# Object localization with RFID Technology

## Projektarbeit


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# 1. Introduction

## 1.1. Motivation

In this work we analyse the approaching of a mobile robot using RFID (Radio Frequency Identification) Technology with the purpose of finding and navigating towards RFID tags without visual object detection.

## 1.2. Goals of the project

The aim is the evaluation of ROS to provide the means to allow a mobile robot to approach to RFID tags, using a radiofrequency antenna as a transmitter/receptor element of signals.

As part of this system the robot emits radiofrequency signals searching for a particular RFID tag, and then it is approached towards the particular RFID tag until the signal strength was maximized, it means that the object was localized and captured.

The approach has been tested using two different algorithms which work together:

- Linear search.
- Advanced search.

All the code and tests of this project are based to work with one antenna. On one hand it means simplicity, but on the other hand it can mean a lack of precision, as we will see further.

## 1.3. Related work

This project represents a practical study based on theoretical researches on the field of RFID Technology. Principally, the work related was based on the next documents. You can see further information on the bibliography part:

- "Dynamic Objects Tracking with a Mobile Robot using Passive UHF RFID Tags"
- "Finding and Navigating to Household Objects with UHF RFID Tags by Optimizing RF Signal Strength"

These papers were used to understand the behavior of RFID technology applied to Mobile Robots from a physical, statistical and mathematical view point. In this work we'll use all this knowledge to reach the main goal of the project, demonstrating the validity of the documents related.

# 2. Parts of the Project

The whole system is formed by next elements: Pioneer 3-DX, Computer, RFID reader, antenna and RFID tags. You can see in the next picture the RFID system:

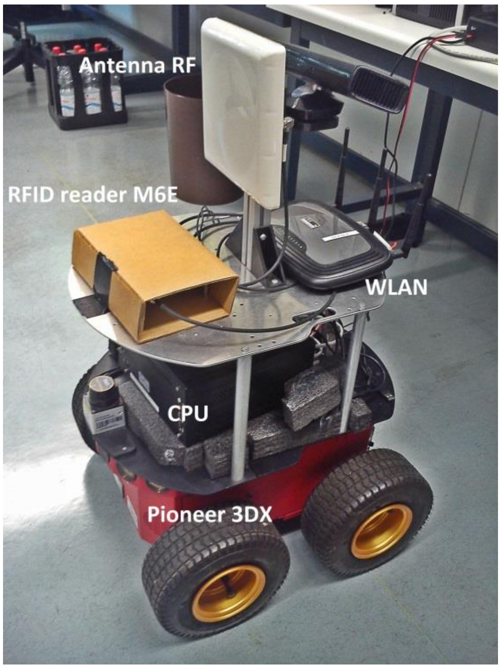



Image 1. RFID system

### 2.1. Pioneer 3-DX

This platform is commonly used as a research mobile robot. His versatility, reliability and durability have made it the reference platform for research.

The platform can reach speeds of 1.6 m/s and carry a payload of up to 23 kg. The robot is powered by three hot-swappable 9Ah sealed batteries.

### 2.2. Computer

To execute the project we use a Mini-PC (Intel I7-2640M @ 4 x 2.80 GHz, 8 GB RAM, 64-bit Ubuntu 12.04) mounted on the robot. Moreover, the system is prepared to execute with a WLAN configuration. It provides a major autonomy to the movements of the system.

### 2.3. RFID reader M6E

The Mercury6e (M6E) hardware embedded module of ThingMagic is an RFID engines which can be integrated with different systems to create RFID products. Using the high level MercuryAPI it's possible the development of applications to control the M6e modules and derivative products. In concrete, the MercuryAPI supports Java, .NET and C programming environments.

The M6e supports four monostatic bidirectional RF antennas through four MMCX (micro-miniature coaxial) connectors. The modules also support using a Multiplexer, allowing up to 16 total logical antenna ports. The performance of the M6e is affected by the antenna quality. Antennas which provide 50Ω match at the operating frequency band will improve the behavior of the system, transferring the maximum RF power to the port, which is 1.4Watts (+31.5dBm). Respect to the RL (return loss), antennas providing 17 dB of RL or better across the operating band, the specified sensitivity performance is achieved. For RL of 1 dB or greater, the performance won't be affected.

The maximum RF power for the combination of antenna and cable is determined from antenna gain and antenna cable loss using the ***Formula 1***:

$$P_{ant} = P_{port\ M6E} - G_{ant} - L_{cable} \qquad \textit{Formula 1}$$

Where $L_{cable}$ = 0.8 dB, because the coaxial cable model is CBL-P6. You can see these values in the M6E Hardware guide.

## 2.4. RFID Tags

The RFID Tags contains information electronically saved. The data is transferred in an wireless way because of the phenomenon of electromagnetic induction generated from the antenna connected to the RFID reader. With the RFID Tags you can create RF identification system. The RFID Tags works as TX/RX RF signals. The Tags receive an RF signal and transmit with a RF signal with the same frequency carrier with the information of the specific Tag. The following table lists the information that can be read from RFID tags.

| Meta Data Field | Description |
|---|---|
| **ID antenna** | The antenna on with the tag was read |
| **Read Count** | Nº times the tag was read on for a certain Antenna |
| **Timestamp** | The time the tag was read, in miliseconds. |
| **Tag Data** | Information of the Tag. For us, it represents the ID Tag. |
| **Frequency** | Frequency on which the tag was read |
| **Tag Phase** | Average phase of tag response in degrees [0°,180°] |
| **RSSI** | The receive signal strength of the tag response in dBm. |
| **GPIO Status** | The signal status of GPIO pins when tag was read |

From the last list, the most important information for this project is Tag Data and RSSI, but for future projects it can be interesting to use other parameters.

In this case we used the RFID tags attached as samples with the RFID Reader. In the next image you can see the RFID tags used in this project.


Image 2. RFID tags

The next table lists the principal features of the RFID Tags:

| | Antenna 1 | Antenna 2 |
|---|---|---|
| **Feature** | Confidex Survivor | Confidex Carrier Pro |
| **Frequency** | 865-869 MHz (EU) | 860-960 MHz |
| **Memory** | 128bit EPC + 512bit | 128 bit EPC + 512 bit |
| **Read range** | On metal → 18m<br>Off metal → 16m | 12.5 m |

### 2.5. Antenna

As TR/RX of RF signals we decided to use the antenna MT-242025, due to it's one of the models recommended for the developers of the RFID reader to achieve an optimal behavior of our system. The important features of this antenna for the project are listened below:

| Feature | Value |
|---|---|
| **Frequency range** | 865 - 956 MHz |
| **Gain** | 865-870 MHz @ 7 dBic (min)<br>902-928 MHz @ 7.5 dBic (min)<br>950-956 MHz @ 6.5 dBic (min) |
| **VSWR(Voltage Standing Wave Ratio)** | [1'2,1] (typ value) |
| **Polarization** | RHCP (Right Hand Circular Polarization) |
| **3dB elevation beamwidth** | 72° |
| **3dB azimuth beamwidth** | 74° |
| **Front to back ratio** | -18 dB (max) |
| **Power** | 6W (max) |
| **Input impedance** | 50 Ω |

In the next graphs you can see the radiation pattern of the antenna used on this project. As we can appreciate, the radiation pattern for vertical plane (elevation angle) is almost reciprocal than the radiation pattern for horizontal plane **(azimuth angle)**. In this case **we only used the horizontal plane** due to the limitations for movements of the platform used, but is important to know for future projects that the behavior of both planes is very similar. It means that realizing some simple adjustments in the source code to control movements and realize measurements of the antenna in the horizontal plane can be reutilized for the vertical plane.

