and the door height of a 40 or 20 feet standard ISO container. A standard ISO container has a door height of about 2.2 meters (not a high cube container) (ISO 668:2013(E), 2013). In the warehouse 2.2 meters is not the distance between the bottoms of two pallets, where the tags are in the middle. The width for the beam on which the pallet is placed is important to take into consideration as well, as space is necessary for a lifting device to store the pallet. Therefore, in the experiment the distance between the tags was set to 2.5 meters. The measurements are sketched in Figure 18.

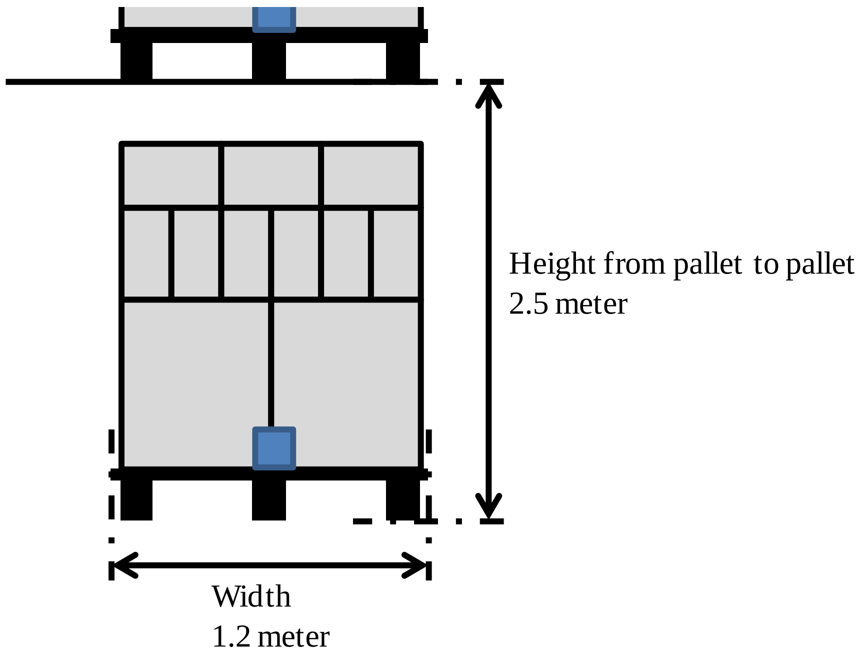

Figure 18 Measurements for a pallet with items in the scenario measurements after (ISO 668:2013(E), 2013; Returnable Packaging Services, 2018)

For the experiment, an area of about 7.31meter by 14.62 meter (24 by 48 feet) at Schneider Electric was used. The ratio of the long edge to the short edge of the space is almost the same as the ratio of the height to the width of the pallet dimensions. So, the long edge of the experimental area was the height of the pallet and the smaller side was the width of the pallet in Figure 17. With twenty tags available it is possible to simulate four rows (6meters long per row) with five columns (10 meters long per column).

In the experiment 19 tags were used to simulate the situation of an empty slot to discover how it might impact the data. Figure 19 and Figure 20 visualize the tag positions on the tables in the experimental area. Additional objects identified in the images are a fence, several 3D printers and a projection area. The information about them is important for Figure 21, where all tag positions are given related to the three named objects. Additionally. Figure 20 visualizes that position S is the empty slot.

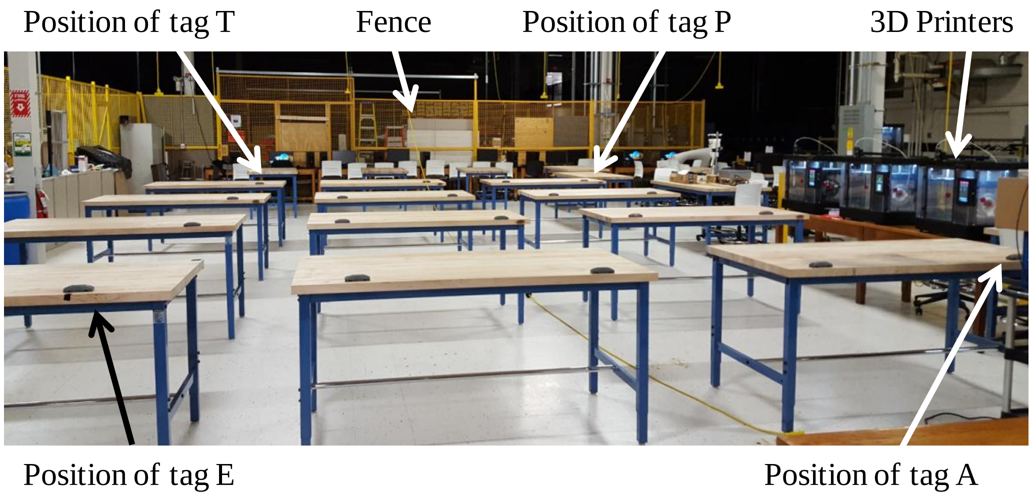

Figure 19 Setting of the Experiment 1

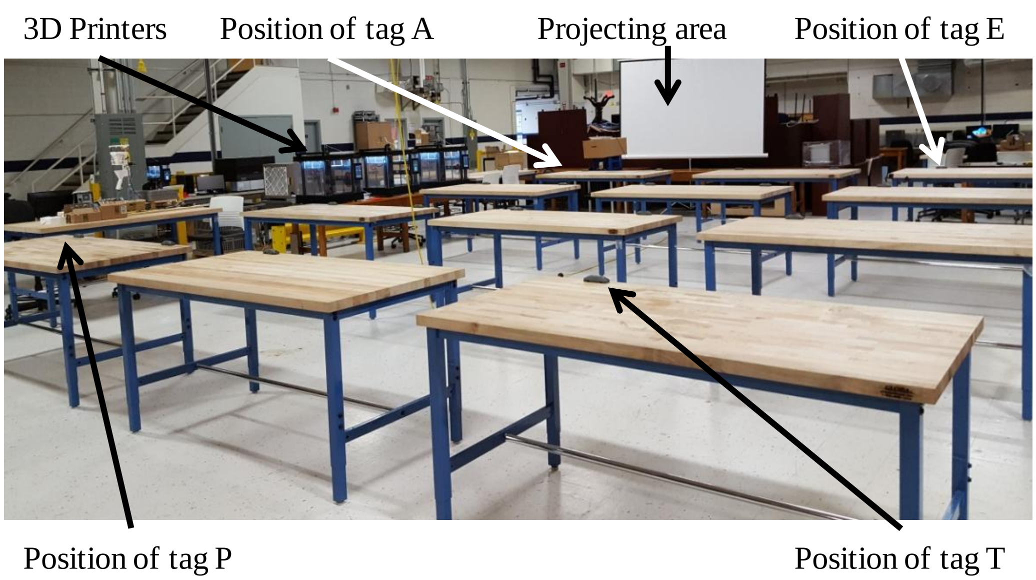

Figure 20 Setting of the Experiment 2

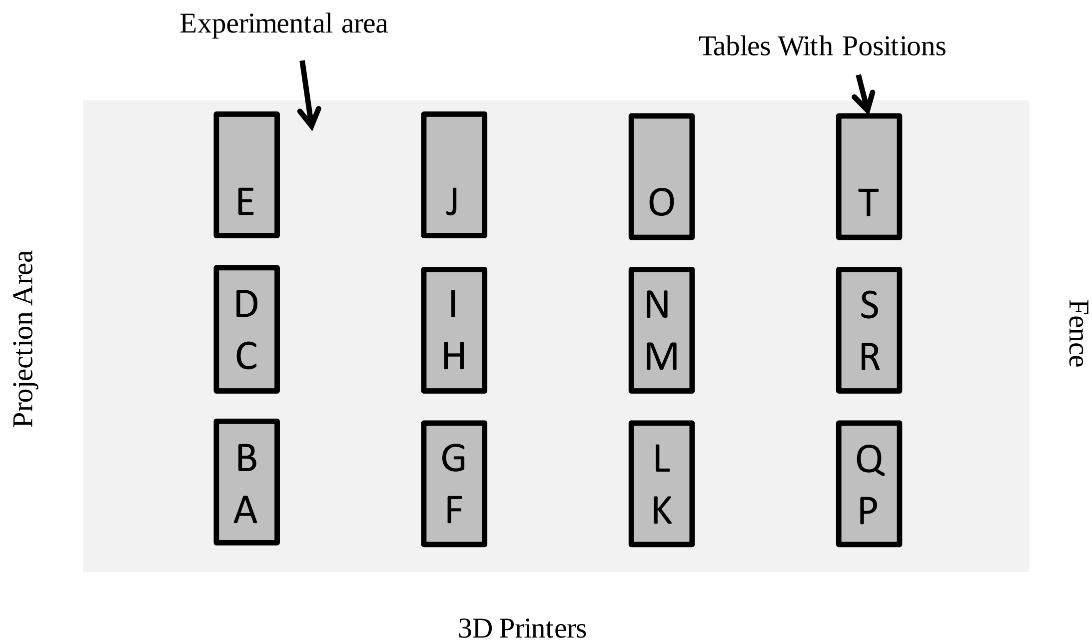

Figure 21 Positions of the Tags in the Experimental area

In Table 7 the tag identification numbers are related to the tag positions in Figure 21. Only the last four digits of the tag ID are given because they are unique for every tag.

The tags placed on D, F and T did not return their identification number. In the column on the right the return value is given. The tag on position T returned an empty identification number (Table 7).

Table 7 Position of Tags

Position	Tag ID	In data given as
A	185A	
B	179C	
C	1924	
D	1621	OFO6 4D58
E	1858	
F	16C5	C703
G	196B	
H	1967	
I	1954	
J	188C	
K	1966	
L	1601	
M	1947	
N	1518	
O	184D	
P	185C	
Q	166A	
R	18B2	
S	No Tag	
T	1662	--

To record comparable data for every trial, the tags were never moved from their position.

To place the antenna in the correct orientation above the tag for scanning, a movable table was used. On the table a cardboard box and a plastic crate were used to boost up the antenna on a beam so that it could scan above the tags. On top of the box and crate a cardboard beam was mounted. The antenna was fixed at the end of the beam (Figure 22).

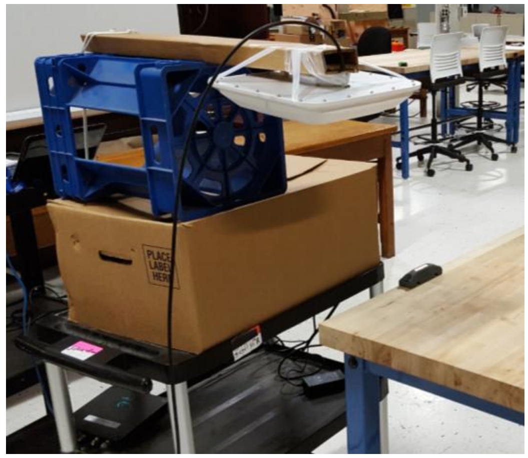

Figure 22 Construction of the movable Antenna

The orientation of the antenna is important for the experiment because the readability of the tags depends on its orientation. The orientation of the antenna with the main lobe facing the tag below it was chosen because it ensures that the tag below is in the read range (Figure 22). Another advantage is that in this orientation the experiment is simulating how the antenna could pass through the space between two shelves, which likely is very small.

For the experiment, the Invengo system containing a reader, an antenna and software were used; the tags used were from Omni-ID. The reader was a XC-RF861 with four possible antenna connections and the antenna was a XC-AF12-A. To operate the system, the RFID Reader Gereric Demo Software in the Version of 1.2.3 was used. The tags that were used were Omni-ID Power 415.

The XC-RF861 reader is shown in Figure 23 and its model label in Figure 24. Its dimensions are 196 x 176 x 38 mm with a weight of about 1 kg. Four antennas can be powered at the same time with different outputs of 9 to 30 dB in increments of 1 dB. The frequency of the signal can be 865 to 869 MHz or 902 to 928 MHz. Supported protocols are the ISO 18000-6C, ISO 18000-6B and the EPC global UHF Class 1Gen2. The read range of antennas attached to this reader can vary from 0 to 6 meters, depending on the tags used, the antenna and the conditions of the scanning environment (Invengo, INVENGO XC-RF861 UHF RFID READER, 2015; Invengo, USER MANUAL XC-RF861 READER, 2015).

Figure 23 Reader XC-RF861

Figure 24 Model label of the used Invengo Reader

For the experiment the antenna Invengo XC-AF12 is used. The dimensions of the antenna are 291 x 291 x 52 mm and the weight is 0.91 kg. For the tag detection, the antenna can send the signal in the UHF region from 840 to 928 MHZ. For sending out the signal the antenna has an impedance of 50 Ohms. The sent signal has not the same strength in all directions. Therefore, Figure 25 and Figure 26 show the radiation pattern of the E- and H Phase which are perpendicular orientated to each other. The half power beam-with in both rotation patterns is 60 degrees. Finally, the model label is displaced, Figure 27.

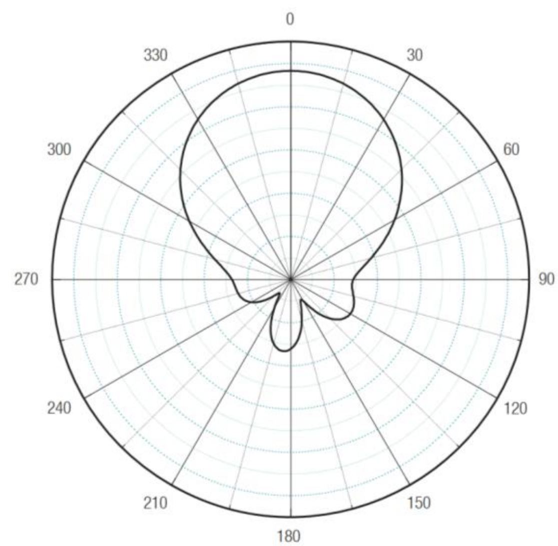

Figure 25 Radiation Pattern of the E-Phase from (Invengo, 2015)

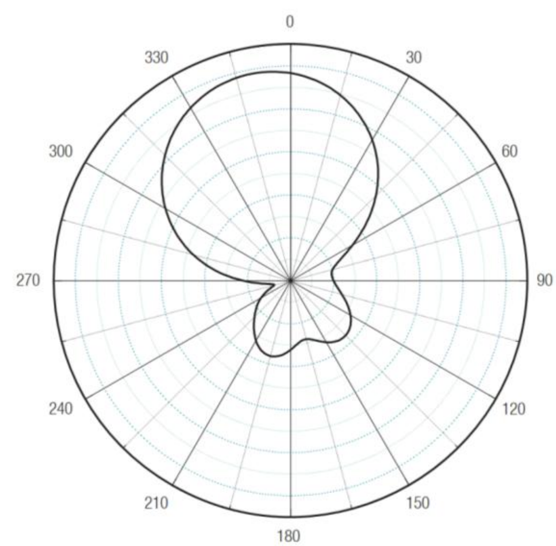

Figure 26 Radiation Pattern of the H-Phase from (Invengo, 2015)

Figure 27 Model label of the used Invengo Antenna

To operate the Invengo RFID Reader Gereric Demo Software, the Graphical User Interface in Figure 28 opened. All buttons which were used in for the experiment are explained below. The scanning was started by clicking the Start button and stopped by clicking the Stop button. The information received of the tags were displayed in the red rectangle and could be exported with a click on the Export button into a txt file. Changing the antenna power was done by clicking on the Configuration button.

