

DEVELOPMENT OF LOCAL POSITIONING SYSTEM FOR A PIPE-LESS PLANT

Automation & Robotics
Group Project SS18

Group Members:

Abdulrahman Abouelkhair(4511328)
Medhini Rajagopal Balamurugan(4511328)
Stefan Rottstegge(191455)
Stephan Vette(198907)

Supervisors:

Afaq Ahmad
Marina Rantanen-Mod  er

Abstract

Summary. Note that the abstract heading is unnumbered, it should remain so. To remove heading numbering use:

```
\section*{}
```

Contents

1	Introduction	5
2	Pipeless Plant	6
2.1	Existing setup	6
2.2	Problems with the Existing Setup	6
3	Selection Process	7
3.1	Triangulation	7
3.2	Pattern Recognition	11
3.3	RFIS	12
3.4	Map-Based Localization	15
4	Theoretical Background	16
4.1	Radio Frequency Identification (Abdul)	16
4.2	Trilateration	16
4.3	17
5	Hardware	18
5.1	RFID reader and antenna	18
5.2	RFID tag ?	19
5.3	Wifi modul (Abdul ?)	19
5.4	HW setup?!? (Abdul ?)	19
6	Simulation	20
6.1	Emulator	20
6.2	RSSI Measurements with real hardware	21
6.3	Simulation with emulated data	22
6.4	Results	22
7	Implementation	23
7.1	Communication (Abdul and/or Stefan)	23
7.2	Initialization procedure (Stephan and Stefan)	23
7.2.1	Recording and filtering data (Stefan)	27
7.2.2	Analysing data (Stefan)	27
7.2.3	Selection of correct distance related to RSSI	28
7.2.4	Estimation of initial position and orientation	30
7.3	Test setup	31
7.4	Results	33
8	Conclusion	35
9	Future Work	36
9.1	Hardware	36
9.2	Software	36
10	References	37
11	Appendixes	38
11.1	Appendix A: Emulator RFID data (Matlab)	38

List of Figures

1	Passive Triangulation set-up with two cameras	7
2	Active Triangulation	8
3	Impmentation of passive triangulation	9
4	Passive RFID System	12
5	Active RFID System	12
6	Overview Trilateration	16
7	RFID reader KTS Systeme RFIDM1356-001	18
8	RFID Antenna KTS Systeme PCBA1356.8	19
9	Relation between RSSI and distance antenna to tag	21
10	Different possible positions for one antenna position	23
11	Possible hazards/obstacles	24
12	Flow Chart: Initial Procedure 360 degree turn	25
13	Test environment in GUI	25
14	Flow Chart: Analizing Measurment Points	28
15	Flow Chart: Selection of correct distance and most proper IDs	29
16	Computing the center of the robot	31
17	Orientation of robot in absolute angle	31
18	testing setup for initialization procedure	32
19	Estimated position in x-direction	33
20	Estimated position in y-direction	34
21	Estimated orientation	34

List of Tables

1	Positive and Negative Points of Passive Triangulation	10
2	Positive and Negative Points of Active Triangulation	10
3	Overview RFID systems	13
4	Pro and cons of active RFID system	14
5	Pro and cons passive RFID system	14
6	Relation between RSSI and distance antenna to tag (data)	21
7	Results Simulation	22
8	Filled Array after 360 degree turn	26
9	String preperation	27
10	Possible shapes of pattern	29
11	Positions of the IDs in the test setup	32

1 Introduction

Add your name to the file name

2 Pipeless Plant

2.1 Existing setup

2.2 Problems with the Existing Setup

..

zb

- Fish eye
- Sunlight..

3 Selection Process

About the 4 techniques..

3.1 Triangulation¹

Summary

Since our plant has a specified size in which the location of multiple objects has to be performed the method of Triangulation is one promising technic in which research was made. Triangulation was already a common principle of measurement in the 18th century and it's divided between active and passive triangulation. Passive triangulation is a geometrical method based on two measurement stations which positions are known exactly. At these two measurement points angles of the desired point in space are measured to compute the localization in the specified coordinate system (x, y, z) with trigonometrical formulas. With respect to the two measurement points which were already used in the 18th century nowadays two cameras are installed to perform a geographical method of 3D object-data estimation fig. 1.