**Antenna radiation diagram**

| Vertical plane (elevation angle) | **Horizontal plane (azimuth angle)** |
| --- | --- |

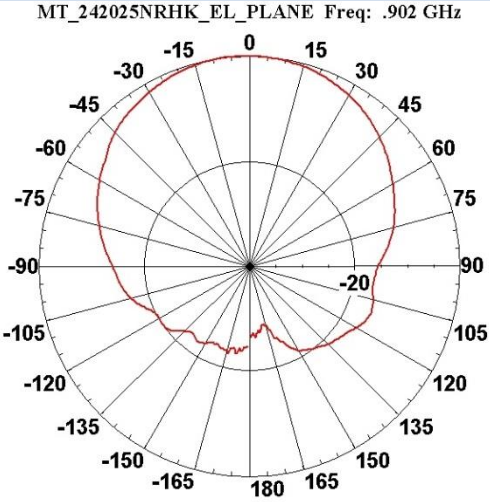



Image 3

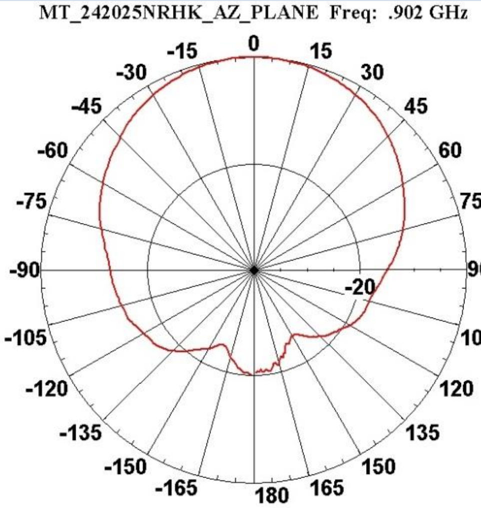



Image 4

Source : MTI Wireless edge LTD. http://www.mtiwe.com/?CategoryID=276&ArticleID=55

### 2.6. ROS

The system was implemented using the framework ROS (Robot Operating System). ROS is a meta-operating system Open Source to control different hardware, devices, robots and different tools and libraries to execute code through different computers. The advantage of ROS is that aim to simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms.

ROS must be executed in a distribution of Ubuntu, because is the OS which offers better guarantees. The programming language used is C++, although you can use other languages, as Python, for example.

## 3. RFID system description. ROS nodes & hardware

In this section will be described the different parts of the RFID system, the dependences between each part and how ROS helps to merge the hardware components and establish the logic of this system.

### 3.1. System architecture

We can see in the next flow chart the overall RFID system. The main goal of the project is find a certain RFID Tag and realize an approach movement until reach the RFID Tag.

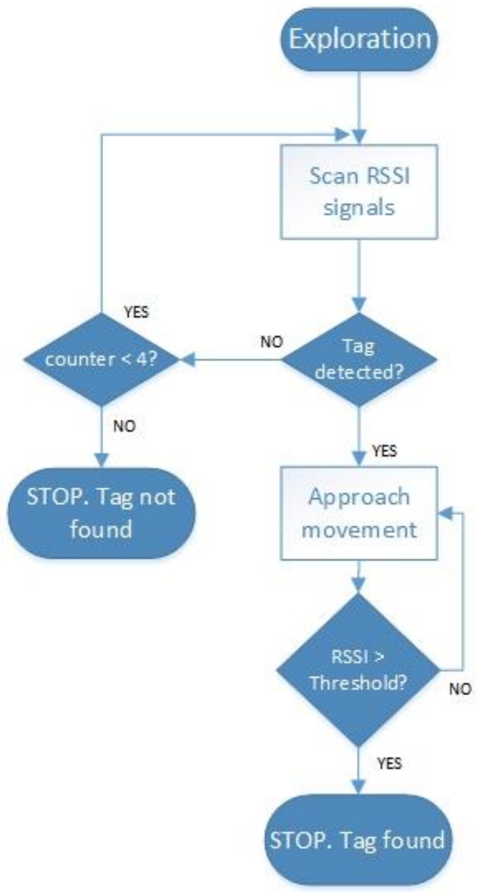



Image 5. System diagram

### 3.2. ROS nodes

The RFID system is established by different ROS nodes. The actions done to interact between nodes define the behavior of the system. Here we explain how these relations between nodes and hardware can be merged to achieve our main goal.

| Node | Function |
|---|---|
| **reader** | Read the signals received by the antenna in the RFID reader and adapt the meta-data of the tags to publish it as a topic "/rfid_tags" |
| **rfid_project_node** | The principal node of the system. This node is subscribed to the topic "/rfid_tags" and read the meta-data of the tags. Moreover, this node is the ActionClient. From this node the actions are executed to approach the Robot to the tag. This node sends goals to the node "server" to realize approach movements with the Pioneer 3DX. |
| **server** | Is the "ActionServer" node. Receive goals of the "rfid_project_node" to realize approach movements with the platform Pioneer 3DX. The node is subscribed to the topic "/odom" |

| | |
|---|---|
| | to read the position of the Pioneer 3DX and publish velocity values to move the platform using the "/cmd_vel" topic. |
| **p2os** | Driver to control the Pioneer 3DX |

Moreover, you can see graphically the relations between nodes and hardware.

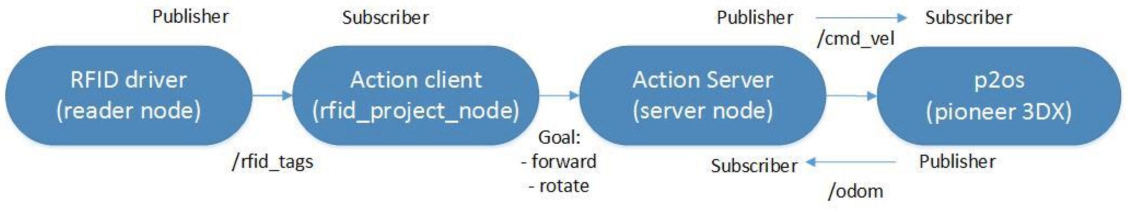



**Image 6. ROS nodes system diagram**

# 4. Pioneer 3DX + ROS

The main function of the Pioneer 3DX is to perform the movements approach toward the corresponding RFID tag. The control of the platform was developed so that the robot moves autonomously.