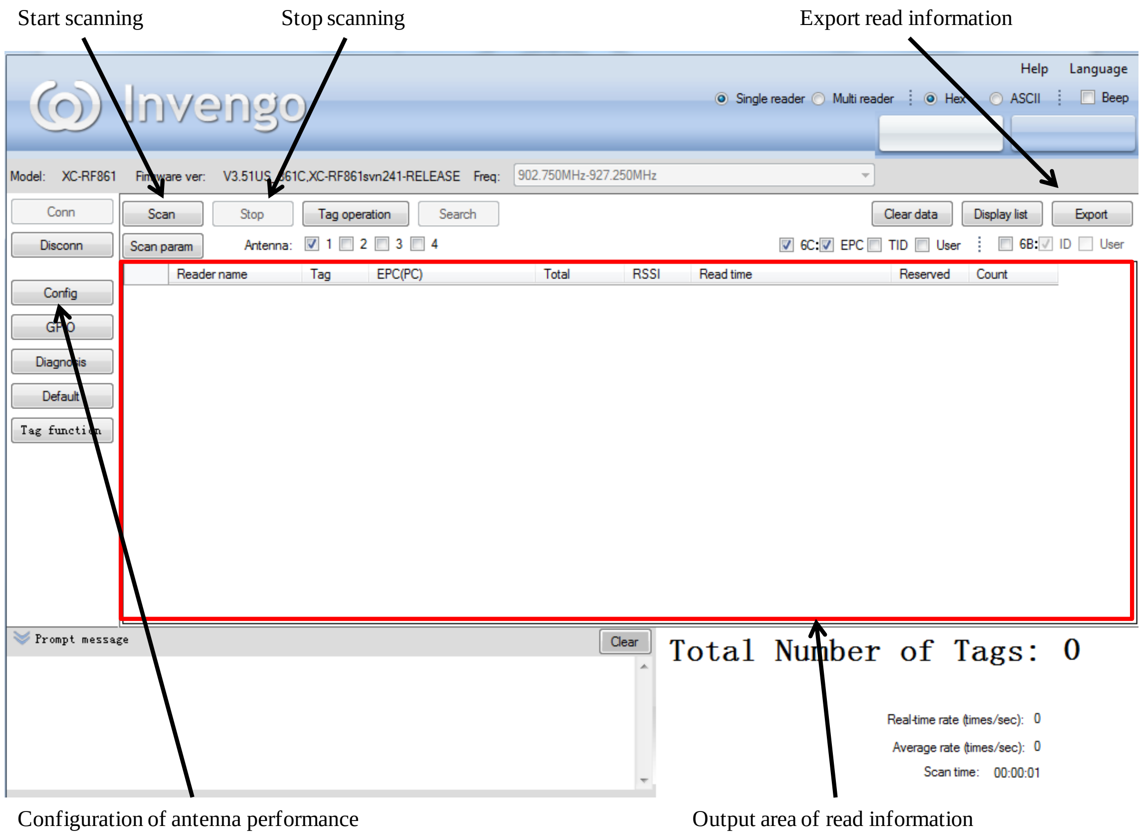

Figure 28 Graphical User Interface of the Invengo software

The Omni-ID Power 415 tags (Figure 29) have a size of 120 x 36 x 30 mm and a weight of about 92 grams. In the active tag, a passive tag is also embedded. The tag operates actively at 433 MHz and passively in the UHF from 860 to 930 MHz. The read range of the tag for the UHF (frequency of the used antenna) depends on the site characteristics, used frequency and tag configuration. Under these conditions it varies between 3 to 6 meters. The capacity of the battery is good for about five years (Omni-ID; Omni-ID, 2017).

Figure 29 Omni-ID Active Tag

Process of the experiment

In the following paragraphs the process of the experiment and data recording will be described.

First, the antenna on the table was moved to a position so that the antenna was above the tag position where data should be collected. Then the power for the antenna was set. For the first scan at a position, the power was set to the highest available, 30 dB. This procedure, working backwards from the highest power level, ensured that at the first scan the read range of the antenna could be determined by the ID of the detected tags. By decreasing the antenna's power, the decreasing read range could be determined. This was done until only one tag could be read with the maximum number of responses per second (Around 50 readings per second was the maximum answering rate).

Each scan at each tag position with each power level was done for 60 seconds (±1 second). After that, the recorded data was saved, and the power was lowered to the next increment. The recorded data will be analyzed in the next chapter.

CHAPTER 4

FINDINGS

In this chapter the results of the analysis of the data recorded from the experiment described in Chapter 3 are discussed. To record the data, the antenna was moved over the tag position to be scanned. For the first scan of a position, the antenna power was set to 30 dB. After 60 seconds the scanning process was stopped. The recorded data were saved and later imported into Excel. After the data were saved, the antenna power was reduced and the scanning was started again. The scanning process for a position was completed when just one tag could be read with about 3000 responses during the reading time of 60 seconds.

The data of the experiment described above are given in Appendix A. With the knowledge of the read tag IDs and the position of these tags in the experimental area (Figure 21), the antenna read range for every position could be visualized. As an example, in Figure 30, Figure 31 and Figure 32, the read ranges for the scanning of the positions B, H and F are given. The scanning position is dark blue, while the other scanned tag positions are marked with light blue. The visualizations indicate that the three examples of read ranges have all different shapes, which are not a circle. So, the real situation might be different than the situation displayed in Figure 8. With different read ranges at every scanning position, the idea of dividing an area into different reading zones might not be suitable. So, another idea must be developed to determine the positions of the tags from the data.

E	J	O	T			
D	I	N	S			scanning position
C	H	M	R			read tags
B	G	L	Q			
A	F	K	P			

Figure 30 Received Tag IDs when scanning position B, antenna power 30 dB

E	J	O	T			
D	I	N	S			scanning position
C	H	M	R			read tags
B	G	L	Q			
A	F	K	P			

Figure 31 Received Tag IDs when scanning position H, antenna power 30 dB

E	J	O	T			
D	I	N	S			scanning position
C	H	M	R			read tags
B	G	L	Q			
A	F	K	P			

Figure 32 Received Tag IDs when scanning position F, antenna power 30 dB

A possible solution to solve this issue is to turn down the antenna power. According to the data in Appendix A, decreasing the antenna's power leads to a decrease in the read range. With this smaller read range, the localization of the tags can be done. Therefore, the antenna should be set to the maximum power that allows just one tag to be read with a total count of about 3000 responses. With this result, the responsive tag is most likely at the scanned position for the set up in the scenario because all tags which lay below the antenna responded with a rate of about 50 readings per second. Tags which were not directly under the antenna responded with a far lower rate. Another consequence of decreasing the antenna's power, which can be seen from the data, is that the shape of the read ranges shrinks. It only occurred once (Position E from 30 to 29 dB) that a Tag ID was read at a lower antenna power level, which could not be read at a higher antenna power.

The scanning of position S is a special case. On position S, no tag was placed to simulate the situation of a free space or a broken tag. However, with the information from the paragraph above (one tag read with 3,000 responses) it can be determined that position S is the position with no tag. This is because the tag 1662 was read with a maximum number of responses of about 2,500, while it was read more than 3,000 times on position T. This implies that the read tag must be at another position (position T) and position S is empty.

Figure 32 visualizes another point about read ranges, which is that they do not always have the shape of a circle. The scanning of position F shows that the tag on position N was scanned, while the tags on positions H and M were not scanned, though their distance to the antenna is shorter. This leads to the hypothesis that the tags also have an influence on their readability and, therefore, on the read range. To prove this hypothesis, the following second experiment was carried out. The aim of this second experiment is to determine whether the selected tags respond equally or not to the same conditions. It was not carried out to describe the level of response at those conditions.

Second Experiment (Tag Responsive Pattern Comparison)

For the second experiment, two tags—one with a high level of response and one with a low level of response—were selected. The tag on position N was selected as the tag with the high level of response because the tag was readable even with an antenna power of 27 dB on position F. On the other hand, the tag on position A was selected as the tag with the low level of response because this tag was only readable when the antenna was directly above the tag. The setup of the experiment is visualized in Figure 33.

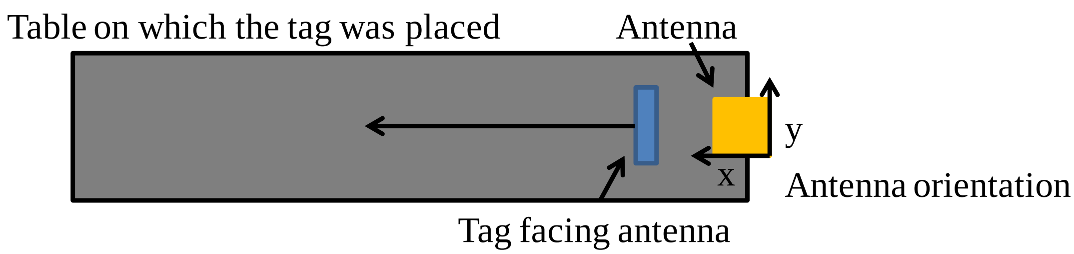

Figure 33 Experimental setup for the Tag response

For the experiment the antenna was placed on one side of a table with the same orientation used in the experiment described in Chapter 3. The tag was placed on the table with different distances to the center of the antenna. For the first scan the distance between tag and the center of the antenna was 1 foot or 0.3 meter. The tag faced the antenna with the long side (Figure 33) for the first scan, and the short side for the second scan. This procedure was chosen to determine if the orientation of the tag influences the readability. The same was done with the antenna to determine if the orientation of the antenna affects the readability Figure 34.

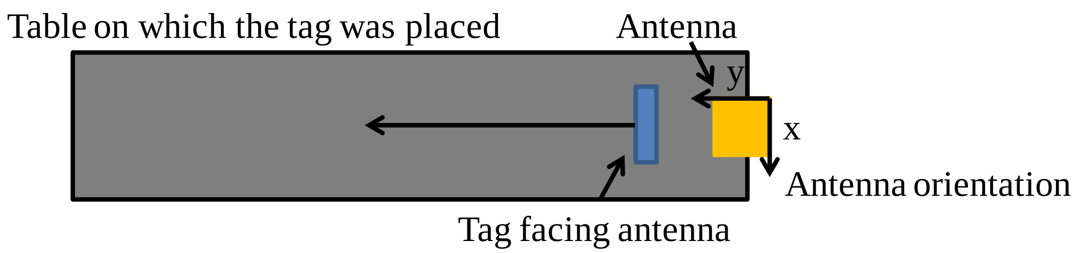

Figure 34 Experimental setup for Tag response for antenna effects

The procedure for the scanning of both tags with both orientations and with both antenna orientations was the same to record comparable data. The reading time was 60 seconds for each scan. At first, the tag was placed at one foot or 30.5 centimeters to the center of the antenna. The power of the antenna was set to the maximum power, then the reading process was started. After the 60 seconds, the average rate for the reading was noted. When the scanning was finished for one distance, the tag was moved another foot or 0.30 meters away from the antenna.

Throughout several scans during the experiments, the tags behaved in a similar way in relation to the antenna's power. The response behavior is diagrammed in Figure 35. First, the tags respond at a certain level of counts per second (section I). With a decrease in the antenna's power, a sharp drop in the numbers of counts occur (section II). This drop is unique to each tag, distance between tag and antenna, antenna's power and orientation of the tag to the antenna. As the antenna's power decreases further, the tags stop responding (section III).

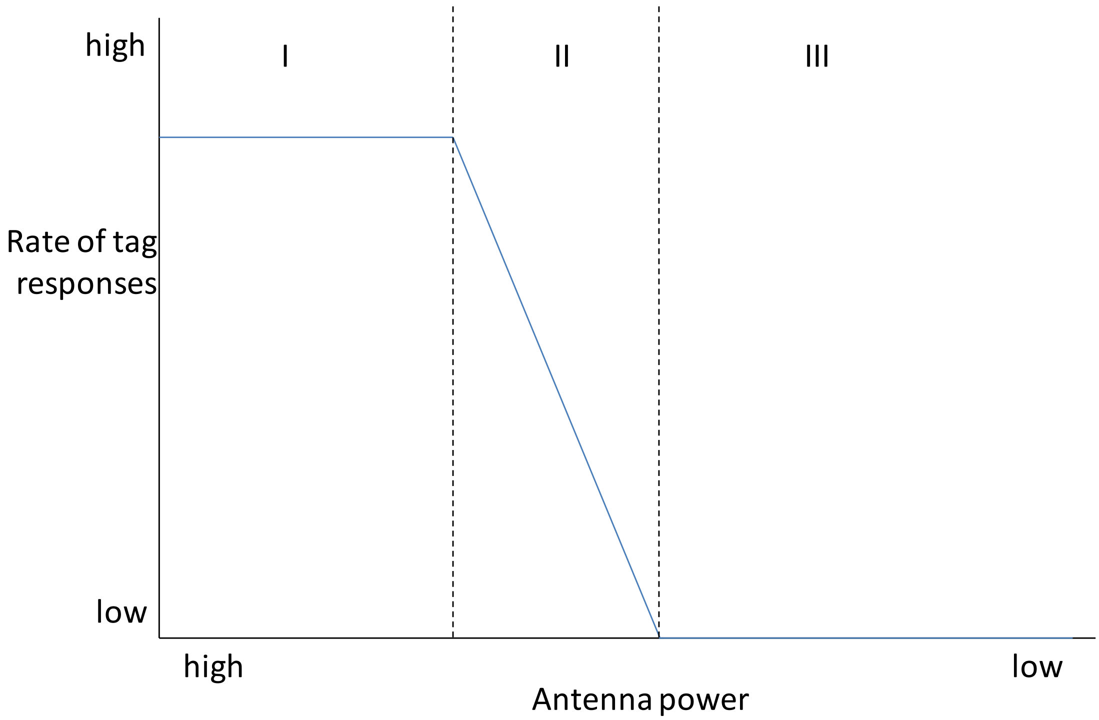

Figure 35 Tag responding behavior

The antenna’s power at the point of the sharp drop in responses was investigated for each scan to compare the tags responses throughout the experiments. Below are two charts (Figure 36 and Figure 37) presenting the differences in the tags’ responding behavior for the same tag orientation (short side) and antenna orientation (x orientation is facing the tag). Further data and charts can be found in Appendix B

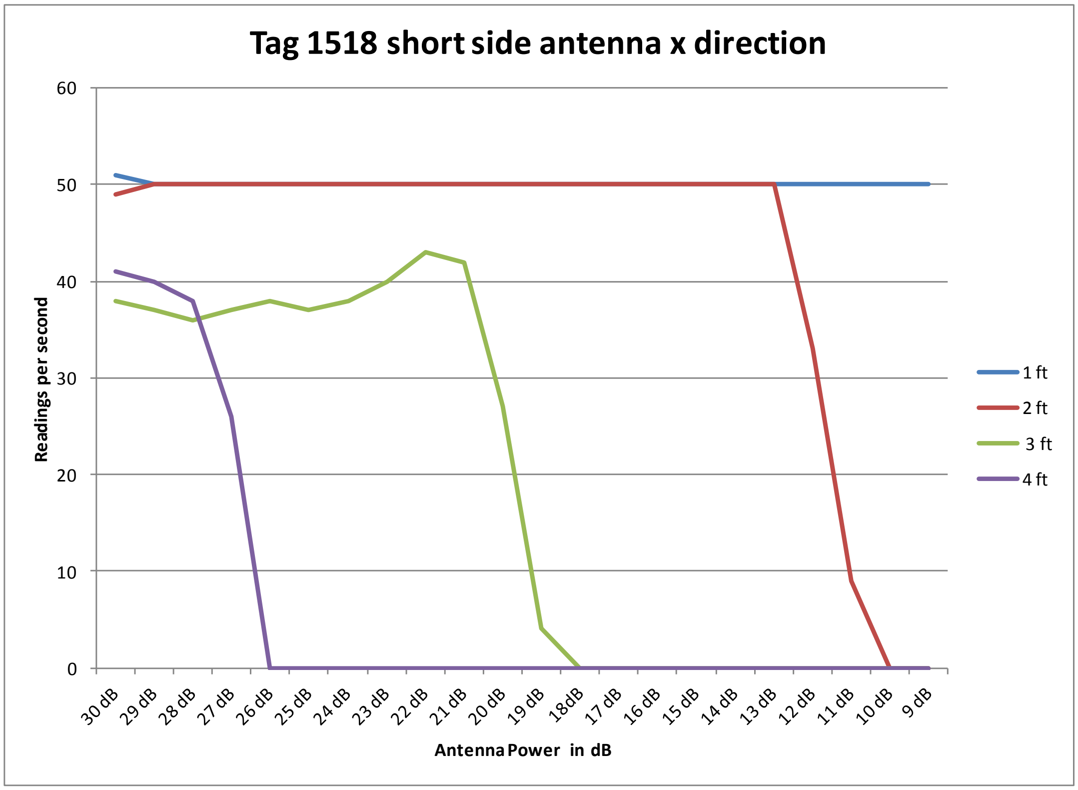

Figure 36 Responses related to read range for the good responsive tag

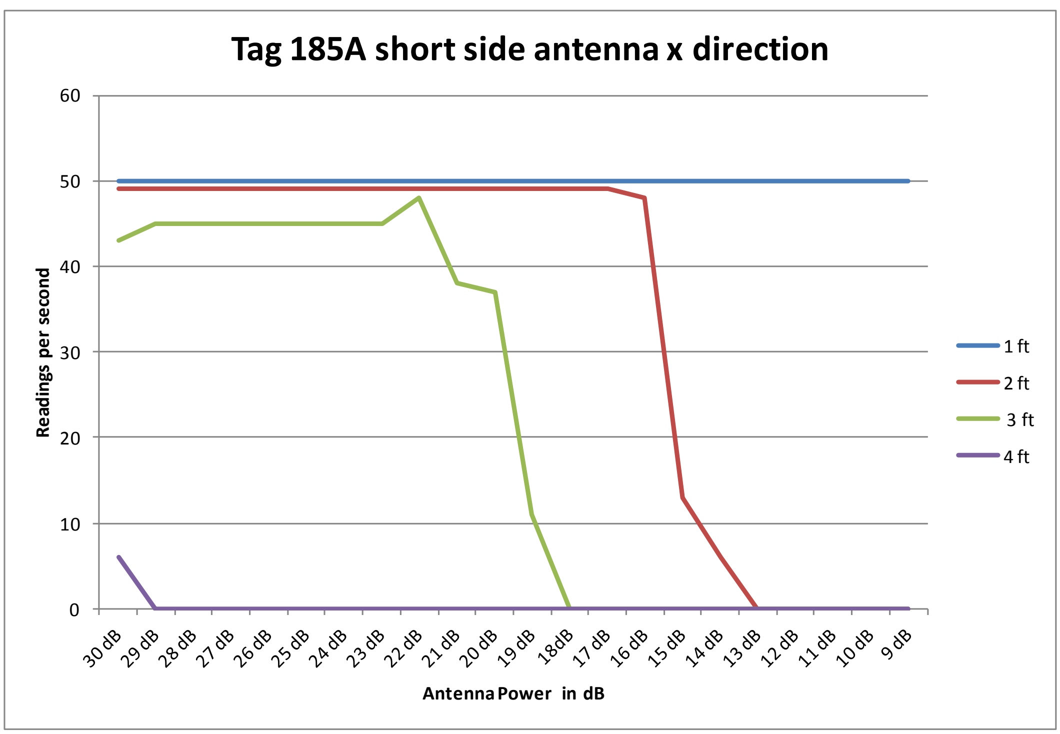

Figure 37 Responses related to read range for the bad responsive tag

Figure 36 andFigure 37 indicate that the tags respond equally for small read ranges. The first difference in responding rate occurs at a distance of two feet or about 0.62 meter. Here, the response rate of the tag 1518 drops at an antenna power of about 11 dB, while the drop of tag 185A occurs earlier at around 15 dB. At 3 feet or about 0.93 meter, the drop of the response rate for both tags is at almost the same antenna power, but the response rate of the tag 1518 is lower than the rate of tag 185A. Finally, at 4 feet or 1.24 meter, the tag 185A only respond at 30 dB with a rate of about 6 readings per second, while the tag 1518 responds with a rate of 41 reading per second. The response of tag 1518 stops at an antenna power of 26 dB.