As you can read in the last section the ROS node "server" manages the control of the Pioneer 3DX. You can find the source code on the next route:

File: **\catkin\src\pioneer_move_server\src\server.cpp**

The main actions that you can achieve with this node are:

| Action | Description |
|---|---|
| **Movement forward /backward** | Move the robot "d" meters<br>• d > 0m →Movement forward<br>• d < 0m →Movement backward |
| **Rotate** | The robot will be turned to a specified angle between [0, 2*π] radians. |

## 4.1. Application Server: actionlib

This node works as an Application Server. As you can see reading the source code, we used the ROS library "actionlib". This library allows receive request to move the platform asynchronously with the actions mentioned before.

There's a Client-Server Interaction between the "rfid_project_node" node (client) and the "server" node (server),. The communication is done via "ROS Action Protocol" sending Goal messages, specified in the file ".action" corresponded. In this communication we specify two goals:

| Goal | Description |
|---|---|
| **distance** | Distance in meters which we desire to move linearly the platform. |
| **angle** | Angle in radians we desire turns the platform. Angle between [0, 2*π] radians. |

### 4.2. Execute movements. Publishers and subscribers

To realize movements, we need to work with two different ROS publishers/subscribers objects which write/read information using the next ROS topics:

| Type object | Topic | Description |
|---|---|---|
| **Publisher (write)** | /cmd_vel | Send velocity values to the platform. In concrete, linear and angular velocity values, depending on the type of movement. |
| **Subscriber (read)** | /odom | It reads the position of the platform to reach to the exact point we desire. |

### 4.3. Node Pioneer 3DX

To control the Pioneer 3DX we use the node “p2os”. This node execute the movements in the platform and publish information about through some ROS topics as “/cmd_vel”, “/odom” y “/tf”, which are the topics we used in this project.

## 5. M6E + ROS

The RFID reader hardware, M6E is controlled by ROS to realize actions as:

- Send power signals to the Tags
- Process the meta-data received from the tags
- Send actions to realize the approach movements
- identify Tags
- Identify RSSI of the Tags

To realize these actions, we have used two different nodes:

- reader.
- rfid_project_node.

### 5.1. RFID reader driver

We need to process the information received from the antenna. This is the task of the reader node. You can read the source code on the next file:

File: **\catkin\src\mercury_rfid\mercury_rfid_driver\src\read.cpp**

Each meta-data sample received from the antenna represents one signal received from one tag. The information is processed to be published by a ROS object in the ROS topic “/rfid_tags”. This topic will be used for the rfid_project_node to read the RFID Tag information enviroment and decide search actions, depending on which is the Tag needed.

## 5.2. Application client: actionlib

The ROS node rfid_project_node is the main part of the project. From this node we execute the actions to approach the platform through the desired RFID tag. This node works as the Action Client of the system. The communication via “ROS Action Protocol” is used to send goals to the Application Server, which is represented by the “server” node, as we mentioned before. You can find the source code in the next route:

File: **catkin\src\rfid_project\src\ActionClientRFID.cpp**
The goals sent to the server are specified in the .action file:

| Goal | Description |
|---|---|
| **distance** | Distance in meters which we desire to move linearly the platform. |
| **angle** | Angle in radians we desire turns the platform. Angle between [0, 2*π] radians. |

Moreover, this node reads the meta-data published by the RFID reader node through a subscriber object, using the ROS topic “/rfid_tags”.

The RFID search + approach algorithm were implemented to work in this node. In concrete, we will use the next search + approach algorithms:

- Linear approach. Find the max RSSI signal after scan in 360° the environment and realize an approach movement to the RFID tag.
- Advanced approach. Find the max RSSI signal after scan in 360° the environment and apply some correction factor to the approach action, to compensate the false max RSSI signal detected, scanning in 60º and 120º.

To read the information about the approach made by platform to reach the RFID tag, you can open the files:

- RSSI vs movements: RSSI_movements.txt
- RSSI vs angle: RSSI_angle.txt
- RSSI scan angle: RSSI_scan_angle.txt

# 6. Characterization of the antenna

The main goal of this project is approach the antenna to a concrete RFID tag. It means we need reach a concrete final pose that maximize the RSSI signal received from the RFID tag. From a statistical view, we denote this problem as an estimation problem:

$$\mathrm{P}^* = \underset{\mathrm{P}}{\mathrm{argmax}}\, \mathrm{E}(\mathbf{RSSI}|\mathbf{P} = \mathrm{P}) \qquad \textit{Formula 2}$$

In the *Formula 2*, "P*" represent the estimated optimum pose of the RFID tag, and "P" represents the pose at each moment. It explains how maximizing the RSSI signals mean for a certain pose we can reach the RFID Tag. In each moment the RSSI signal value changes due to factors as the environment, noise and stochasticity intentionally introduced by communication protocols.

Here we talk about a theoretical view and the ideal response we should achieve, but, as you can see in the final experiments, there are many factors which we have to consider. In the case the response would be lineal. In the next image you can see the schema of RF signals of our systems between antenna and RFID Tag.

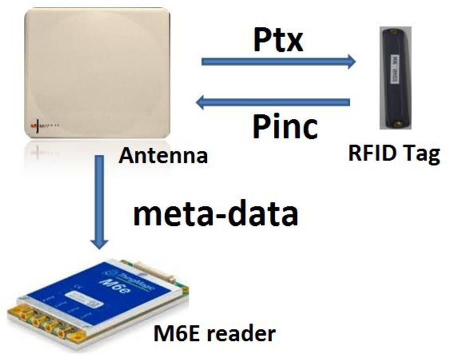



Image 7. RFID reader + antenna + RFID Tag

The *Formula 3* represents the radar equation. The result, $P_{radar}^{inc}$ represents the incident RF power received from the RFID Tag, as a function of the distance (d in meters) and the gain of the antenna and the RFID Tag ( $G_{ant}$, $G_{tag}$).

$$P_{ant}^{inc}[W] \propto G_{tag}^2 \cdot \left(\frac{1}{d}\right)^4 \cdot G_{ant}^2 \qquad \textit{Formula 3}$$

The antenna gain depends on the relative orientation between the antenna and the RFID tag. It's a physical feature of the antennas. As the antenna used is non-isotropic, the orientation is relevant to reach the maximum $G_{ant}$. We can see an example of the radiation pattern for our system in the next images.