With the knowledge that the tags respond differently to the antennas' signal and that the read range of the antenna is not a perfect circle, the idea from Figure 8 to divide the area into different zones is not suitable. So, additional scanning positions might be necessary to record additional data. With the additional recorded data the tags' positions might be localized. One possibility is to scan the field of tags from the side. This is also possible for the storage scenario, so a new scanning process was started (Figure 38).

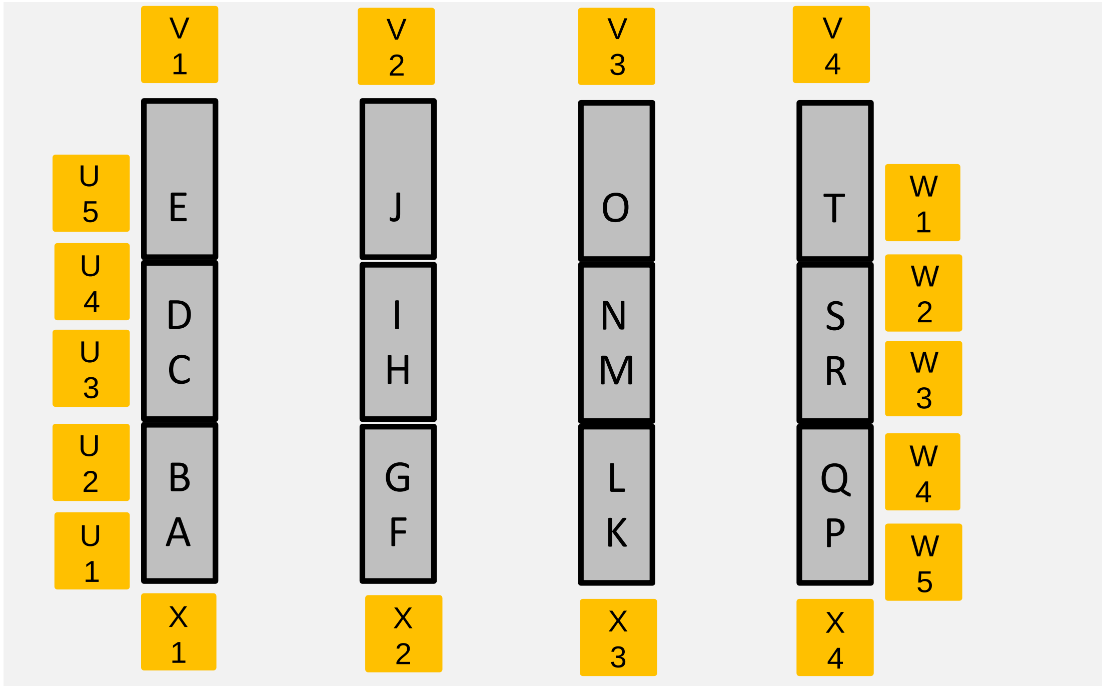

Figure 38 Antenna positions for side scanning

At every scanning position, the antenna was facing the experimental area (Figure 39).

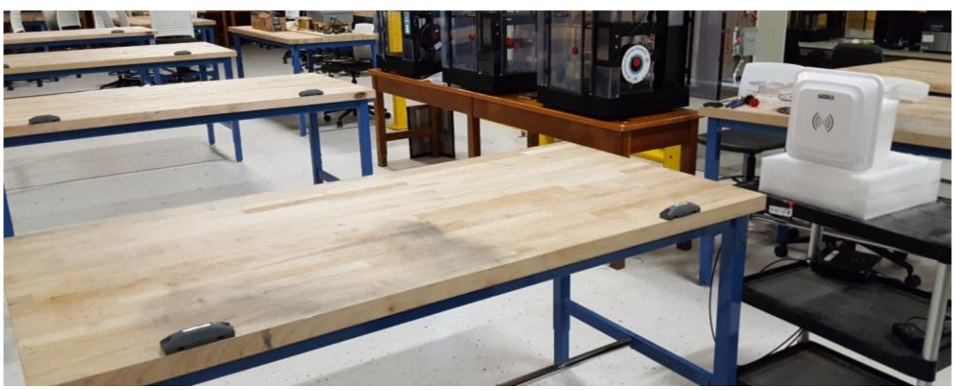

Figure 39 Antenna at position X1 facing tags

To place the antenna with the right distance to the tags for the storage scenario, it was assumed that the pallets with the tags on the Positions A, B, C, D and E were standing on the floor. Therefore, the antenna was placed right next to the tag at the scanning positions U1, U2, U3, U4 and U5 (Figure 40).

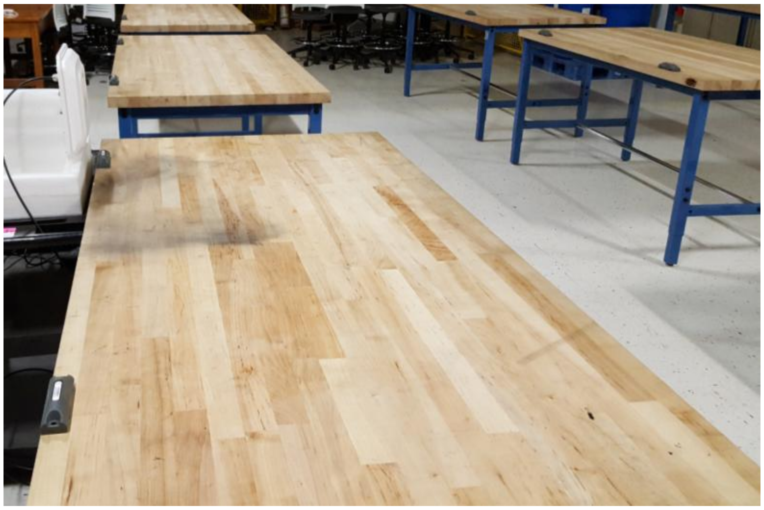

Figure 40 Antenna at position U2 facing tags

For the scanning positions X1, X2, X3, X4, V1, V2, V3 and V4 the antenna was not placed right next to the tag. For these positions the width of the pallets is important. In the scenario the width of the pallets was 1.2 meter and the tags were mounted in the middle of the pallets. Therefore, the distance from antenna to tag was set to 0.6 meter. This is visualized for the Position X1 in Figure 39.

The same procedure was done for the positions W1, W2, W3 and W4. For these scanning positions the antenna was placed at the considered height of the pallet, 2.5 meter (pallet measurement information is displayed in Figure 18), Figure 41.

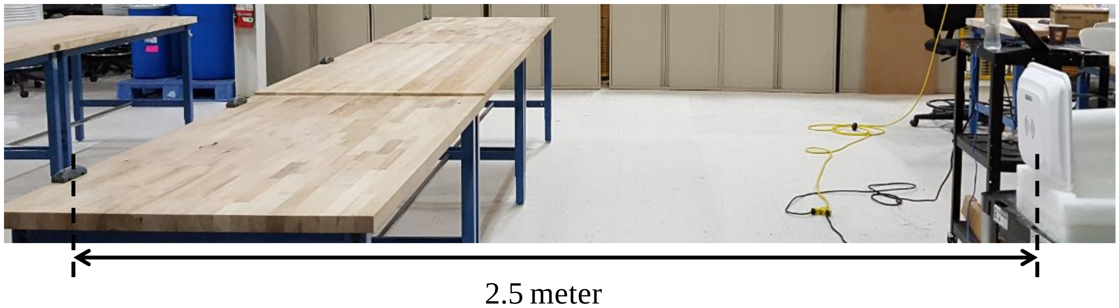

Figure 41 Distance tag to antenna for scanning the W positions

The conditions and procedure of the scanning process were the same as for the experiment introduced in Chapter 3, with a scanning time of 60 seconds and an antenna power of 30 dB, decreasing by 1 dB after every scanning.

The recorded data are given in Appendix C. The data indicate that the scans for positions of U, V and X are like the data of the first experiment. The antenna read ranges has a shape which is not a circle and the read ranges decrease with decreasing antenna power. Finally, at a certain power just the tag which the antenna is facing can be read. A difference to the data of the first experiment is the variation in the number of counts. For the positions of U and X it was over 3000, while for the positions V the number of counts were below 3000.

On the opposite, the scanned data of the positions W are different. For example, while scanning the position W1 facing the tag 1662, it was not read. With decreasing antenna power, it turned out that the tag 18B2 on Position R was read with a total count of about 860. The same results were recorded for the scanning position W2, scanned tag 166A, position Q, with a total count of about 1300 and W3, were the tags 196B, position G and 1966, position K were read with total counts of 1500 and 270.

Just the reading at the positions W4 and W5 scanned the faced tag at the end. In this case the total counts were about 2300 and 2200. This indicates that recorded data were just one tag was read with a total count of about 2200, the tag in front of the antenna was scanned, while a total count of 1500 or less indicates that the antenna is not facing the read tag.

One hypothesis for the differences to the other scanned data at the other positions is that the distance is larger. Additionally, the orientation, of the tags is different at the reading positions, but may have an influence. At the scanning positions W and U, the tags faced the antenna with the long side, at the positions V and X with the short side. To proof this hypothesis a similar experiment to the one displayed in Figure 33 and Figure 34 was done, but in this case the antenna was turned to the orientation of the antenna for the side scanning experiment like in Figure 40. For the scanning the tag 1518, the good responsive tag, was picked. The data of the experiment is given in Appendix D.

The Figure 42 shows the responses at certain distances for an antenna power of 30 dB. The chart indicates that both tag orientations respond equally at a distance of 1 foot. After that the responses for the short side facing the antenna decrease faster than the long side. Between 6 to 10 feet both orientations behave equally again. The sharp decrease of responses for the short side orientation occurs at 12 feet, while the drop for the long side orientation occurs at 14 feet.

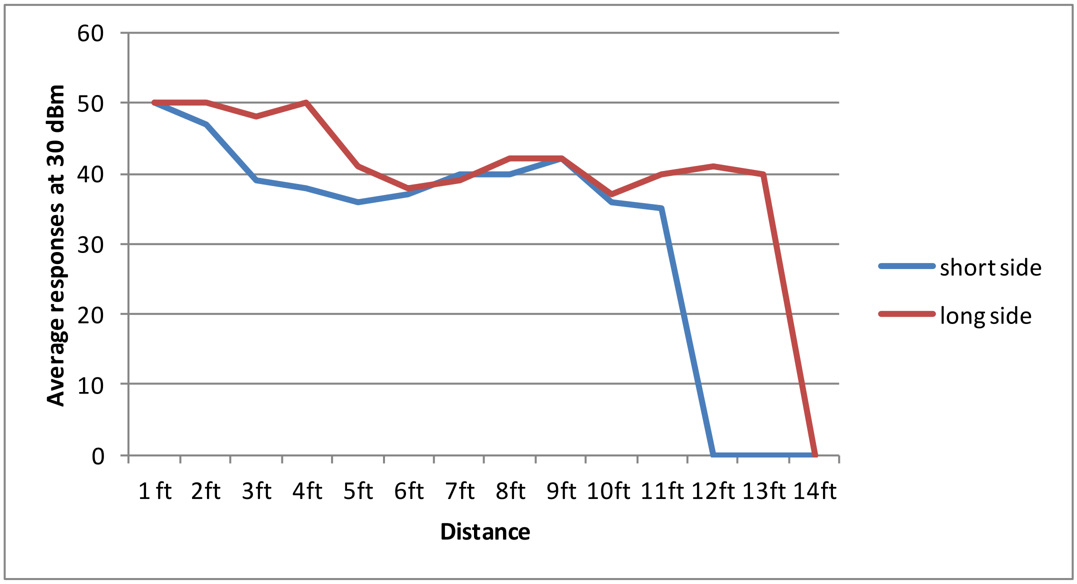

Figure 42 Tag responses related to distance for 30 dB

In Figure 43 the minimum power for both tag orientations is displayed depending on the distance. The chart indicates that for the long side tag orientation, at every distance less antenna power is necessary to trigger the tag. An explanation for this measurement is that the tag might receive the trigger signal easier, when it is orientated with the long side to the antenna.

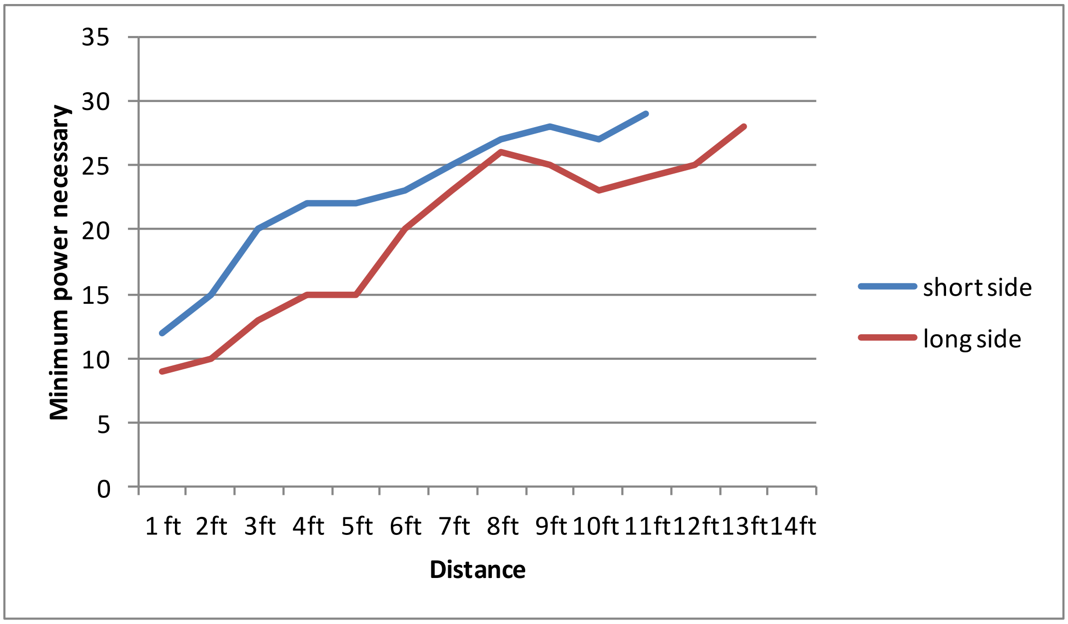

Figure 43 Minimum power (in dB) to read tag at certain distance

Finally, Figure 44 displays the connection between the responses with an antenna power of 30 dB to the distances between tag and antenna for both tag orientations. From the chart the assumptions which were made for the data of the scanning positions W were correct because at a distance of 2.5 meter, or about 8 feet the tag responded about 2200 to 2500 times. These values can vary for the other tags but give a good estimation, how often a tag should be read when it is facing the antenna.