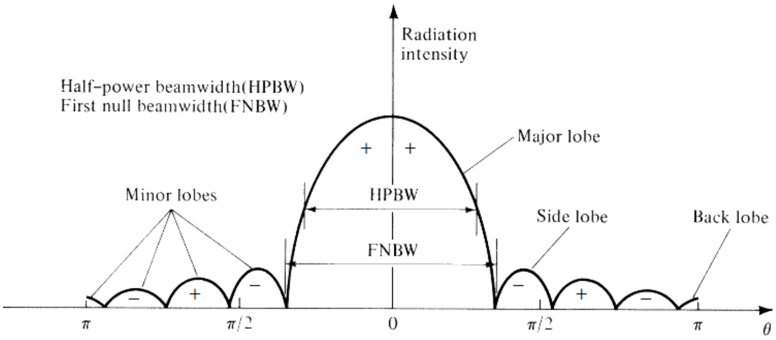



**Image 8. Linear plot of power pattern and its associated lobes and beamwidths.**

Source: Antenna Theory: Analysis Design, Third Edition, by Constantine A. Balanis

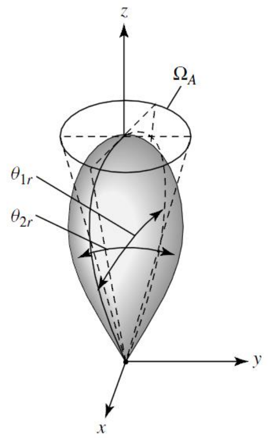



**Image 9. Beam solid angles for radiation patterns.**

Source: Antenna Theory: Analysis Design, Third Edition, by Constantine A. Balanis

As we can see in the radiation pattern of the antenna selected (*Image 3*) and in the last *images 8, 9* for a real case there is not a single point with maximum gain, because the real antennas works with the HPBW value (Half- Power Beamwidth), and in this beam angle range, the power is similar in every points.

Moreover, we can see in the *Image 9* how important is that the beam solid angles $(\theta_{1r}, \theta_{2r})$ in the azimuth and elevation planes were the same or similar in both planes of the radiation pattern. In our case the radiation pattern of our antenna is almost the same in both planes, which allows reuse the work of this project for future projects using the elevator angle.

The concept of the indicator RSSI (Received Signal Strength Indicator) represents physically the$P_{ant}^{inc}$, as we can see in the ***Formula 4***.

$$RSSI \propto P_{ant}^{inc}[dBW] = 10 \cdot \log\left(P_{ant}^{inc}[W]\right) \qquad \textit{Formula 4}$$

On the other hand, we explain how the RSSI depends on the distance and the relative orientation of the antenna. We use both parameters to approach the platform to the RFID Tag.

- RSSI vs Distance. ***Formula 5*** and ***Formula 6*** consider a single ray incident on the antenna, generated by the RFID tag. As we can see, the distance d is inverse to the $P_{ant}^{inc}$. Then, the RSSI is increased when the distance between the antenna and RFID Tag is decreased.

$$P_{ant}^{inc}[W] \propto \left(\frac{1}{d}\right)^4$$ **Formula 5**

$$RSSI \propto P_{ant}^{inc}[dBW] \propto -\log(d)$$ **Formula 6**

In the next image you can see a graphical representation of these formulas, where d is the distance between Antenna - RFID Tag.

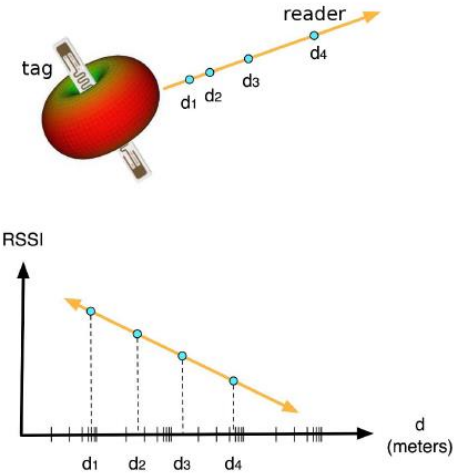



**Image 10. RSSI vs distance**

Source: Finding and Navigating to Household Objects with UHF RFID Tags by Optimizing RF Signal Strengt
Travis Deyle, Matthew S. Reynolds, and Charles C. Kemp

- RSSI vs Bearing angle. As we can see in the ***Formula 7*** and ***Formula 8***, the value of the antenna gain( $G_{ant}$) depends proportionally of the orientation of the antenna. Considering a fixed angle $\theta$ as a z-axis orientation we can describe the value of the $P_{ant}^{inc}$ , as in consequence, the RSSI value. The radiation pattern of the antenna describes this physical magnitude.

$$P_{ant}^{inc}[W] \propto G_{ant}^2(\theta)$$ **Formula 7**

$$RSSI \propto P_{ant}^{inc}[dBW] \propto G_{ant}^2(\theta)[dB]$$ **Formula 8**

From a statistical view point, if the antenna is turned in 360º, there is one point where the RSSI is maximized, and it represents the angle we should turn the platform to achieve the RFID Tag. This is the ideal case.

$$\hat{\theta} = \underset{\theta}{\text{argmax}} \, \mathrm{E}(\mathbf{RSSI}|\boldsymbol{\theta} = \theta)$$ **Formula 9**

In the next image you can see a graphical representation of how affects the orientation between the antenna and RFID tag to maximize the RSSI value.

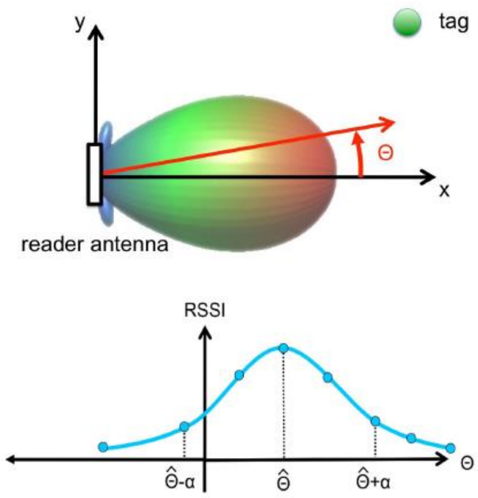



**Image 11. RSSI vs bearing angle**

Source: Finding and Navigating to Household Objects with UHF RFID Tags by Optimizing RF Signal Strengt
Travis Deyle, Matthew S. Reynolds, and Charles C. Kemp

## 7. Experiments

In this section is presented the results of some experiments with the RFID system implemented. The general purpose is to simulate the graphics described in Image 10,11 with de data achieve varying some parameters as:

- **RFID Tags**. Two different tags, as we described before.
- **Distance Antenna –RFID tag.** In meters. Depending on the antenna you can establish higher or lower distance detection.
- **RSSI threshold to reach the RFID tag.** With a value recommended between [-35, -70] dBm. For higher RSSI values, the detection is difficult, because of orientation problems (Polarization Loss), non-ideality of the system, reflections Loss, absorption Loss. If you approach the antenna to a concrete RFID tag, you can observe an RSSI value near from -20dBm, but the best option is leave a margin of safety of -15dBm for this project.
- **Angle resolution.** It's the angle which the antenna will be turned to scan the RFID Tag orientation. To improve the accuracy of the system is better use an angle between [10º, 20º]. Value in radians.
- **Distance resolution.** Is the distance to move forward the robot in each approach movements. It's recommendable use low values to improve the approach of the platform towards the RFID tag. A value between [0'1,0,3] meters is acceptable.