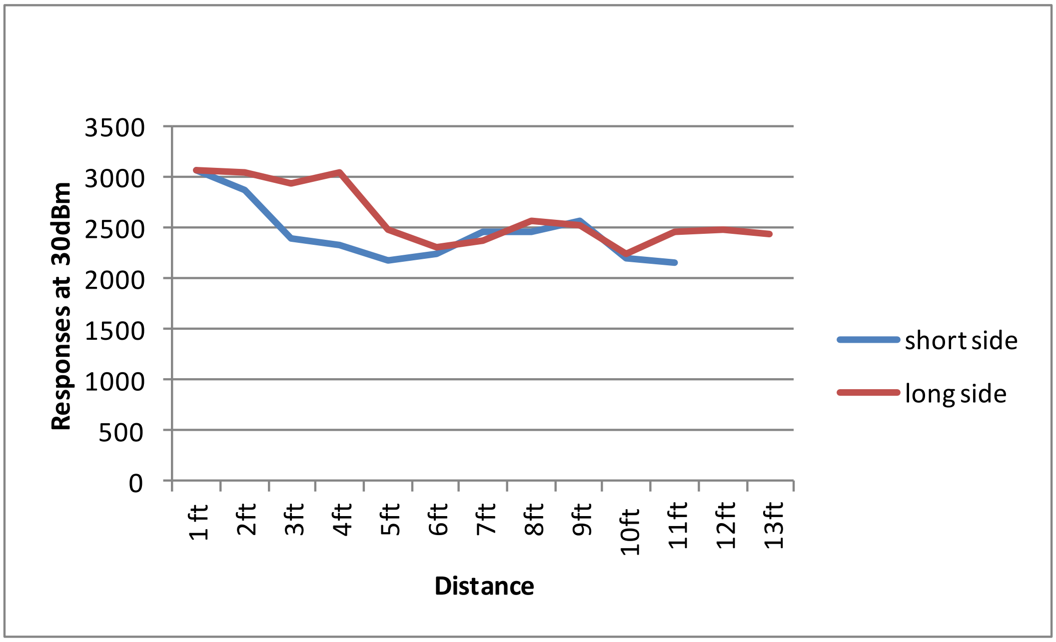

Figure 44 Responses of the tag orientations related to distances

Another experiment was done to record the read range of the antenna at different angles at the maximum power. For this experiment the antenna was orientated similar as in the scanning positions U, V, W and X. The increment for the angle was set to 15 degrees. To ensure that the correct angle the edges of a triangular were calculated. For the hypothenuse an 18 feet long string was used. With this length the missing cathetus lengths could be calculated for the desired angle. The calculated cathetus lengths were the coordinates for one of the points were the string was fixed. The coordinates were transferred to the experimental area starting from the point at the center of the antenna. With the known position of these two points, the string was mounted between the center of the antenna and the calculated point. During the experiment the tag was moved guided by the string position. This procedure ensured that the tag was always orientated at the desired angle is shown in Figure 45.

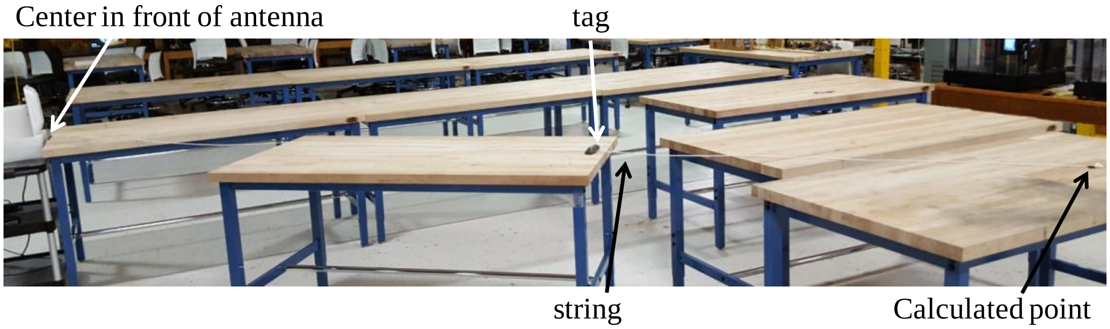

Figure 45 Experimental setup

The tag was moved to the position were the sharp drop in the read ranges appeared. Then the distance between tag and antenna was measured. The measured data are presented in Appendix E and visualized in Figure 46.

The area 90 to 270 degrees (clockwise) is the area at the back of the antenna were also the screws to mount the antenna and the attachment for the reader signal are. In this area the read range is low. Against to this is the area from 270 to 90 degrees (clockwise) which has a wider read range with a peak of about 6 meters at 0 degrees. Zero degrees was also the orientation for the tags in the third experiment.

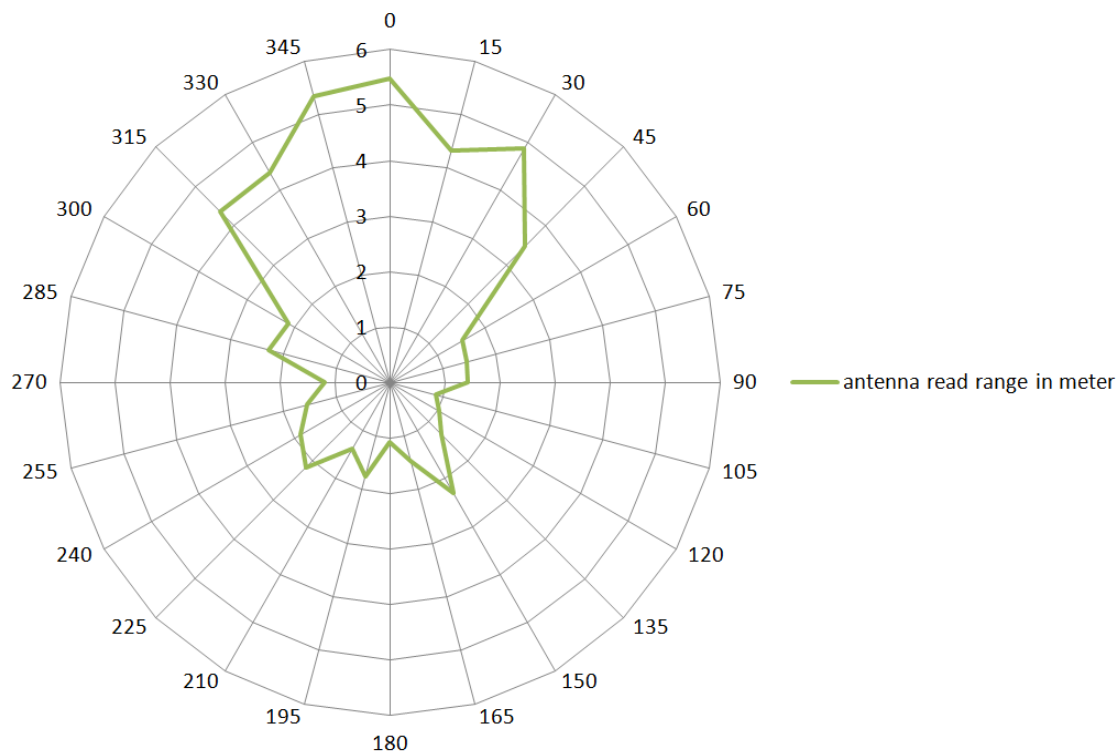

Figure 46 Antenna read range

From the results and findings out of all described experiments a procedure to locate the target tag can be determined. First, a scan with the maximum antenna power should be done to ensure that the tags inside the antenna read range are known or that a specific tag can be located. To start the scanning procedure with the highest antenna power can reduce the necessary number of scans and so the time, if the scan for a position can be finished before the lowest antenna power is set for scanning. After the first scan with the highest antenna power, the received information have to be saved and the antenna power has to be set to the next smaller value. The saving and decreasing procedure is finished when no tag can be read or when the lowest antenna power is reached. The steps are listed below and visualized in Figure 47. From the saved data the lowest antenna power where the desired tag can be detected is essential to know because the tag is for this antenna power close to the maximum read range. With additional scans at other antenna positions the tag location can be determined because all of the read ranges should intersect in one point.

1) set the antenna power to maximum

2) scan the tags

3) save the received data

4) if no tag was read at step 2 or when the antenna power was the lowest possible for the system, scan is finished

5) else reduce antenna power to next smaller than used for the scan at step 2 and go to step 2

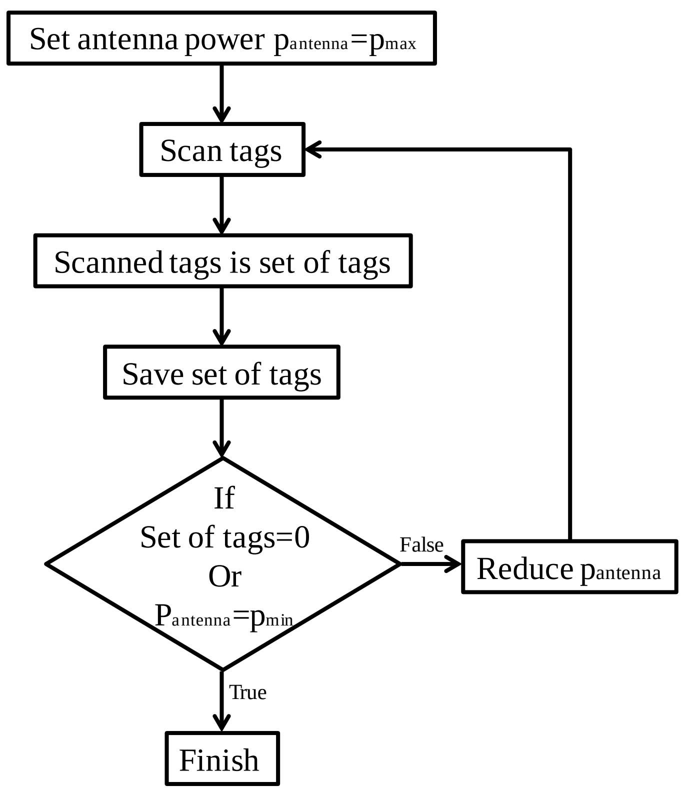

Figure 47 Procedure of the scanning process

CHAPTER 5

CONCLUSION

In this chapter the findings of Chapter 4 will be summarized, a method to locate the tags for the selected scenario of Chapter 3 will be given and a view to the future will be given.

Findings

In the previous chapters 3 and 4 the experimental conditions were given and the recorded data were analyzed. From the recorded data for the experiment described in Chapter 3 it can be seen that the real read range of the antenna, shown for the positions B, H and F in Figure 30, Figure 31 and Figure 32, is not a circle as it was assumed in Figure 8. Therefore the concept of dividing the area in different zones, which are characterized by the antennas which could detect a target in this zone, is not possible because the read ranges have, in addition to the non circular read range, different shapes. So, another method is needed determine the tag positions out of the recorded data. One possibility is to start the scanning with the highest antenna power and decrease the power by 1 dB after every scanning. The consequence is that the read range will shrink. This procedure needs to be done until just one tag can be read with a total count of 3,000 in one minute. The procedure ensures that positions were no tag is placed will be found because at these empty positions the total count will be below 3,000 readings in one minute due to the greater distance between tag and antenna.

Another assumption which can be made out of the recorded data is that the tags may respond differently, depending on the orientation of antenna and tag and the distance between both. Therefore, the second experiment was done. The analyzed data indicate that the compared tags are responding on a specific amount of counts for the full antenna power. At a certain lower antenna power the number of counts read per second decreases sharply. The power where this sharp decrease occurs is different for all measurements depending on the distance between antenna and tag, the tag itself and the tag and antenna orientation. The result is that the responsive behavior of every tag has to take into consideration as well.

After that, the tags were also scanned from the side, Figure 38, to investigate if this antenna to tag orientation would be suitable to calculate the tag position with the previous explained concept of reading zones. The results show that the read ranges in this setting are, as well as for the first presented experiment, not of a circular shape. The effect that a decreasing antenna power decreases the readable range was the same. Additionally, the response of a tag was recorded for various antenna power levels, antenna to tag distances and for the orientations that the long- or the short tag side is facing the antenna. The results of this experiment are that the number of responses for a tag which is facing the antenna with the long side is equal or higher than for the same tag which is facing the antenna with the short side. Additionally, for the orientation of the long side, the necessary antenna power to trigger the tag is less than for the orientation of the short side.

To understand the behavior and the influence of the antenna, the read range of the antenna was measured at different angles. One of these measurements is shown in

Figure 45. Therefore, a tag was moved on a string, which was orientated at the desired angle, to the unknown maximum antenna read range. When the maximum read range for the antenna at a certain angle was found, the distance between antenna and tag was measured. All measurements are shown in Figure 46. Figure 46 indicate that the read range of the antenna is not a circle and is not symmetric.

Localization method

Despite to the found obstacles that the read range of the antenna is not a symmetric circle, the location of the tags in the picked scenario of Chapter 3 can be determined by the following procedure. The first scan should be done with the full antenna power. The reason is to ensure that tags are in the antenna's read range. If no tags are detected, the antenna can move on to the next position because with decreasing antenna power the read range would also decrease. For the case that tags are detected the antenna power has to decrease until a sharp decrease in the total counts can be recorded. For this situation the location can be estimated with the used antenna power.

Future view

With the findings it indicates that the positions of the tags can be determined in the covered scenario. However, not all possibilities of the previous chapters were discussed in detail. As an example further investigation can be done for the described but not selected scenarios of Chapter 3. Furthermore, research could be done to optimize the antenna as well as the used tags for the desired case.

Another possible research field is to establish and process experiments to describe the interaction between the antenna and tag better. Therefore, the responses with many more tags than just two tags would needed to be recorded.

When the Invengo system will be used for further investigation, the purchase of the complete version could be important to receive the RSSI. With the RSSI the distance between the tag and antenna could be determined. To determine the distance multiple tag readings might be necessary.

The recorded data and the findings are also essential to know for the artificial intelligence. Without the known read range or the fact that the antenna read range for the used antenna is not a perfect symmetric circle with the antenna in the center, the algorithm could calculate the antenna positions wrong.

APPENDICES

APPENDIX A

RECORDED DATA FOR THE EXPERIMENT PRESENTED IN CHAPTER3

Table 8 Recorded Data for the Antenna Positions A to T with Antenna Power of 30 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2349	A	6483 0711 9C61 1D00 0000 1954	2238	I
6483 0711 9C61 1D00 0000 196B	1254	A	6483 0711 9C61 1D00 0000 188C	1766	I
6483 0111 9C61 1D00 0000 179C	198	A	6483 0711 9C61 1D00 0000 1947	768	I
635B 30F5 7E23 F224 C964 C703	1407	A	6483 0711 9C61 1D00 0000 184D	498	I
6483 0711 9C61 1D00 0000 1924	14	A	0F06 4D58	339	I
6483 0111 9C61 1D00 0000 179C	2054	B	5825 0111 9C61 1D00 0000 1518	58	I
635B 30F5 7E23 F224 C964 C703	1619	B	6483 0711 9C61 1D00 0000 188C	2357	J
6483 0711 9C61 1D00 0000 1967	971	B	5825 0111 9C61 1D00 0000 1518	1993	J
6483 0711 9C61 1D00 0000 196B	554	B	6483 0711 9C61 1D00 0000 184D	817	J
5825 0111 9C61 1D00 0000 1601	413	B	6483 0711 9C61 1D00 0000 1967	210	J
6483 0711 9C61 1D00 0000 1924	243	B	6483 0711 9C61 1D00 0000 1966	2184	K
6483 0711 9C61 1D00 0000 1954	34	B	6483 0711 9C61 1D00 0000 185C	1420	K
6483 0711 9C61 1D00 0000 188C	9	B	5825 0111 9C61 1D00 0000 166A	1315	K
0F06 4D58	6	B	5825 0111 9C61 1D00 0000 1601	740	K
6483 0711 9C61 1D00 0000 1924	2095	C	5825 0111 9C61 1D00 0000 1601	1880	L
6483 0711 9C61 1D00 0000 196B	1357	C	6483 0711 9C61 1D00 0000 185C	1564	L
6483 0711 9C61 1D00 0000 1954	1118	C	6483 0711 9C61 1D00 0000 18B2	1520	L
6483 0711 9C61 1D00 0000 1967	1006	C	6483 0711 9C61 1D00 0000 1947	477	L
0F06 4D58	1828	D	6483 0711 9C61 1D00 0000 1967	269	L
1122 3344 5566 7788 9900 AAC1	1345	D	6483 0711 9C61 1D00 0000 196B	160	L
6483 0711 9C61 1D00 0000 1967	1283	D	5825 0111 9C61 1D00 0000 166A	24	L
6483 0711 9C61 1D00 0000 1954	752	D	6483 0711 9C61 1D00 0000 1947	2393	M
6483 0711 9C61 1D00 0000 188C	385	D	5825 0111 9C61 1D00 0000 166A	1075	M
6483 0711 9C61 1D00 0000 196B	131	D	6483 0711 9C61 1D00 0000 18B2	962	M
6483 0711 9C61 1D00 0000 1924	20	D	6483 0711 9C61 1D00 0000 1954	320	M
1122 3344 5566 7788 9900 AAC1	2315	E	5825 0111 9C61 1D00 0000 1518	130	M
6483 0711 9C61 1D00 0000 1954	1947	E	6483 0711 9C61 1D00 0000 184D	105	M
6483 0711 9C61 1D00 0000 188C	1466	E	6483 0711 9C61 1D00 0000 1967	21	M
6483 0711 9C61 1D00 0000 1924	46	E	5825 0111 9C61 1D00 0000 1601	5	M
635B 30F5 7E23 F224 C964 C703	2043	F	5825 0111 9C61 1D00 0000 1518	1964	N
5825 0111 9C61 1D00 0000 1601	1753	F	6483 0711 9C61 1D00 0000 184D	1754	N
6483 0711 9C61 1D00 0000 1966	1523	F	1662	909	N
5825 0111 9C61 1D00 0000 1518	403	F	6483 0711 9C61 1D00 0000 18B2	888	N
6483 0711 9C61 1D00 0000 196B	188	F	6483 0711 9C61 1D00 0000 1954	704	N
6483 0711 9C61 1D00 0000 196B	2190	G	6483 0711 9C61 1D00 0000 184D	2860	O
6483 0711 9C61 1D00 0000 1966	1953	G	1662	1107	O
6483 0711 9C61 1D00 0000 1947	892	G	5825 0111 9C61 1D00 0000 1518	186	O
6483 0711 9C61 1D00 0000 1967	617	G	6483 0711 9C61 1D00 0000 188C	179	O
5825 0111 9C61 1D00 0000 1601	247	G	6483 0711 9C61 1D00 0000 185C	2626	P
6483 0111 9C61 1D00 0000 179C	21	G	5825 0111 9C61 1D00 0000 166A	2436	P
6483 0711 9C61 1D00 0000 1967	1653	H	5825 0111 9C61 1D00 0000 166A	2419	Q
5825 0111 9C61 1D00 0000 1518	1483	H	6483 0711 9C61 1D00 0000 18B2	2085	Q
5825 0111 9C61 1D00 0000 1601	933	H	6483 0711 9C61 1D00 0000 185C	533	Q
6483 0711 9C61 1D00 0000 1947	600	H	5825 0111 9C61 1D00 0000 1601	219	Q
635B 30F5 7E23 F224 C964 C703	461	H	6483 0711 9C61 1D00 0000 1947	1	Q
6483 0711 9C61 1D00 0000 1966	392	H	6483 0711 9C61 1D00 0000 18B2	2948	R
6483 0711 9C61 1D00 0000 1954	267	H	1662	453	R
6483 0711 9C61 1D00 0000 188C	122	H	6483 0711 9C61 1D00 0000 185C	210	R
6483 0711 9C61 1D00 0000 196B	100	H	6483 0711 9C61 1D00 0000 1947	20	R
			1662	2469	S
			5825 0111 9C61 1D00 0000 1518	317	S
			1662	3124	T