In this case the RFID Tag is in the back side of one chair. The RFID system must approach towards the chair until reach the RSSI threshold.

This is the flow chart of the approach to the RFID Tag:

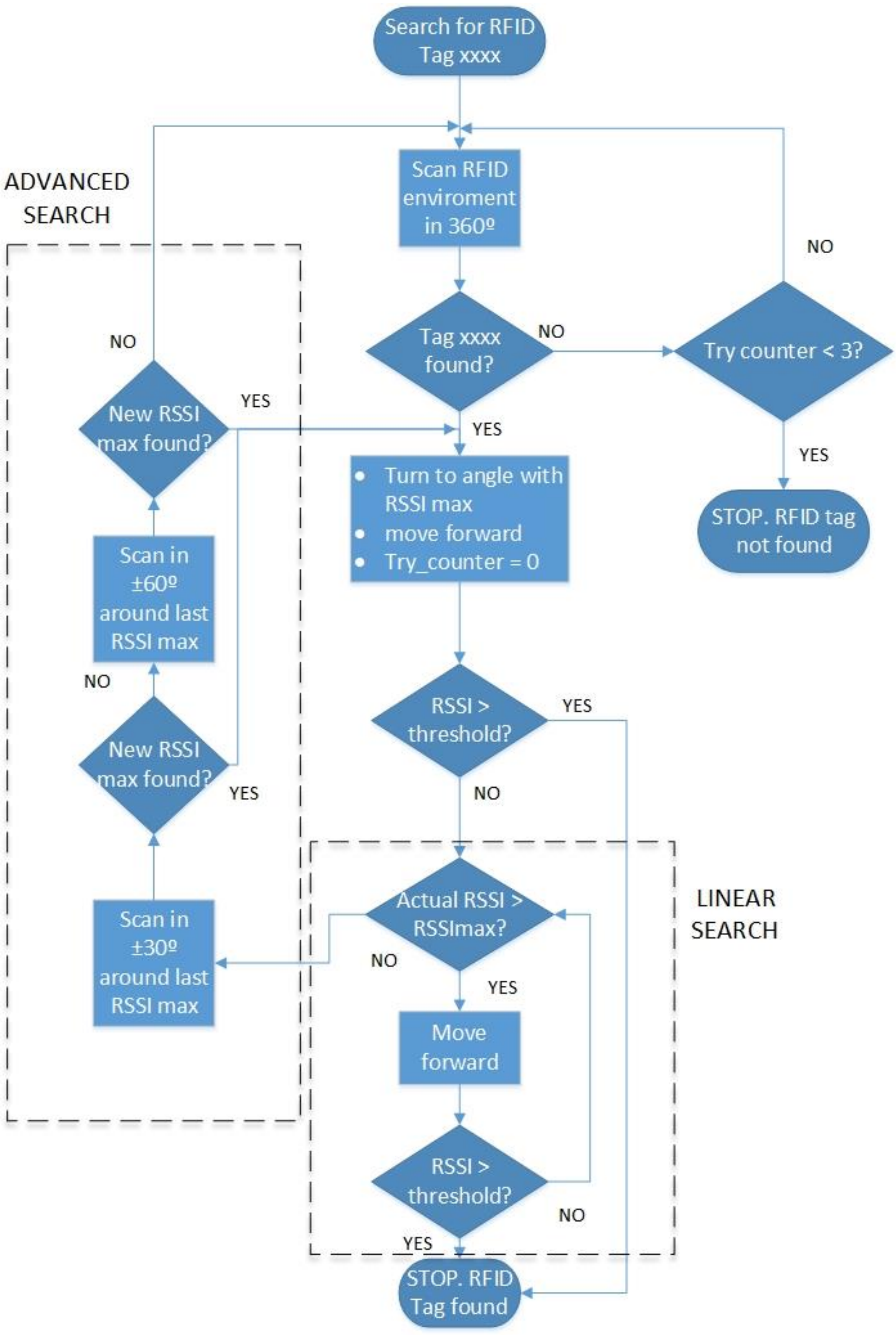



Image 12. Flow chart of the search algorithm

## 7.1. Experiment 1

Parameters:

- Tag: Confidex Survivor
- Distance = 5m
- RSSI Threshold = - 40dBm
- Distance resolution = 0,3m

- Angle resolution = 0,174 rad = π/18 rad ≈ 10º

Results:

- RSSI vs bearing angle

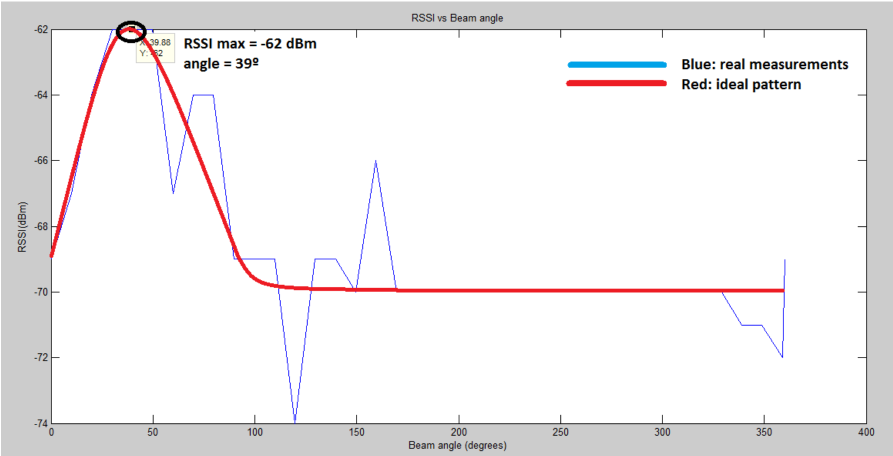



Image 13. RSSI vs bearing angle. Experiment 1

- RSSI vs distance

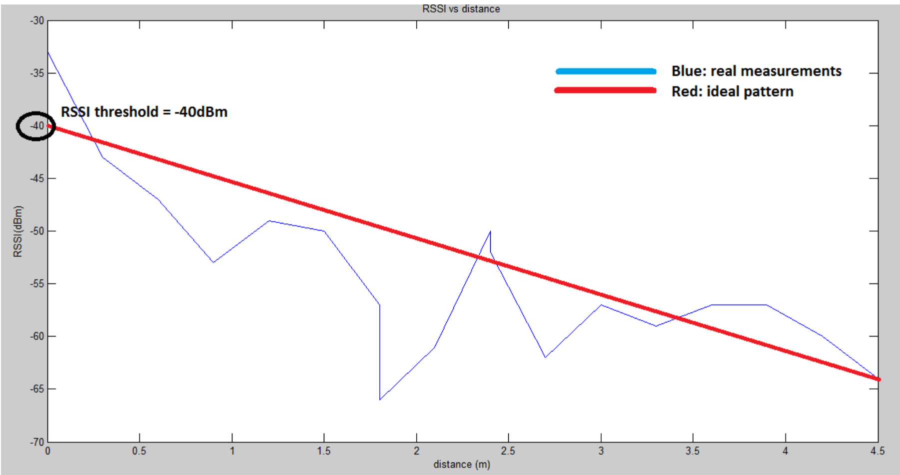



Image 14. RSSI vs distance. Experiment 1

## 7.2. Experiment 2

Parameters:

- Tag: Confidex Survivor
- Distance = 5m
- RSSI Threshold = - 38dBm
- Distance resolution = 0,2m
- Angle resolution = 0,174 rad = π/18 rad ≈ 10º

Results:

- RSSI vs Bearing angle

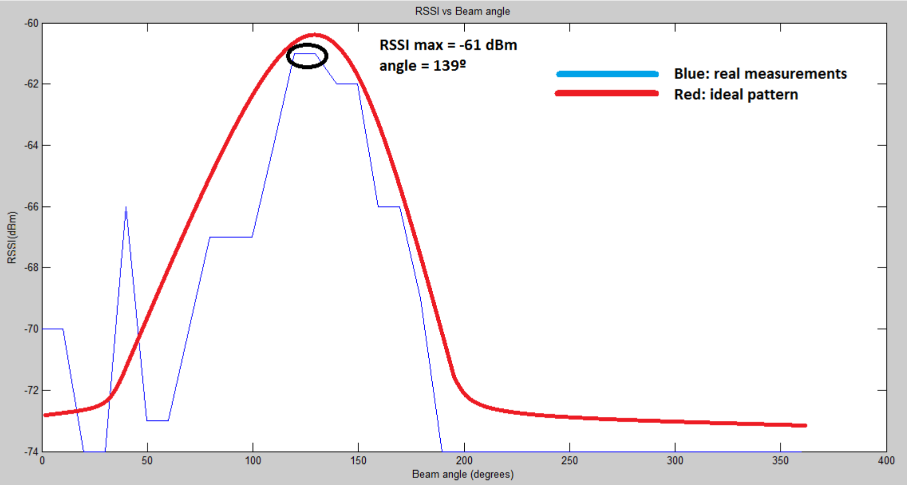



**Image 15. RSSI vs bearing angle. Experiment 2**

- RSSI vs distance

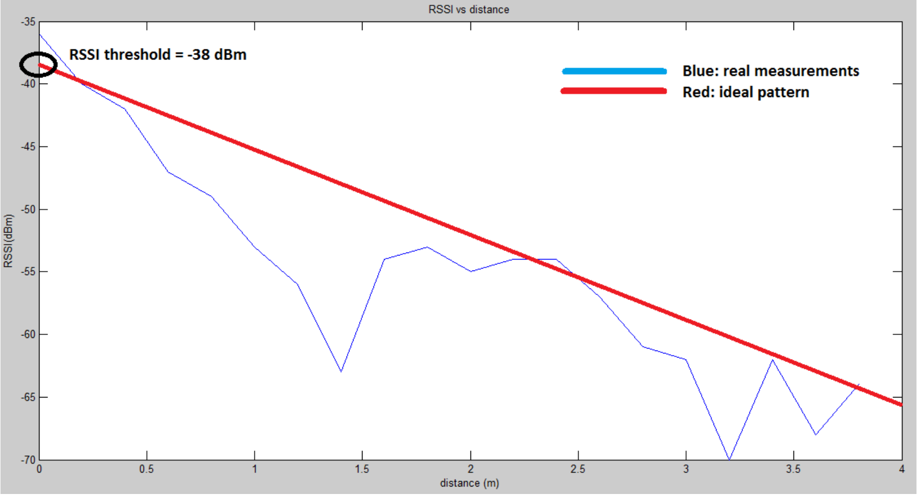



**Image 16. RSSI vs distance. Experiment 2**

## 7.3. Experiment 3

Parameters:

- Tag model: Confidex Carrier Pro
- Distance = 5m
- RSSI Threshold = - 40dBm
- Distance resolution = 0,3m
- Angle resolution = 0,174 rad = π/18 rad ≈ 10º

Results:

- RSSI vs Bearing angle

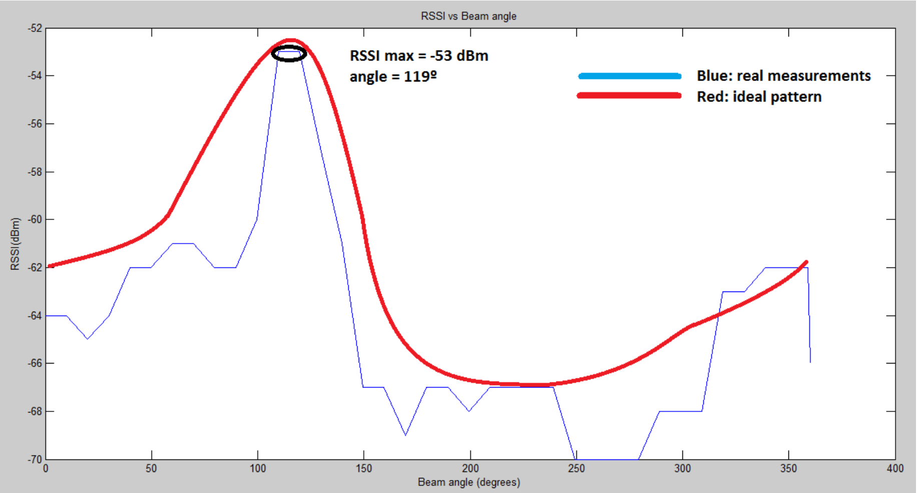



Image 17. RSSI vs bearing angle. Experiment 3

- RSSI vs distance

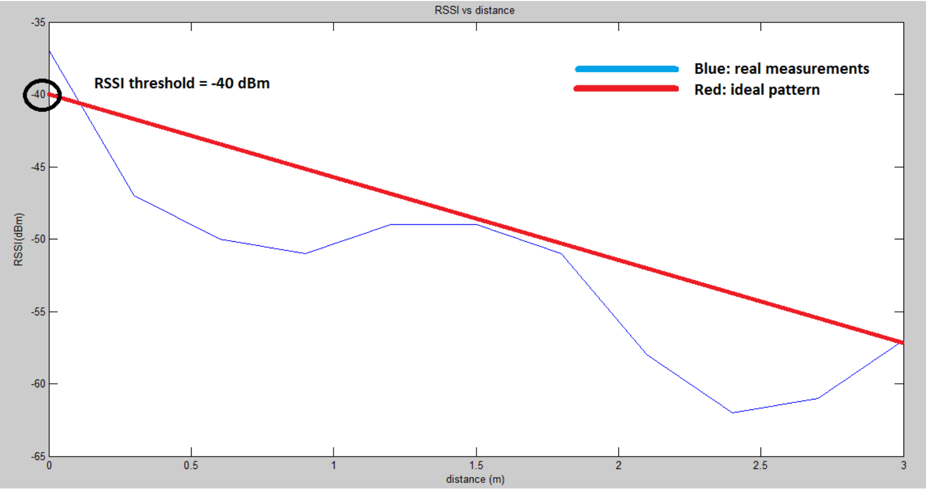



Image 18. RSSI vs distance. Experiment 3

### 7.4. Correcting fading of the signal

This is part of the algorithm of advanced approach. As we know, the RSSI is not constant and vary all the time due to multiple factors. As a result, when the robot reads the signals of the environment in a movement of 360º, sometimes it can make mistakes, as select samples in the wrong direction as a RSSI max and realize a wrong movement. To compensate these types of errors, the system operates as you can see in the next images:

- Scanning in ±30º around the last angle with RSSI max found.

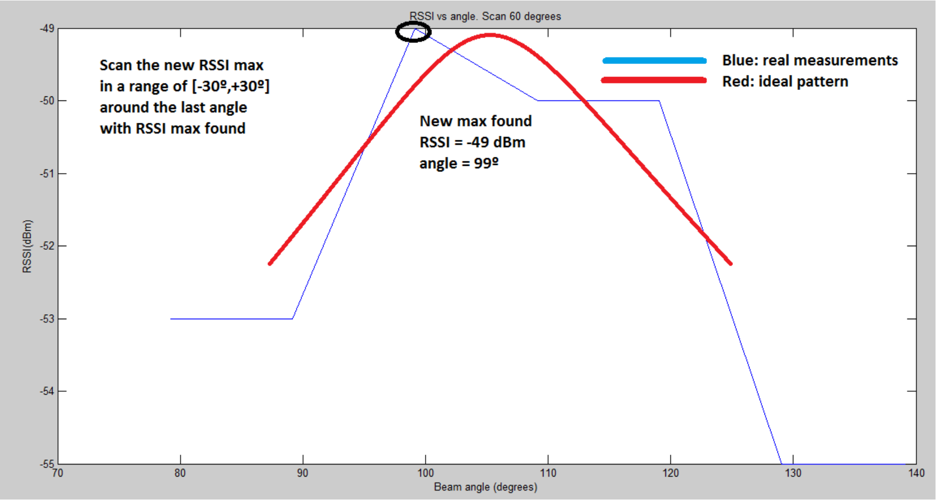



Image 19. RSSI vs angle. Scanning 60º

- Scanning in ±60º around the last angle with RSSI max found.

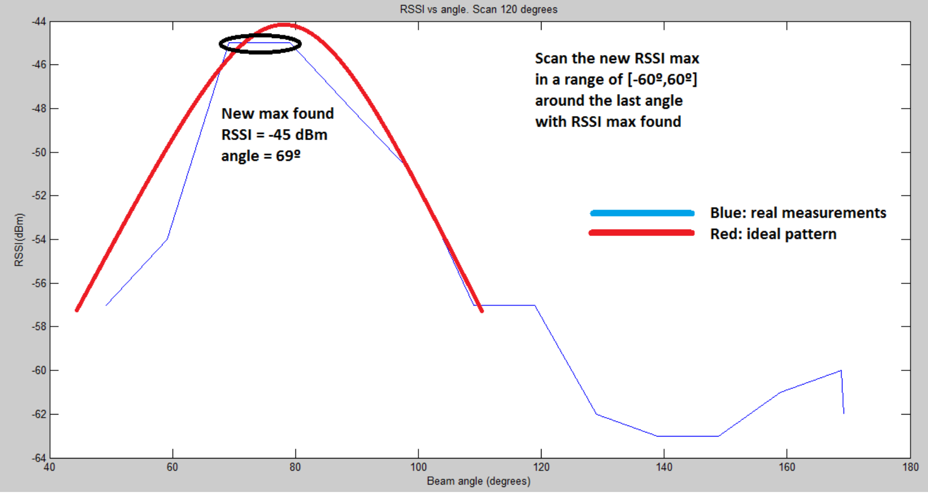



Image 20. RSSI vs angle. Scanning 120º

- Photo with a path done by the robot to reach the RFID tag in the chair after the corrections.

Image 21. Path to reach the RFID tag

## 7.5. Comments about the results

In each one of the experiments we can observe the similitude between the ideal and real results. In each simulation we can see:

- RSSI vs bearing angle.
- RSSI vs distance.

The information used to generate this graphics does not consider physical factors as the friction of the wheels, obstacles, explore the exact distance which we introduce as a parameter, and time to approach the RFID tag, because the only goal of this system is reach the RSSI threshold, which means that the robot was approached the RFID tag desired. These experiments were realized with direct vision between the RFID tag and the robot, because this robot only can turn the antenna around the z-axis.

Phenomena as reflection absorption, interferences and other physical factors can create a fading on the truly RSSI from the RFID tag and generate false RSSI max (false positives) in the wrong orientation (angle). Then, we need to compensate this factor. Using the HPBW (Half Power Beamwidth) of the antenna and three different scan ranges we can create an optimal algorithm to compensate it with only one antenna. These are the scan ranges:

- Scan range 360º. Is the same initial scanning from the RFID system.
- Scan range ±30º. Try to find a new RSSI max value around the last angle found with RSSI max.
- Scan range ±60º. Try to find a new RSSI max value around the last angle found with RSSI max.

This is the scan algorithm. It after realize a linear movement the RSSI actual < RSSI max the advanced search starts. It means that the orientation is not correct:

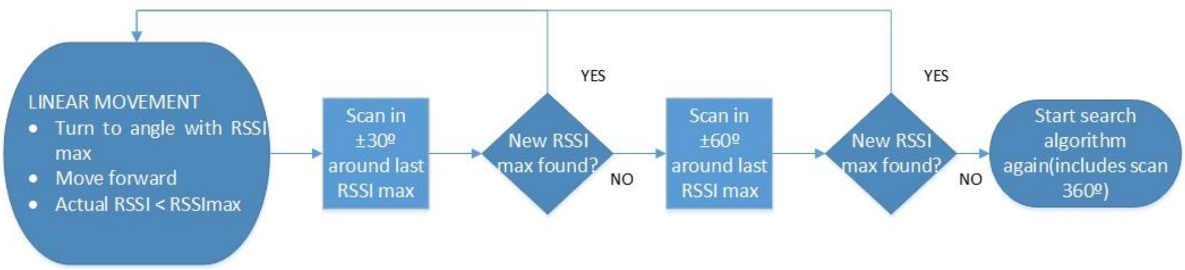
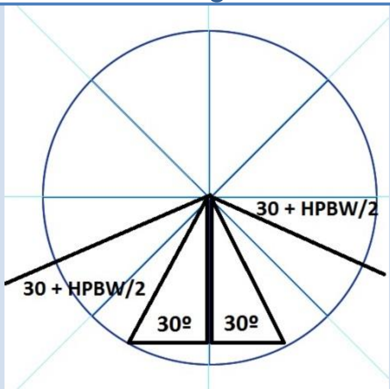
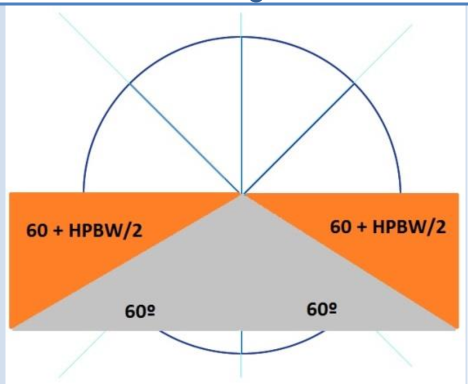



Image 22

| Scan range ±30º | Scan range ±60º |
| --- | --- |
| <br><br>Image 23. Scan 60º | <br><br>Image 24. Scan 120º |

In the last two images we can see how can turn the Robot in function of the scan range (±30º, ± 60º). Moreover, you can read other angles as 30 + HPBW/2 and 60 + HPBW/2. These last angles represents until where can reach the radiation pattern of the antenna. The HPBW has a value of 74º, as you can see at the features of the antenna of this project. Now you can read an example to understand how works the radiation pattern:

If the robot is turned +60º, it means that the major lobe of the radiation pattern of the antenna can reach [60 - HPBW/2, 60 + HPBW/2] = [23º, 97º].

If the robot is turned -60º, it means that the major lobe of the radiation pattern of the antenna can reach [-60 - HPBW/2, -60 + HPBW/2] = [-97º, -23º].

Then, we can cover a range of 97º - (-97º) = 194º. Similar to 180º, with a margin of 14º.

Then we can guarantee cover at least 180º the half of the x-y plane to explore the RSSI max value desired. If the scan movements fail, the algorithm explores in a range of 360º again.

Each one of the results of the experiment is unique and is not possible obtain the same data simulating again with the same parameters because of the constant variation of the RSSI due to the environment.

## 8. Another considerations

The Radio Frequency signal is highly influenced by the environmental factors. That's the principal reason why I decided to work with a corrector algorithm to reach the tag desired. Factors as iron tables, walls, water or other common objects of our world nowadays can be a problem for the RFID tag detection. In concrete, we should be careful with the next factors:

- Environmental factors
  - Materials: all type of metals may enhance or degrade the system performance.
  - Devices that operate at 900 MHz (as cordless phones and WLAN's) can degrade Reader performance.
  - Moving machinery can interfere the Reader performance.
  - Fluorescent lighting fixtures are a source of strong electromagnetic interference.
  - Coaxial from the Reader to antennas should be laid flat and not coiled up. It can be a strong source of electromagnetic radiation.

- Tag considerations
    - Application Surface: Some materials, including metal and moisture, interfere with tag performance.
    - Tag Orientation: the performance is affected by the orientation of the tag in the antenna field. The antenna is circularly polarized, so it reads face-to.
    - Tag Model: Many tag models are available with different performance.

# 9. Future work

- Advanced approach based on the angle which represents the major lobe of the radiation pattern (implemented but not tested). This code is implemented to work for the ROS node rfid_project_node, in the file:

  File: **catkin\src\rfid_project\src\ActionClientRFID.cpp**

  This algorithm reads in 360º all the RFID signals of the environment and decide based on the nearest maximum samples of RSSI vs bearing angle which is the angle to reach the RFID tag. It is an estimation of the orientation of the Tag.

- Approach to the RFID tag based on the phase of the signals. With the phase is possible improve the accurate localization of RFID tags. More information on the documents:
    - Phase Based Spatial Identification of UHF RFID Tags
    - Accurate Localization of RFID Tags Using Phase Difference
- Work with two or more antennas and find the position of the RFID tag by trigonometry. More information about this topic on the document:
- Create a base to move the antenna around another axis with a servo motor. Then, you can work with the vertical major lobe of the radiation pattern of the antenna to find objects in the vertical plane.

# 10. Execute the project

To execute the Project in the computer is necessary make the next actions:

Access to the catkin folder.

**>>cd catkin**

Launch the core of ROS to communicate the nodes

**>> roscore**

Execute node read_node, which control the M6E hardware. The USB port can be ttyACM0 or ttyACM1.

**>> rosrun mercury_rfid_driver read_node tmr:///dev/ttyACM0**

Execute the node which active the pioneer 3DX to realize movements.

**>> roslaunch slamtastic p2os.launch**

Execute the action server noder.

**>> rosrun pioneer_move_server server**

Unlock the motor of the Pioneer 3DX. There are two possible ways.

- Publishing the "state: 1" in the topic /MotorState.

**>> rostopic pub /cmd_motor_state p2os_driver/MotorState "state: 1"**

- **Pressing the button "MOTORS**" of the Pioneer 3DX

Launch the new task. Find a concrete RFID Tag. As example, you can realize the next approach:

- RSSI threshold = -40dBm, distance resolution = 0.2m, angle resolution = 0.174rad (10º), antenna "A".

**>> rosrun rfid_project rfid_project_node 0.174 0.2 "A", "-40"**

- RSSI threshold = -38dBm, distance resolution = 0.3m, angle resolution = 0.2617 rad (15º), antenna "C".

**>> rosrun rfid_project rfid_project_node 0.2617 0.3 "C", "-38"**

In case of need to move the Pioneer 3DX, you can use another node to control it by keyboard. Don't forget stop the node of the keyboard after move the Pioneer to the desired position.

Execute the node which active the pioneer 3DX to realize movements.
**>> roslaunch slamtastic p2os.launch**

Launch the keyboard

**>> roslaunch p2os_launch teleop_keyboard.launch**

# 11. Conclusions

As we said before, the mean goal of this project was to build a RFID system detection which reaches RFID tags using a mobile platform. We demonstrate how the theoretical graphs of localization and approaching movements towards RFID Tags works in the real world. To complete this project it was necessary to develop a system which combines ROS and different hardware components, such as a computer, a mobile platform, RFID Reader, RF antennas and RFID tags. As important part for RFID projects, we can say that factors as radiation pattern, RSSI threshold, resolution of the movements and the explained considerations about work with RFID systems will be definitely decisive in the future. Moreover, the indications for the future can help to future students to follow up to work with of projects of the same topic.

To reach this goal I had to learn how works ROS from the beginning to develop robotic systems, how works the RFID systems and simulate real cases of telecommunication systems with Radiofrequency antennas. It has been a very enriching project and I could use all the skills acquired during my studies as a Telecommunication Engineer.

## 12. References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