Table 9 Recorded Data for the Antenna Positions A to T with Antenna Power of 29 dB

Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2361	A
6483 0711 9C61 1D00 0000 196B	1336	A
6483 0111 9C61 1D00 0000 179C	118	A
635B 30F5 7E23 F224 C964 C703	1529	A
6483 0711 9C61 1D00 0000 1924	96	A
6483 0111 9C61 1D00 0000 179C	2389	B
635B 30F5 7E23 F224 C964 C703	1546	B
6483 0711 9C61 1D00 0000 1967	938	B
6483 0711 9C61 1D00 0000 196B	307	B
6483 0711 9C61 1D00 0000 1924	199	B
5825 0111 9C61 1D00 0000 1601	141	B
0F06 4D58	35	B
6483 0711 9C61 1D00 0000 1924	2120	C
6483 0711 9C61 1D00 0000 196B	1333	C
6483 0711 9C61 1D00 0000 1967	1141	C
6483 0711 9C61 1D00 0000 1954	1041	C
0F06 4D58	2067	D
6483 0711 9C61 1D00 0000 1967	1606	D
1122 3344 5566 7788 9900 AAC1	1366	D
6483 0711 9C61 1D00 0000 1954	667	D
6483 0711 9C61 1D00 0000 188C	303	D
1122 3344 5566 7788 9900 AAC1	2408	E
6483 0711 9C61 1D00 0000 1954	2166	E
6483 0711 9C61 1D00 0000 188C	1176	E
0F06 4D58	4	E
635B 30F5 7E23 F224 C964 C703	2103	F
5825 0111 9C61 1D00 0000 1601	1783	F
6483 0711 9C61 1D00 0000 1966	1445	F
5825 0111 9C61 1D00 0000 1518	431	F
6483 0711 9C61 1D00 0000 196B	222	F
6483 0711 9C61 1D00 0000 196B	2410	G
6483 0711 9C61 1D00 0000 1966	2136	G
6483 0711 9C61 1D00 0000 1967	452	G
6483 0711 9C61 1D00 0000 1947	446	G
5825 0111 9C61 1D00 0000 1601	101	G
6483 0711 9C61 1D00 0000 1967	2004	H
5825 0111 9C61 1D00 0000 1518	1755	H
5825 0111 9C61 1D00 0000 1601	1056	H
6483 0711 9C61 1D00 0000 1947	517	H
6483 0711 9C61 1D00 0000 1966	266	H
6483 0711 9C61 1D00 0000 1954	164	H
635B 30F5 7E23 F224 C964 C703	41	H

Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 1954	2161	I
6483 0711 9C61 1D00 0000 188C	1750	I
6483 0711 9C61 1D00 0000 184D	676	I
6483 0711 9C61 1D00 0000 1947	625	I
0F06 4D58	433	I
6483 0711 9C61 1D00 0000 188C	2554	J
5825 0111 9C61 1D00 0000 1518	1828	J
6483 0711 9C61 1D00 0000 184D	611	J
6483 0711 9C61 1D00 0000 1966	2253	K
6483 0711 9C61 1D00 0000 185C	1206	K
5825 0111 9C61 1D00 0000 166A	1028	K
5825 0111 9C61 1D00 0000 1601	922	K
5825 0111 9C61 1D00 0000 1601	2046	L
6483 0711 9C61 1D00 0000 18B2	1823	L
6483 0711 9C61 1D00 0000 185C	1277	L
6483 0711 9C61 1D00 0000 1947	329	L
5825 0111 9C61 1D00 0000 166A	89	L
6483 0711 9C61 1D00 0000 1967	73	L
6483 0711 9C61 1D00 0000 196B	20	L
6483 0711 9C61 1D00 0000 1947	2742	M
5825 0111 9C61 1D00 0000 166A	731	M
6483 0711 9C61 1D00 0000 18B2	575	M
6483 0711 9C61 1D00 0000 1954	96	M
5825 0111 9C61 1D00 0000 1518	94	M
5825 0111 9C61 1D00 0000 1518	2044	N
6483 0711 9C61 1D00 0000 184D	1843	N
6483 0711 9C61 1D00 0000 18B2	916	N
1662	903	N
6483 0711 9C61 1D00 0000 1954	317	N
6483 0711 9C61 1D00 0000 184D	3054	O
1662	737	O
5825 0111 9C61 1D00 0000 1518	20	O
6483 0711 9C61 1D00 0000 188C	10	O
6483 0711 9C61 1D00 0000 185C	2649	P
5825 0111 9C61 1D00 0000 166A	2280	P
5825 0111 9C61 1D00 0000 166A	2735	Q
6483 0711 9C61 1D00 0000 18B2	1865	Q
6483 0711 9C61 1D00 0000 185C	171	Q
6483 0711 9C61 1D00 0000 18B2	3041	R
1662	186	R
6483 0711 9C61 1D00 0000 185C	108	R
5825 0111 9C61 1D00 0000 1518	134	S
1662	2612	S
1662	3137	T

Table 10 Recorded Data for the Antenna Positions A to T with Antenna Power of 28 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2597	A	6483 0711 9C61 1D00 0000 1954	2275	I
6483 0711 9C61 1D00 0000 196B	1139	A	6483 0711 9C61 1D00 0000 188C	1790	I
6483 0111 9C61 1D00 0000 179C	22	A	6483 0711 9C61 1D00 0000 184D	578	I
6483 0711 9C61 1D00 0000 1924	38	A	6483 0711 9C61 1D00 0000 1947	480	I
635B 30F5 7E23 F224 C964 C703	1152	A	0F06 4D58	329	I
6483 0111 9C61 1D00 0000 179C	2861	B	6483 0711 9C61 1D00 0000 188C	2825	J
635B 30F5 7E23 F224 C964 C703	891	B	5825 0111 9C61 1D00 0000 1518	1401	J
6483 0711 9C61 1D00 0000 1967	397	B	6483 0711 9C61 1D00 0000 184D	229	J
6483 0711 9C61 1D00 0000 196B	1	B	6483 0711 9C61 1D00 0000 1966	2466	K
6483 0711 9C61 1D00 0000 1924	2380	C	6483 0711 9C61 1D00 0000 185C	1258	K
6483 0711 9C61 1D00 0000 1954	1214	C	5825 0111 9C61 1D00 0000 166A	819	K
6483 0711 9C61 1D00 0000 196B	886	C	5825 0111 9C61 1D00 0000 1601	451	K
6483 0711 9C61 1D00 0000 1967	679	C	5825 0111 9C61 1D00 0000 1601	2440	L
0F06 4D58	2314	D	6483 0711 9C61 1D00 0000 18B2	1242	L
1122 3344 5566 7788 9900 AAC1	1399	D	6483 0711 9C61 1D00 0000 185C	1022	L
6483 0711 9C61 1D00 0000 1967	1176	D	6483 0711 9C61 1D00 0000 1947	403	L
6483 0711 9C61 1D00 0000 1954	667	D	6483 0711 9C61 1D00 0000 1947	2983	M
1122 3344 5566 7788 9900 AAC1	2541	E	6483 0711 9C61 1D00 0000 18B2	305	M
6483 0711 9C61 1D00 0000 1954	2354	E	5825 0111 9C61 1D00 0000 166A	284	M
6483 0711 9C61 1D00 0000 188C	403	E	5825 0111 9C61 1D00 0000 1518	57	M
635B 30F5 7E23 F224 C964 C703	2379	F	5825 0111 9C61 1D00 0000 1518	2164	N
5825 0111 9C61 1D00 0000 1601	1825	F	6483 0711 9C61 1D00 0000 184D	1980	N
6483 0711 9C61 1D00 0000 1966	1238	F	1662	936	N
5825 0111 9C61 1D00 0000 1518	98	F	6483 0711 9C61 1D00 0000 18B2	734	N
6483 0711 9C61 1D00 0000 196B	34	F	6483 0711 9C61 1D00 0000 184D	3027	O
6483 0711 9C61 1D00 0000 196B	2578	G	1662	406	O
6483 0711 9C61 1D00 0000 1966	2301	G	6483 0711 9C61 1D00 0000 185C	2813	P
6483 0711 9C61 1D00 0000 1967	142	G	5825 0111 9C61 1D00 0000 166A	1521	P
6483 0711 9C61 1D00 0000 1947	43	G	5825 0111 9C61 1D00 0000 166A	2886	Q
6483 0711 9C61 1D00 0000 1967	2349	H	6483 0711 9C61 1D00 0000 18B2	1360	Q
5825 0111 9C61 1D00 0000 1518	1925	H	6483 0711 9C61 1D00 0000 18B2	3147	R
5825 0111 9C61 1D00 0000 1601	626	H	1662	66	R
6483 0711 9C61 1D00 0000 1947	238	H	6483 0711 9C61 1D00 0000 185C	15	R
6483 0711 9C61 1D00 0000 1954	116	H	1662	2578	S
6483 0711 9C61 1D00 0000 1966	103	H	5825 0111 9C61 1D00 0000 1518	1	S
			1662	3180	T

Table 11 Recorded Data for the Antenna Positions A to T with Antenna Power of 27 dB

Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2884	A
6483 0711 9C61 1D00 0000 196B	981	A
635B 30F5 7E23 F224 C964 C703	288	A
6483 0111 9C61 1D00 0000 179C	2912	B
635B 30F5 7E23 F224 C964 C703	794	B
6483 0711 9C61 1D00 0000 1967	254	B
6483 0711 9C61 1D00 0000 1924	2586	C
6483 0711 9C61 1D00 0000 1954	1384	C
6483 0711 9C61 1D00 0000 1967	473	C
6483 0711 9C61 1D00 0000 196B	389	C
0F06 4D58	2684	D
1122 3344 5566 7788 9900 AAC1	1252	D
6483 0711 9C61 1D00 0000 1954	399	D
6483 0711 9C61 1D00 0000 1967	272	D
1122 3344 5566 7788 9900 AAC1	2670	E
6483 0711 9C61 1D00 0000 1954	2159	E
6483 0711 9C61 1D00 0000 188C	208	E
635B 30F5 7E23 F224 C964 C703	2516	F
5825 0111 9C61 1D00 0000 1601	1384	F
6483 0711 9C61 1D00 0000 1966	1370	F
5825 0111 9C61 1D00 0000 1518	51	F
6483 0711 9C61 1D00 0000 196B	2652	G
6483 0711 9C61 1D00 0000 1966	2473	G
6483 0711 9C61 1D00 0000 1967	2713	H
5825 0111 9C61 1D00 0000 1518	1520	H
5825 0111 9C61 1D00 0000 1601	277	H
6483 0711 9C61 1D00 0000 1954	2590	I
6483 0711 9C61 1D00 0000 188C	1786	I
0F06 4D58	316	I
6483 0711 9C61 1D00 0000 184D	271	I
6483 0711 9C61 1D00 0000 188C	2937	J
5825 0111 9C61 1D00 0000 1518	1152	J
6483 0711 9C61 1D00 0000 1966	2749	K
6483 0711 9C61 1D00 0000 185C	900	K
5825 0111 9C61 1D00 0000 166A	657	K
5825 0111 9C61 1D00 0000 1601	83	K
5825 0111 9C61 1D00 0000 1601	2861	L
6483 0711 9C61 1D00 0000 185C	425	L
6483 0711 9C61 1D00 0000 18B2	419	L
6483 0711 9C61 1D00 0000 1947	255	L
6483 0711 9C61 1D00 0000 1947	3026	M
6483 0711 9C61 1D00 0000 18B2	273	M
5825 0111 9C61 1D00 0000 166A	73	M
5825 0111 9C61 1D00 0000 1518	2555	N
6483 0711 9C61 1D00 0000 184D	1705	N
6483 0711 9C61 1D00 0000 18B2	396	N
1662	286	N
6483 0711 9C61 1D00 0000 184D	3076	O
1662	131	O
6483 0711 9C61 1D00 0000 185C	2881	P
5825 0111 9C61 1D00 0000 166A	1123	P
5825 0111 9C61 1D00 0000 166A	2906	Q
6483 0711 9C61 1D00 0000 18B2	1310	Q
6483 0711 9C61 1D00 0000 18B2	3110	R
6483 0711 9C61 1D00 0000 185C	9	R
1662	2509	S

Table 12Recorded Data for the Antenna Positions A to T with Antenna Power of 26 dB

Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2998	A
6483 0711 9C61 1D00 0000 196B	388	A
635B 30F5 7E23 F224 C964 C703	56	A
6483 0111 9C61 1D00 0000 179C	3106	B
635B 30F5 7E23 F224 C964 C703	336	B
6483 0711 9C61 1D00 0000 1924	2735	C
6483 0711 9C61 1D00 0000 1954	765	C
6483 0711 9C61 1D00 0000 1967	502	C
6483 0711 9C61 1D00 0000 196B	286	C
0F06 4D58	2970	D
1122 3344 5566 7788 9900 AAC1	1009	D
6483 0711 9C61 1D00 0000 1954	53	D
1122 3344 5566 7788 9900 AAC1	2832	E
6483 0711 9C61 1D00 0000 1954	1364	E
635B 30F5 7E23 F224 C964 C703	2777	F
5825 0111 9C61 1D00 0000 1601	1281	F
6483 0711 9C61 1D00 0000 1966	545	F
6483 0711 9C61 1D00 0000 196B	2602	G
6483 0711 9C61 1D00 0000 1966	2540	G
6483 0711 9C61 1D00 0000 1967	2894	H
5825 0111 9C61 1D00 0000 1518	1000	H
6483 0711 9C61 1D00 0000 1954	2800	I
6483 0711 9C61 1D00 0000 188C	1055	I
6483 0711 9C61 1D00 0000 184D	477	I
6483 0711 9C61 1D00 0000 188C	2980	J
5825 0111 9C61 1D00 0000 1518	606	J
6483 0711 9C61 1D00 0000 1966	3053	K
6483 0711 9C61 1D00 0000 185C	463	K
5825 0111 9C61 1D00 0000 166A	28	K
5825 0111 9C61 1D00 0000 1601	1	K
5825 0111 9C61 1D00 0000 1601	3096	L
6483 0711 9C61 1D00 0000 185C	22	L
6483 0711 9C61 1D00 0000 18B2	1	L
6483 0711 9C61 1D00 0000 1947	3069	M
6483 0711 9C61 1D00 0000 18B2	124	M
5825 0111 9C61 1D00 0000 1518	2851	N
6483 0711 9C61 1D00 0000 184D	1161	N
6483 0711 9C61 1D00 0000 184D	3099	O
6483 0711 9C61 1D00 0000 185C	2999	P
5825 0111 9C61 1D00 0000 166A	502	P
5825 0111 9C61 1D00 0000 166A	2965	Q
6483 0711 9C61 1D00 0000 18B2	673	Q
6483 0711 9C61 1D00 0000 18B2	3110	R
1662	1927	S

Table 13 Recorded Data for the Antenna Positions A to T with Antenna Power of 25 dB

Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3100	A
6483 0711 9C61 1D00 0000 196B	193	A
635B 30F5 7E23 F224 C964 C703	21	A
6483 0111 9C61 1D00 0000 179C	3106	B
635B 30F5 7E23 F224 C964 C703	30	B
6483 0711 9C61 1D00 0000 1924	3077	C
6483 0711 9C61 1D00 0000 1967	210	C
6483 0711 9C61 1D00 0000 1954	42	C
0F06 4D58	3096	D
1122 3344 5566 7788 9900 AAC1	416	D
1122 3344 5566 7788 9900 AAC1	3047	E
6483 0711 9C61 1D00 0000 1954	260	E
635B 30F5 7E23 F224 C964 C703	2996	F
5825 0111 9C61 1D00 0000 1601	581	F
6483 0711 9C61 1D00 0000 1966	184	F
6483 0711 9C61 1D00 0000 196B	2581	G
6483 0711 9C61 1D00 0000 1966	2573	G
6483 0711 9C61 1D00 0000 1967	3042	H
5825 0111 9C61 1D00 0000 1518	167	H
6483 0711 9C61 1D00 0000 1954	2974	I
6483 0711 9C61 1D00 0000 188C	518	I
6483 0711 9C61 1D00 0000 188C	3157	J
6483 0711 9C61 1D00 0000 1966	3052	K
6483 0711 9C61 1D00 0000 185C	251	K
5825 0111 9C61 1D00 0000 1601	3156	L
6483 0711 9C61 1D00 0000 185C	28	L
6483 0711 9C61 1D00 0000 1947	3095	M
5825 0111 9C61 1D00 0000 1518	3021	N
6483 0711 9C61 1D00 0000 184D	313	N
6483 0711 9C61 1D00 0000 185C	3089	P
5825 0111 9C61 1D00 0000 166A	82	P
5825 0111 9C61 1D00 0000 166A	3093	Q
6483 0711 9C61 1D00 0000 18B2	56	Q
1662	1509	S

Table 14 Recorded Data for the Antenna Positions A to T with Antenna Power of 24 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3136	A	6483 0711 9C61 1D00 0000 1967	3087	H
6483 0711 9C61 1D00 0000 196B	37	A	5825 0111 9C61 1D00 0000 1518	26	H
6483 0111 9C61 1D00 0000 179C	3104	B	6483 0711 9C61 1D00 0000 1954	3078	I
6483 0711 9C61 1D00 0000 1924	3159	C	6483 0711 9C61 1D00 0000 188C	305	I
0F06 4D58	3076	D	6483 0711 9C61 1D00 0000 1966	3106	K
1122 3344 5566 7788 9900 AAC1	266	D	6483 0711 9C61 1D00 0000 185C	2	K
1122 3344 5566 7788 9900 AAC1	3098	E	5825 0111 9C61 1D00 0000 1601	3102	L
635B 30F5 7E23 F224 C964 C703	3110	F	5825 0111 9C61 1D00 0000 1518	3059	N
5825 0111 9C61 1D00 0000 1601	451	F	6483 0711 9C61 1D00 0000 184D	174	N
6483 0711 9C61 1D00 0000 196B	2890	G	6483 0711 9C61 1D00 0000 185C	3154	P
6483 0711 9C61 1D00 0000 1966	984	G	5825 0111 9C61 1D00 0000 166A	3149	Q

Table 15 Recorded Data for the Antenna Positions A to T with Antenna Power of 23 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3085	A	6483 0711 9C61 1D00 0000 1967	3157	H
0F06 4D58	3182	D	6483 0711 9C61 1D00 0000 1954	3151	I
635B 30F5 7E23 F224 C964 C703	3082	F	6483 0711 9C61 1D00 0000 1966	3114	K
5825 0111 9C61 1D00 0000 1601	102	F	5825 0111 9C61 1D00 0000 1518	3064	N
6483 0711 9C61 1D00 0000 196B	3045	G	6483 0711 9C61 1D00 0000 184D	121	N
6483 0711 9C61 1D00 0000 1966	252	G			

Table 16 Recorded Data for the Antenna Positions A to T with Antenna Power of 22 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
635B 30F5 7E23 F224 C964 C703	3105	F	5825 0111 9C61 1D00 0000 1518	3076	N
6483 0711 9C61 1D00 0000 196B	3110	G	6483 0711 9C61 1D00 0000 184D	34	N

Table 17 Recorded Data for the Antenna Positions A to T with Antenna Power of 21 dB

Tag ID	Counts	Position
5825 0111 9C61 1D00 0000 1518	3096	N

APPENDIX B

COMPARISON OF TAG RESPONSES

In this appendix the data for the response of the measured tag depending on the distance to the antenna and the antenna power are given. The tags can be compared by the responding rate at an antenna power of 30 dB and by the point where the sharp drop in the responses occur. Therefore, not all possible measurements need to be taken. In the following, the not taken measurements are marked yellow, while the read data are marked green. All measurements have the aim to show that the tags are working different. Therefore, just the measurements were taken to compare the tags.

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	
1 ft	47	48	48	48	48	48	48	48	48	48	50	50	50	50	50	50	34	9	0	0	0	0	
2 ft	31	35	31	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	measuremer
3 ft	27	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	estimated
4 ft	42	42	42	42	42	39	36	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 48 Responses Tag: 1518, long side facing antenna, antenna orientation: X

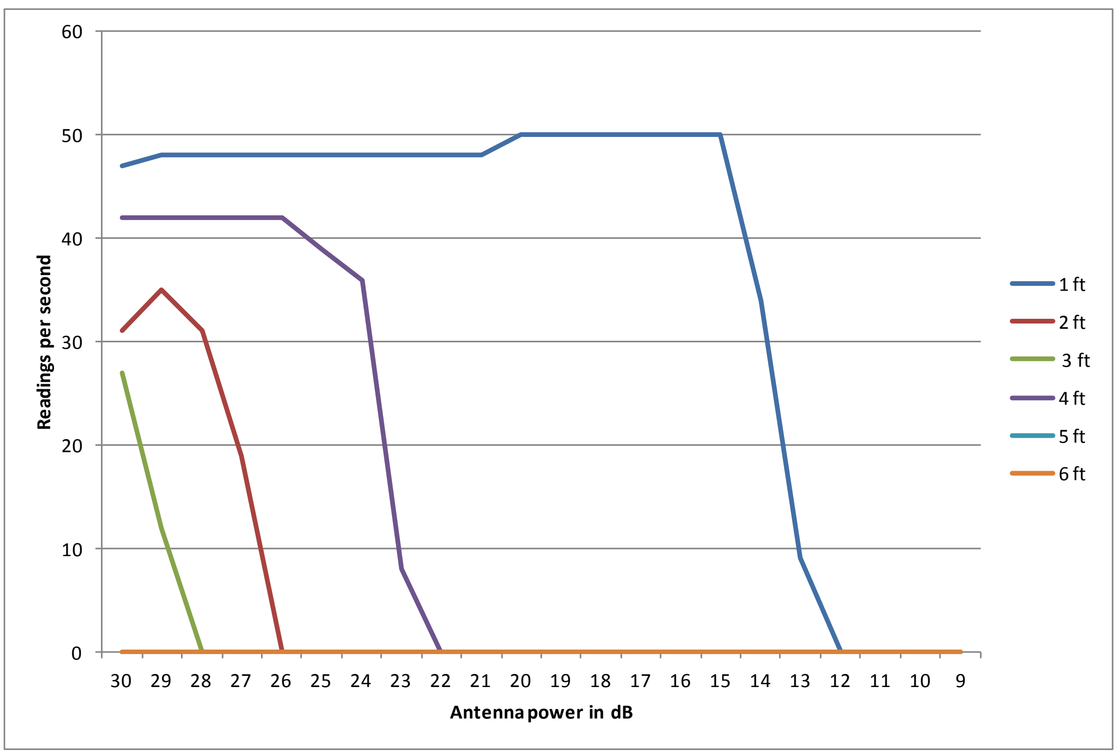

Figure 49 Visualization of the data from Figure 48

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9
1 ft	51	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
2 ft	49	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	33	9	0	0
3 ft	38	37	36	37	38	37	38	40	43	42	27	4	0.8	0	0	0	0	0	0	0	0	0
4 ft	41	40	38	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 ft	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 ft	6	0,3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 ft	33	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9 ft	2,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 ft	29	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 ft	0,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 ft	26	22	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 ft	17	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

measurements
estimated

Figure 50 Responses Tag: 1518, short side facing antenna, antenna orientation: X

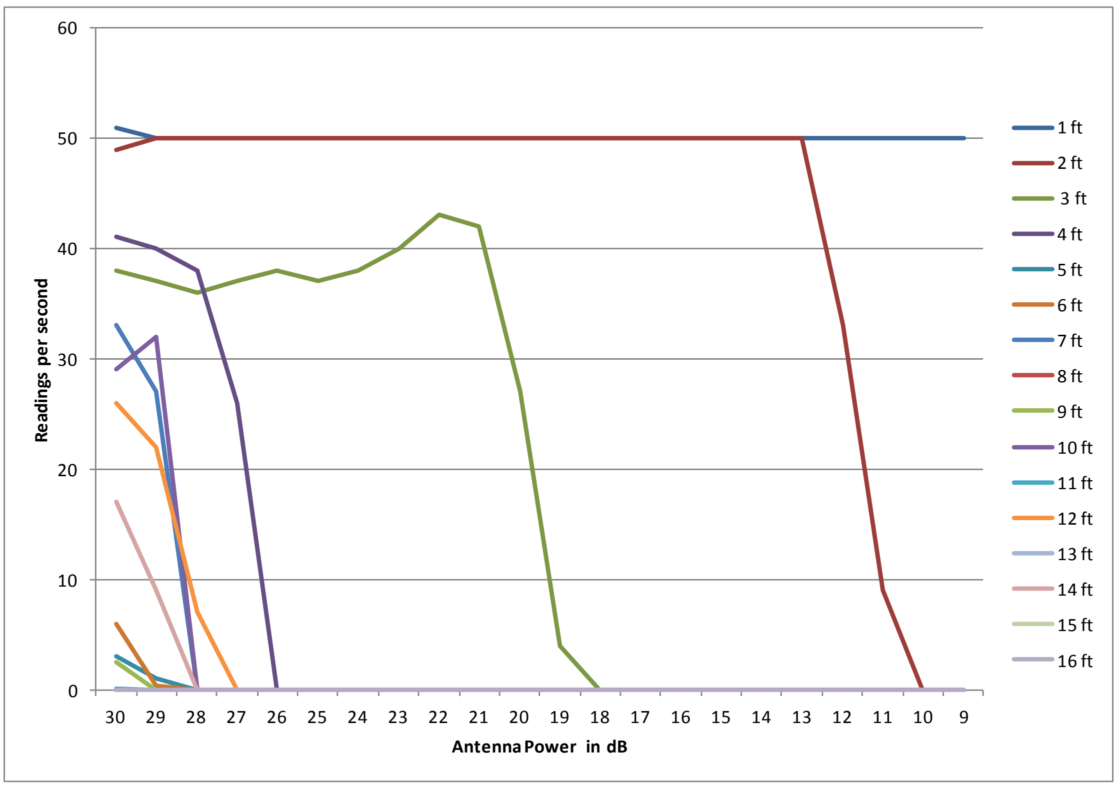

Figure 51 Visualization of the data from Figure 50

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	
1 ft	47	48	48	48	48	48	48	48	48	48	49	49	49	31	6	0	0	0	0	0	0	0	
2 ft	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	measurements
3 ft	42	40	24	0,3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	estimated
4 ft	41	40	40	40	40	40	19	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 52 Responses Tag: 185A, long side facing antenna, antenna orientation: X

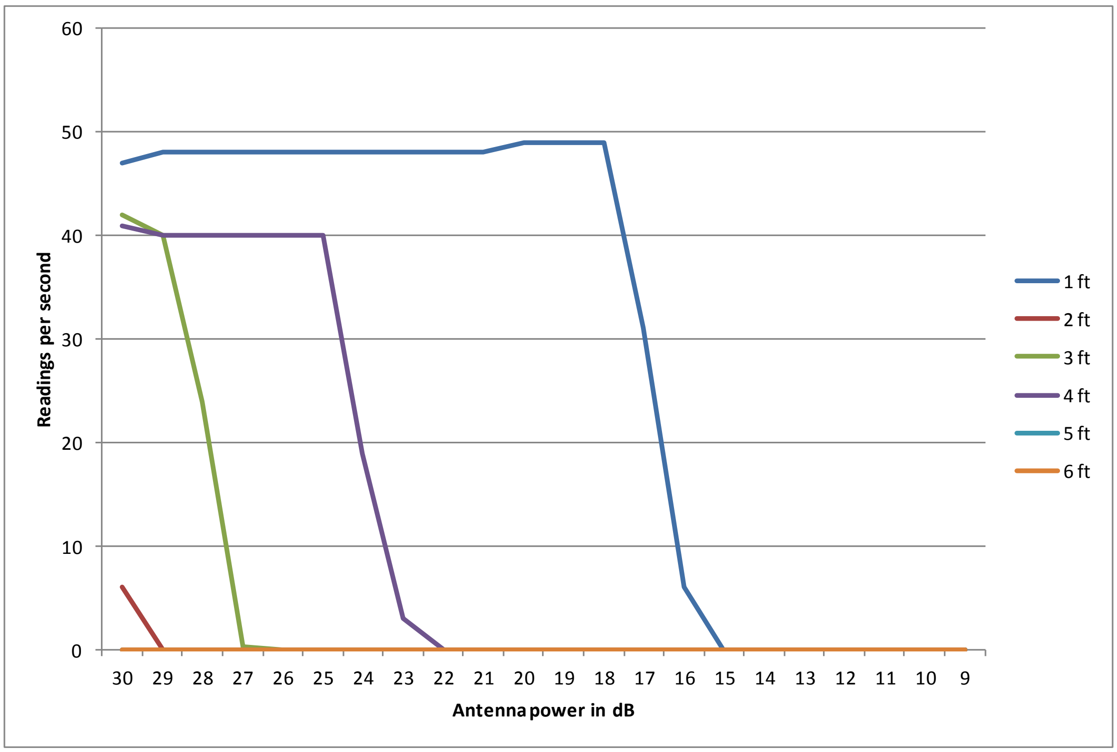

Figure 53 Visualization of the data from Figure 52

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	
1 ft	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	
2 ft	49	49	49	49	49	49	49	49	49	49	49	49	49	49	48	13	6	0	0	0	0	0	measurements
3 ft	43	45	45	45	45	45	45	45	48	38	37	11	0	0	0	0	0	0	0	0	0	0	estimated
4 ft	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5 ft	33	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7 ft	30	27	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
9 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10 ft	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14 ft	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 54 Responses Tag: 185A, short side facing antenna, antenna orientation: X

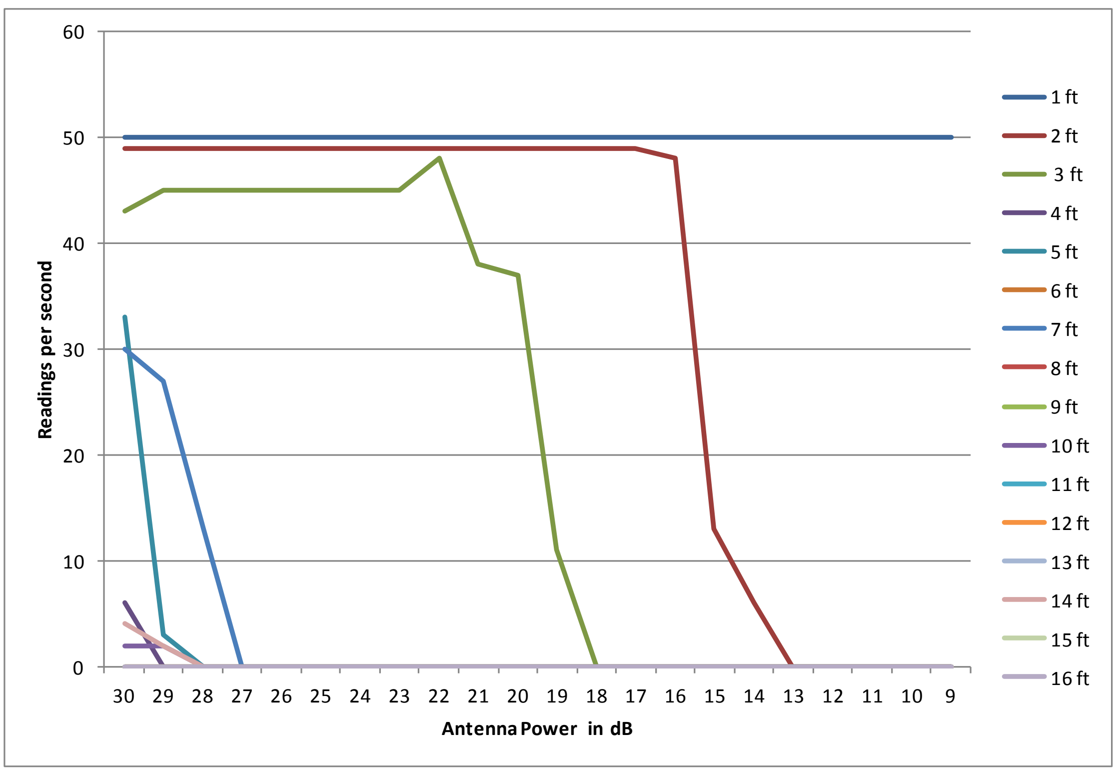

Figure 55 Visualization of the data from Figure 54

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	
1 ft	37	38	38	39	39	40	43	43	43	43	46	44	42	28	14	0	0	0	0	0	0	0	
2 ft	39	40	40	41	39	36	31	21	1	0	0	0	0	0	0	0	0	0	0	0	0	0	measurements
3 ft	38	41	42	41	36	37	24	22	2	0	0	0	0	0	0	0	0	0	0	0	0	0	estimated
4 ft	37	36	36	36	35	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 56 Responses Tag: 1518, long side facing antenna, antenna orientation: Y

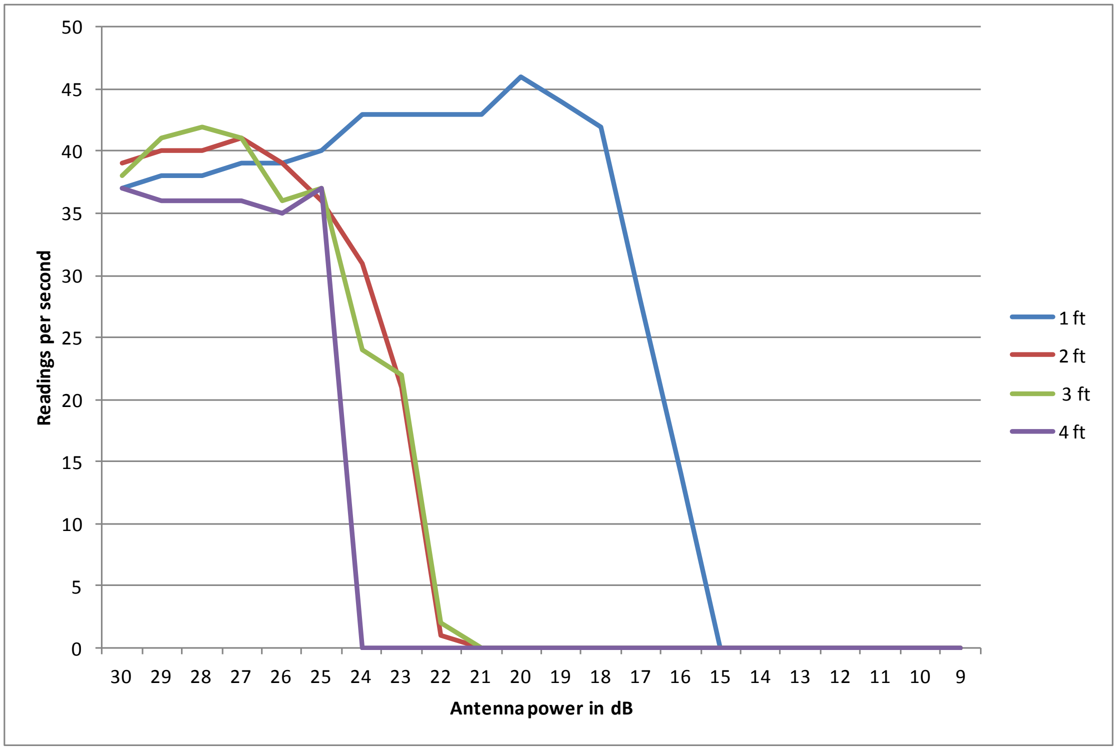

Figure 57 Visualization of the data from Figure 56

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	
1 ft	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	51	46	8	
2 ft	41	41	41	41	41	41	33	26	19	6	0	0	0	0	0	0	0	0	0	0	0	0	measurements
3 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	estimated
4 ft	40	41	42	35	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5 ft	32	18	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7 ft	13	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
9 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10 ft	0,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12 ft	0,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 58 Responses Tag: 1518, short side facing antenna, antenna orientation: Y

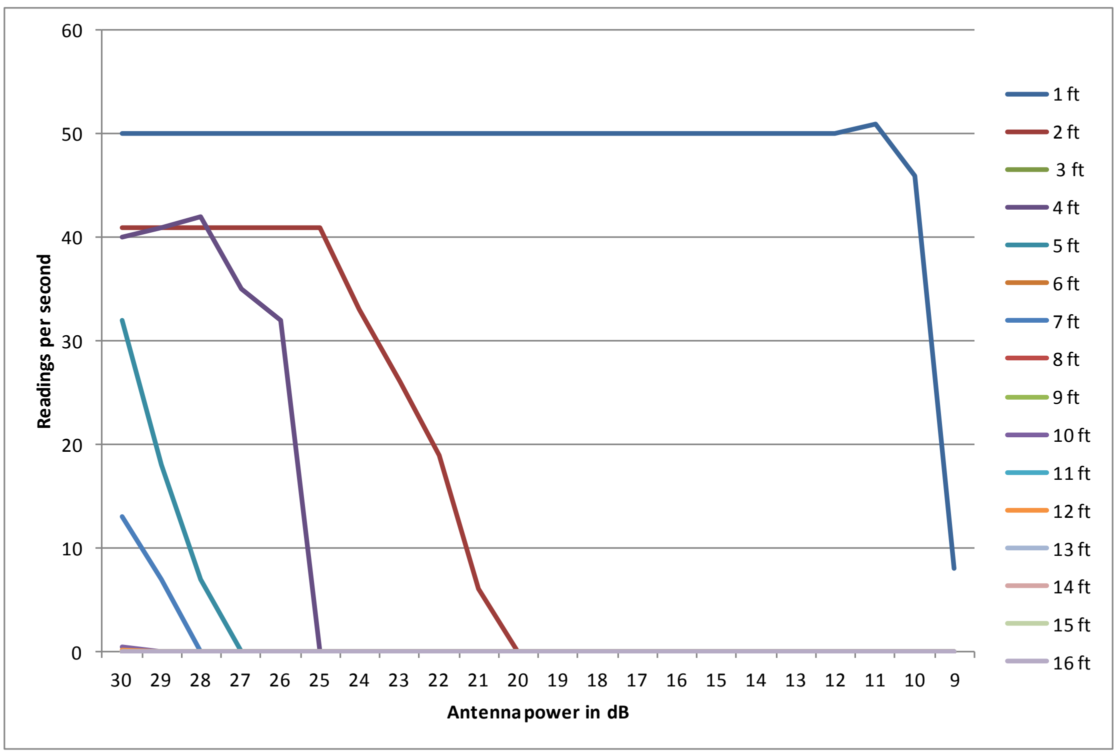

Figure 59 Visualization of the data from Figure 58

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	
1 ft	45	45	45	45	45	45	45	45	45	45	45	32	12	0,2	0	0	0	0	0	0	0	0	
2 ft	27	27	28	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	measurements
3 ft	42	42	42	42	40	29	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	estimated
4 ft	41	42	42	42	30	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5 ft	17	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 60 Responses Tag: 185A, long side facing antenna, antenna orientation: Y

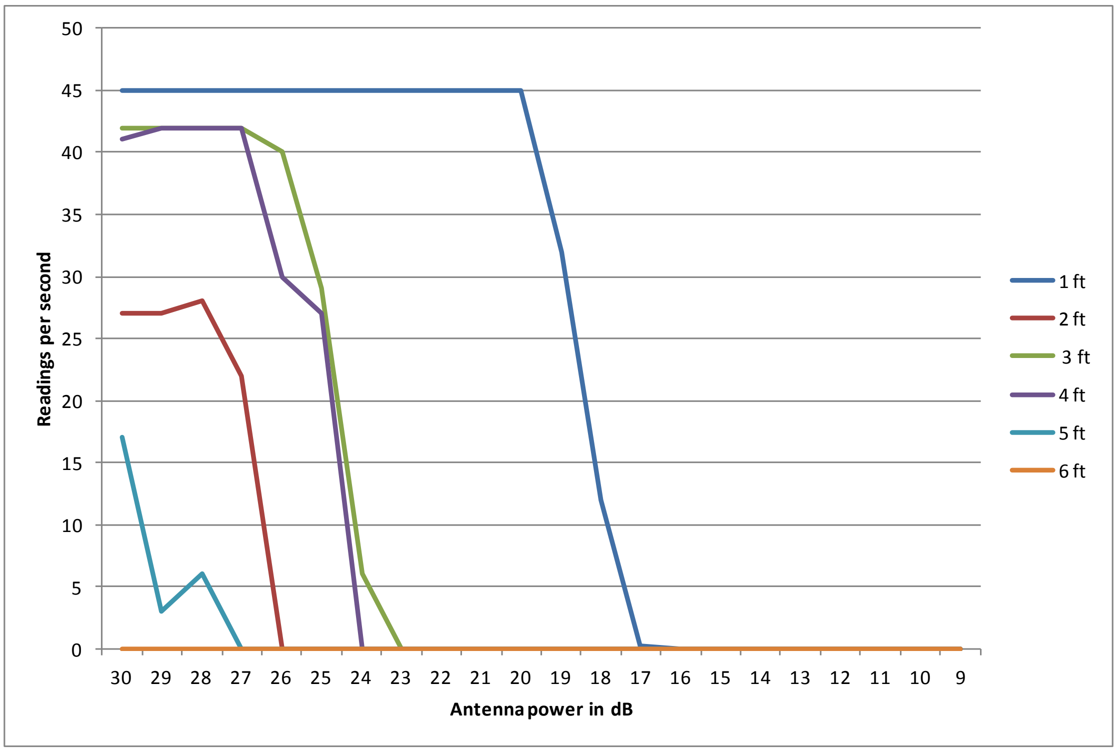

Figure 61 Visualization of the data from Figure 60

distance\power	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	
1 ft	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	51	44	12	0,7	
2 ft	42	42	42	42	42	42	42	42	41	24	5	0	0	0	0	0	0	0	0	0	0	0	measurements
3 ft	6	6	1,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	estimated
4 ft	15	29	32	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5 ft	3	0,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 ft	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7 ft	0,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 62 Responses Tag: 185A, short side facing antenna, antenna orientation: Y

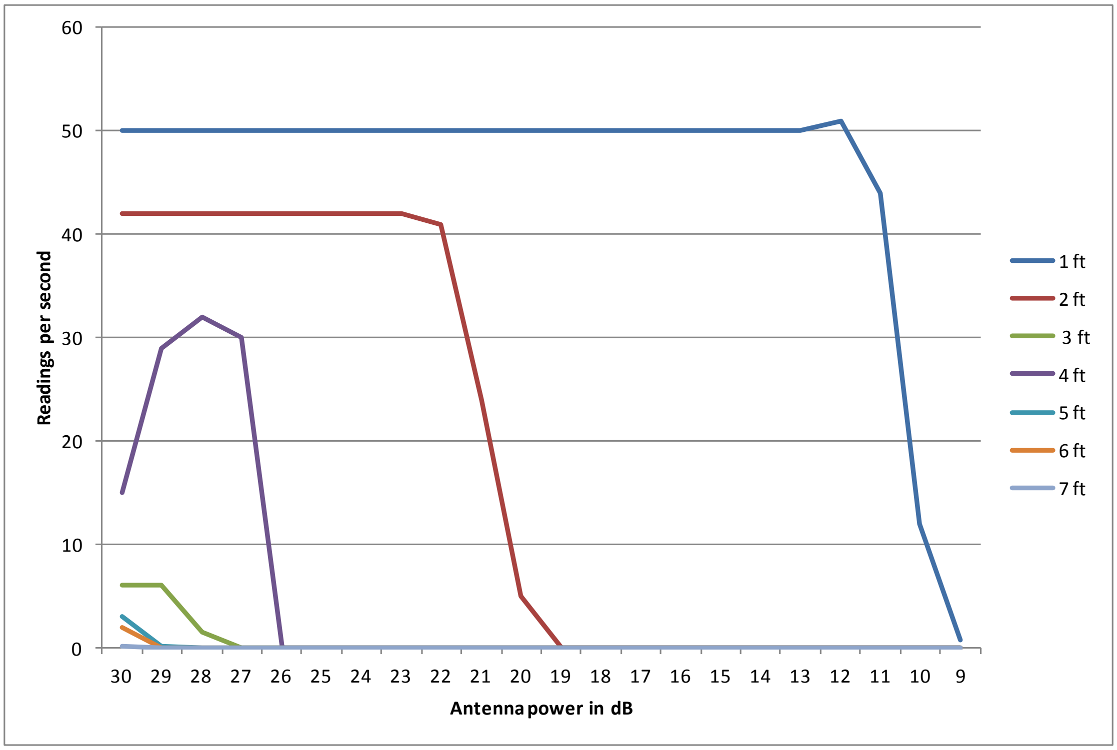

Figure 63 Visualization of the data from Figure 62

APPENDIX C

RECORDED SIDE SCANNING DATA

Table 18 Recorded data for side scanning with an antenna power of 30 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2783	U1	6483 0711 9C61 1D00 0000 185C	2223	X4
6483 0711 9C61 1D00 0000 1967	254	U1	5825 0111 9C61 1D00 0000 166A	2033	X4
5825 0111 9C61 1D00 0000 1518	238	U1	6483 0711 9C61 1D00 0000 18B2	427	X4
6483 0111 9C61 1D00 0000 179C	202	U1	5825 0111 9C61 1D00 0000 1518	804	X4
635B 30F5 7E23 F224 C964 C703	698	U1	6483 0711 9C61 1D00 0000 18B2	536	W1
6483 0711 9C61 1D00 0000 1924	3	U1	6483 0711 9C61 1D00 0000 1967	88	W1
6483 0111 9C61 1D00 0000 179C	2174	U2	5825 0111 9C61 1D00 0000 1518	399	W1
6483 0711 9C61 1D00 0000 1954	1351	U2	0F06 4D58	529	W1
6483 0711 9C61 1D00 0000 196B	384	U2	635B 30F5 7E23 F224 C964 C703	950	W1
6483 0711 9C61 1D00 0000 188C	821	U2	6483 0711 9C61 1D00 0000 18B2	769	W2
6483 0711 9C61 1D00 0000 1967	902	U2	5825 0111 9C61 1D00 0000 166A	368	W2
5825 0111 9C61 1D00 0000 1601	42	U2		159	W2
6483 0711 9C61 1D00 0000 1947	13	U2	635B 30F5 7E23 F224 C964 C703	24	W2
6483 0711 9C61 1D00 0000 1924	2484	U3	6483 0711 9C61 1D00 0000 1966	1583	W3
6483 0711 9C61 1D00 0000 196B	1378	U3	6483 0711 9C61 1D00 0000 196B	272	W3
6483 0711 9C61 1D00 0000 1954	225	U3	5825 0111 9C61 1D00 0000 166A	2367	W4
6483 0111 9C61 1D00 0000 179C	112	U3	6483 0711 9C61 1D00 0000 185C	322	W4
6483 0711 9C61 1D00 0000 1967	624	U3	6483 0711 9C61 1D00 0000 18B2	135	W4
0F06 4D58	2816	U4	6483 0711 9C61 1D00 0000 185C	2364	W5
6483 0711 9C61 1D00 0000 184D	171	U4	6483 0711 9C61 1D00 0000 185A	231	W5
6483 0711 9C61 1D00 0000 1954	642	U4	6483 0711 9C61 1D00 0000 1966	1	W5
6483 0711 9C61 1D00 0000 188C	135	U4	5825 0111 9C61 1D00 0000 1601	10	W5
5825 0111 9C61 1D00 0000 1518	202	U4	1122 3344 5566 7788 9900 AAC1	1859	V1
1122 3344 5566 7788 9900 AAC1	2834	U5	0F06 4D58	1816	V1
	81	U5	6483 0711 9C61 1D00 0000 188C	643	V1
6483 0711 9C61 1D00 0000 188C	912	U5	6483 0711 9C61 1D00 0000 1954	489	V1
6483 0711 9C61 1D00 0000 185A	2420	X1	6483 0711 9C61 1D00 0000 1967	350	V1
6483 0111 9C61 1D00 0000 179C	2198	X1	6483 0711 9C61 1D00 0000 188C	1828	V2
6483 0711 9C61 1D00 0000 1924	384	X1	6483 0711 9C61 1D00 0000 1954	992	V2
635B 30F5 7E23 F224 C964 C703	19	X1	6483 0711 9C61 1D00 0000 184D	1304	V2
635B 30F5 7E23 F224 C964 C703	2105	X2	5825 0111 9C61 1D00 0000 1518	768	V2
6483 0711 9C61 1D00 0000 1967	1424	X2	5825 0111 9C61 1D00 0000 1518	1539	V3
6483 0711 9C61 1D00 0000 196B	1914	X2	6483 0711 9C61 1D00 0000 184D	1835	V3
6483 0711 9C61 1D00 0000 1966	259	X2		618	V3
6483 0711 9C61 1D00 0000 1924	101	X2	6483 0711 9C61 1D00 0000 18B2	410	V3
0F06 4D58	118	X2	5825 0111 9C61 1D00 0000 166A	54	V3
6483 0711 9C61 1D00 0000 1966	2257	X3		2877	V4
6483 0711 9C61 1D00 0000 196B	437	X3			
6483 0711 9C61 1D00 0000 1947	545	X3			
5825 0111 9C61 1D00 0000 1601	2062	X3			
6483 0711 9C61 1D00 0000 1967	141	X3			
6483 0711 9C61 1D00 0000 1954	630	X3			

Table 19 Recorded data for side scanning with an antenna power of 29 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2956	U1	6483 0711 9C61 1D00 0000 185C	2384	X4
6483 0711 9C61 1D00 0000 1967	46	U1	5825 0111 9C61 1D00 0000 166A	2189	X4
635B 30F5 7E23 F224 C964 C703	604	U1	5825 0111 9C61 1D00 0000 1518	439	X4
5825 0111 9C61 1D00 0000 1518	41	U1	6483 0711 9C61 1D00 0000 18B2	113	X4
6483 0111 9C61 1D00 0000 179C	2570	U2	6483 0711 9C61 1D00 0000 18B2	1257	W1
6483 0711 9C61 1D00 0000 1954	1698	U2	5825 0111 9C61 1D00 0000 1518	320	W1
6483 0711 9C61 1D00 0000 196B	122	U2	0F06 4D58	369	W1
6483 0711 9C61 1D00 0000 188C	362	U2	5825 0111 9C61 1D00 0000 166A	2072	W2
6483 0711 9C61 1D00 0000 1967	203	U2	5825 0111 9C61 1D00 0000 166A	2510	W4
6483 0711 9C61 1D00 0000 1924	2790	U3	6483 0711 9C61 1D00 0000 185C	31	W4
6483 0711 9C61 1D00 0000 196B	1129	U3	6483 0711 9C61 1D00 0000 18B2	130	W4
6483 0711 9C61 1D00 0000 1954	62	U3	6483 0711 9C61 1D00 0000 185C	2433	W5
6483 0711 9C61 1D00 0000 1967	333	U3	6483 0711 9C61 1D00 0000 1966	3	W5
0F06 4D58	3022	U4	6483 0711 9C61 1D00 0000 185A	147	W5
6483 0711 9C61 1D00 0000 184D	174	U4	0F06 4D58	2165	V1
6483 0711 9C61 1D00 0000 1954	285	U4	1122 3344 5566 7788 9900 AAC1	2072	V1
6483 0711 9C61 1D00 0000 188C	63	U4	6483 0711 9C61 1D00 0000 1954	116	V1
5825 0111 9C61 1D00 0000 1518	16	U4	6483 0711 9C61 1D00 0000 188C	510	V1
1122 3344 5566 7788 9900 AAC1	2932	U5	6483 0711 9C61 1D00 0000 1954	1249	V2
6483 0711 9C61 1D00 0000 188C	711	U5	6483 0711 9C61 1D00 0000 188C	1967	V2
6483 0711 9C61 1D00 0000 185A	2530	X1	5825 0111 9C61 1D00 0000 1518	322	V2
6483 0111 9C61 1D00 0000 179C	2330	X1	6483 0711 9C61 1D00 0000 184D	1227	V2
6483 0711 9C61 1D00 0000 1924	194	X1	6483 0711 9C61 1D00 0000 184D	1973	V3
635B 30F5 7E23 F224 C964 C703	17	X1	5825 0111 9C61 1D00 0000 1518	1923	V3
635B 30F5 7E23 F224 C964 C703	2204	X2		618	V3
6483 0711 9C61 1D00 0000 196B	2048	X2	6483 0711 9C61 1D00 0000 18B2	146	V3
6483 0711 9C61 1D00 0000 1967	1328	X2		2834	V4
5825 0111 9C61 1D00 0000 1601	2154	X3			
6483 0711 9C61 1D00 0000 1966	2277	X3			
6483 0711 9C61 1D00 0000 1947	381	X3			
6483 0711 9C61 1D00 0000 196B	512	X3			
6483 0711 9C61 1D00 0000 1967	96	X3			
6483 0711 9C61 1D00 0000 1954	720	X3			

Table 20 Recorded data for side scanning with an antenna power of 28 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	2977	U1	6483 0711 9C61 1D00 0000 18B2	5	X4
6483 0711 9C61 1D00 0000 1967	16	U1	5825 0111 9C61 1D00 0000 166A	2284	X4
635B 30F5 7E23 F224 C964 C703	565	U1	6483 0711 9C61 1D00 0000 185C	2488	X4
6483 0111 9C61 1D00 0000 179C	2777	U2	5825 0111 9C61 1D00 0000 1518	317	X4
6483 0711 9C61 1D00 0000 1954	1516	U2	6483 0711 9C61 1D00 0000 18B2	1676	W1
6483 0711 9C61 1D00 0000 188C	164	U2	5825 0111 9C61 1D00 0000 1518	46	W1
6483 0711 9C61 1D00 0000 1924	3046	U3	5825 0111 9C61 1D00 0000 166A	1319	W2
6483 0711 9C61 1D00 0000 1967	175	U3	5825 0111 9C61 1D00 0000 166A	2494	W4
6483 0711 9C61 1D00 0000 196B	241	U3	6483 0711 9C61 1D00 0000 185C	2438	W5
0F06 4D58	3085	U4	1122 3344 5566 7788 9900 AAC1	2204	V1
6483 0711 9C61 1D00 0000 184D	38	U4	0F06 4D58	2031	V1
6483 0711 9C61 1D00 0000 1954	148	U4	6483 0711 9C61 1D00 0000 188C	62	V1
1122 3344 5566 7788 9900 AAC1	3020	U5	6483 0711 9C61 1D00 0000 1954	9	V1
6483 0711 9C61 1D00 0000 188C	442	U5	6483 0711 9C61 1D00 0000 188C	2198	V2
6483 0711 9C61 1D00 0000 185A	2570	X1	6483 0711 9C61 1D00 0000 1954	1234	V2
6483 0111 9C61 1D00 0000 179C	2362	X1	6483 0711 9C61 1D00 0000 184D	689	V2
6483 0711 9C61 1D00 0000 1924	451	X1	5825 0111 9C61 1D00 0000 1518	243	V2
635B 30F5 7E23 F224 C964 C703	2289	X2	6483 0711 9C61 1D00 0000 184D	1958	V3
6483 0711 9C61 1D00 0000 1967	1008	X2	5825 0111 9C61 1D00 0000 1518	1989	V3
6483 0711 9C61 1D00 0000 196B	2094	X2		399	V3
5825 0111 9C61 1D00 0000 1601	2524	X3	6483 0711 9C61 1D00 0000 18B2	161	V3
6483 0711 9C61 1D00 0000 1966	2638	X3		2829	V4

Table 21 Recorded data for side scanning with an antenna power of 27 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3063	U1	5825 0111 9C61 1D00 0000 1601	2524	X3
635B 30F5 7E23 F224 C964 C703	161	U1	6483 0711 9C61 1D00 0000 1966	2638	X3
6483 0111 9C61 1D00 0000 179C	2867	U2	6483 0711 9C61 1D00 0000 185C	2480	X4
6483 0711 9C61 1D00 0000 1954	1186	U2	5825 0111 9C61 1D00 0000 166A	2332	X4
6483 0711 9C61 1D00 0000 1924	3045	U3	6483 0711 9C61 1D00 0000 18B2	862	W1
6483 0711 9C61 1D00 0000 1967	38	U3	5825 0111 9C61 1D00 0000 166A	2380	W4
6483 0711 9C61 1D00 0000 196B	210	U3	6483 0711 9C61 1D00 0000 185C	2196	W5
0F06 4D58	3119	U4	1122 3344 5566 7788 9900 AAC1	2277	V1
1122 3344 5566 7788 9900 AAC1	3043	U5	0F06 4D58	1814	V1
6483 0711 9C61 1D00 0000 188C	290	U5	6483 0711 9C61 1D00 0000 1954	1068	V2
6483 0711 9C61 1D00 0000 185A	2522	X1	6483 0711 9C61 1D00 0000 188C	2489	V2
6483 0111 9C61 1D00 0000 179C	2374	X1	6483 0711 9C61 1D00 0000 184D	50	V2
6483 0711 9C61 1D00 0000 1924	200	X1	6483 0711 9C61 1D00 0000 184D	2020	V3
635B 30F5 7E23 F224 C964 C703	2537	X2	5825 0111 9C61 1D00 0000 1518	2039	V3
6483 0711 9C61 1D00 0000 1967	331	X2		285	V3
6483 0711 9C61 1D00 0000 196B	1982	X2			

Table 22 Recorded data for side scanning with an antenna power of 26 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3063	U1	5825 0111 9C61 1D00 0000 1601	2616	X3
635B 30F5 7E23 F224 C964 C703	161	U1	6483 0711 9C61 1D00 0000 1966	2722	X3
6483 0111 9C61 1D00 0000 179C	3054	U2	5825 0111 9C61 1D00 0000 166A	2331	X4
6483 0711 9C61 1D00 0000 1954	491	U2	6483 0711 9C61 1D00 0000 185C	2504	X4
6483 0711 9C61 1D00 0000 1924	3372	U3	1122 3344 5566 7788 9900 AAC1	2389	V1
6483 0711 9C61 1D00 0000 196B	72	U3	0F06 4D58	884	V1
0F06 4D58	3121	U4	6483 0711 9C61 1D00 0000 1954	205	V2
1122 3344 5566 7788 9900 AAC1	3061	U5	6483 0711 9C61 1D00 0000 188C	2658	V2
6483 0711 9C61 1D00 0000 188C	192	U5	6483 0711 9C61 1D00 0000 184D	2108	V3
6483 0111 9C61 1D00 0000 179C	2625	X1	5825 0111 9C61 1D00 0000 1518	2042	V3
6483 0711 9C61 1D00 0000 185A	2681	X1		122	V3
635B 30F5 7E23 F224 C964 C703	2616	X2			
6483 0711 9C61 1D00 0000 1967	138	X2			
6483 0711 9C61 1D00 0000 196B	2042	X2			

Table 23 Recorded data for side scanning with an antenna power of 25 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3093	U1	6483 0711 9C61 1D00 0000 1966	2737	X3
6483 0111 9C61 1D00 0000 179C	3157	U2	5825 0111 9C61 1D00 0000 1601	2711	X3
6483 0711 9C61 1D00 0000 1954	11	U2	5825 0111 9C61 1D00 0000 166A	2397	X4
6483 0711 9C61 1D00 0000 1924	3147	U3	6483 0711 9C61 1D00 0000 185C	2533	X4
1122 3344 5566 7788 9900 AAC1	3094	U5	1122 3344 5566 7788 9900 AAC1	2700	V1
6483 0111 9C61 1D00 0000 179C	2224	X1	6483 0711 9C61 1D00 0000 1954	72	V2
6483 0711 9C61 1D00 0000 185A	2712	X1	6483 0711 9C61 1D00 0000 188C	2735	V2
635B 30F5 7E23 F224 C964 C703	2787	X2	5825 0111 9C61 1D00 0000 1518	1098	V3
6483 0711 9C61 1D00 0000 196B	1629	X2	6483 0711 9C61 1D00 0000 184D	2339	V3

Table 24 Recorded data for side scanning with an antenna power of 24 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3115	U1	6483 0711 9C61 1D00 0000 185C	2628	X4
6483 0111 9C61 1D00 0000 179C	3100	U2	5825 0111 9C61 1D00 0000 166A	2019	X4
6483 0711 9C61 1D00 0000 1924	3090	U3	1122 3344 5566 7788 9900 AAC1	2583	V1
6483 0711 9C61 1D00 0000 185A	2900	X1	6483 0711 9C61 1D00 0000 188C	2739	V2
6483 0111 9C61 1D00 0000 179C	1024	X1	6483 0711 9C61 1D00 0000 184D	2434	V3
6483 0711 9C61 1D00 0000 196B	951	X2	5825 0111 9C61 1D00 0000 1518	627	V3
635B 30F5 7E23 F224 C964 C703	2934	X2			
6483 0711 9C61 1D00 0000 1966	2718	X3			
5825 0111 9C61 1D00 0000 1601	2633	X3			

Table 25 Recorded data for side scanning with an antenna power of 23 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0111 9C61 1D00 0000 179C	3089	U2	6483 0711 9C61 1D00 0000 185C	2954	X4
6483 0711 9C61 1D00 0000 185A	3023	X1	5825 0111 9C61 1D00 0000 166A	802	X4
6483 0111 9C61 1D00 0000 179C	249	X1	6483 0711 9C61 1D00 0000 188C	2743	V2
635B 30F5 7E23 F224 C964 C703	2964	X2	6483 0711 9C61 1D00 0000 184D	2665	V3
6483 0711 9C61 1D00 0000 196B	542	X2			
6483 0711 9C61 1D00 0000 1966	2835	X3			
5825 0111 9C61 1D00 0000 1601	1464	X3			

Table 26 Recorded data for side scanning with an antenna power of 22 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3071	X1	6483 0711 9C61 1D00 0000 185C	3041	X4
6483 0111 9C61 1D00 0000 179C	70	X1	5825 0111 9C61 1D00 0000 166A	206	X4
635B 30F5 7E23 F224 C964 C703	3115	X2	6483 0711 9C61 1D00 0000 184D	2728	V3
6483 0711 9C61 1D00 0000 196B	130	X2			
6483 0711 9C61 1D00 0000 1966	3040	X3			
5825 0111 9C61 1D00 0000 1601	228	X3			

Table 27 Recorded data for side scanning with an antenna power of 21 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 185A	3078	X1	6483 0711 9C61 1D00 0000 185C	3115	X4
635B 30F5 7E23 F224 C964 C703	3141	X2	5825 0111 9C61 1D00 0000 166A	112	X4
6483 0711 9C61 1D00 0000 1966	3071	X3			
5825 0111 9C61 1D00 0000 1601	46	X3			

Table 28 Recorded data for side scanning with an antenna power of 20 dB

Tag ID	Counts	Position	Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 1966	3144	X3	6483 0711 9C61 1D00 0000 185C	3147	X4
5825 0111 9C61 1D00 0000 1601	8	X3			

Table 29 Recorded data for side scanning with an antenna power of 19 dB

Tag ID	Counts	Position
6483 0711 9C61 1D00 0000 1966	3112	X3

APPENDIX D

READ RANGES FOR SIDE SCANNING

Table 30 Data side scan I

Tag 1518 side scanning read range, short tag side facing antenna				
distance	responses at 30 dBm	avg responses at 30 dBm	responses at minimum reading power	min reading power
1 ft	3065	50	986	12
2ft	2874	47	252	15
3ft	2394	39	504	20
4ft	2329	38	174	22
5ft	2186	36	458	22
6ft	2243	37	1353	23
7ft	2453	40	588	25
8ft	2463	40	1479	27
9ft	2581	42	1868	28
10ft	2206	36	1529	27
11ft	2150	35	1632	29
12ft	0	0	no answer	
13ft	0	0	no answer	
14ft	0	0	no answer	

Table 31 Data side scan II

Tag 1518 side scanning read range, long tag side facing antenna				
distance	responses at 30 dBm	avg responses at 30 dBm	responses at minimum reading power	min reading power
1 ft	3066	50	3146	9
2ft	3049	50	271	10
3ft	2942	48	1596	13
4ft	3058	50	1383	15
5ft	2494	41	132	15
6ft	2317	38	380	20
7ft	2379	39	332	23
8ft	2571	42	211	26
9ft	2534	42	648	25
10ft	2255	37	940	23
11ft	2464	40	1504	24
12ft	2491	41	738	25
13ft	2436	40	931	28
14ft	0	0	no answer	

APPENDIX E

ANTENNA ANGULAR READ RANGE

Table 32 Antenna read range related to angle

degree	read range in meter	read range ft	read range inch
0	5,4864	18	0
15	4,318	14	2
30	4,8768	16	0
45	3,4798	11	5
60	1,524	5	0
75	1,4478	4	9
90	1,4224	4	8
105	0,8636	2	10
120	1,0414	3	5
135	1,3208	4	4
150	2,3114	7	7
165	1,4732	4	10
180	1,0668	3	6
195	1,7526	5	9
210	1,3716	4	6
225	2,159	7	1
240	1,8796	6	2
255	1,5494	5	1
270	1,1938	3	11
285	2,286	7	6
300	2,1336	7	0
315	4,3688	14	4
330	4,3688	14	4
345	5,334	17	6

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