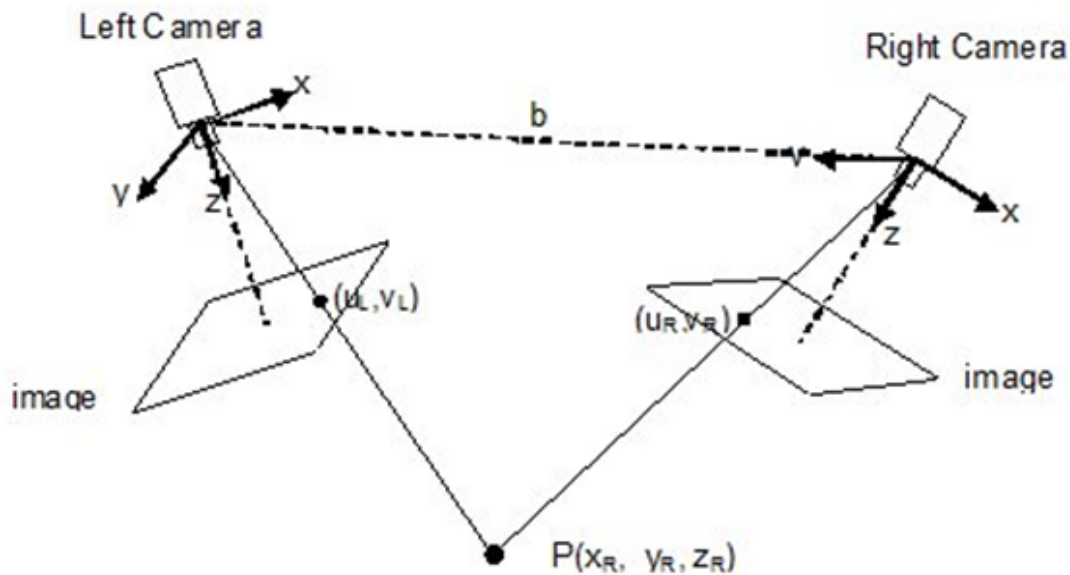


Figure 1: Passive Triangulation set-up with two cameras

To Solve the problem, it is necessary to know the parameters of the left and the right camera visualized in the figure. In theory the triangulation is trivial, since each and every point of the images of the respective cameras maps to a line in 3D space. If a pair of corresponding points, in the case of the pipes less plant it would be an AGV, is found the projection of a point x in

¹Stefan

3D space can be computed. Active triangulation in comparison to passive triangulation needs one camera and at least one source of structured light (e.g. Laser). As the passive way here the geometrical location and orientation of the camera and light source is space need to be known. Two possible set-ups with either a laser point and a stripe as structured light are shown in fig. 2.

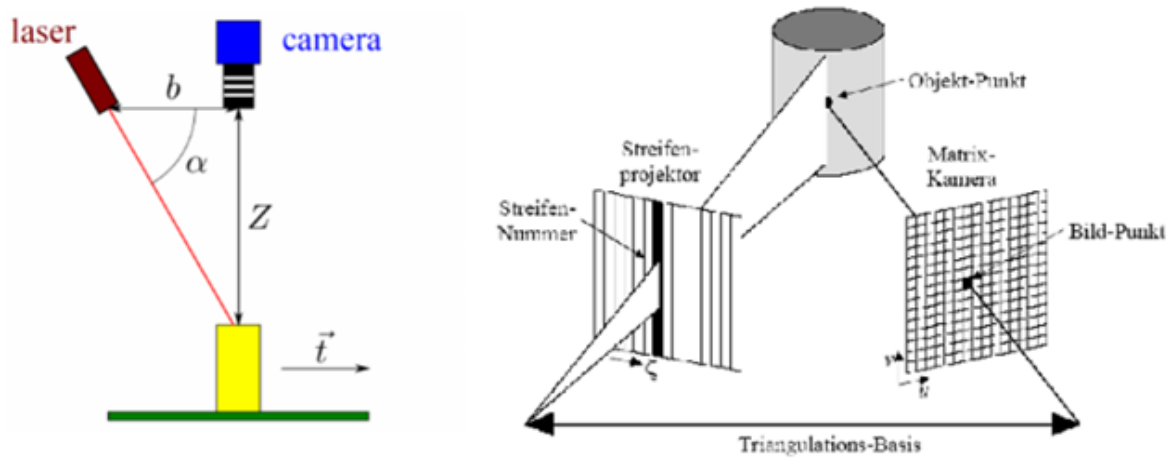


Figure 2: Active Triangulation

To solve the active triangulation problem, the structured light has to point on object which location is desired to estimate, in the case of the pipe less plant it would be the AGV. If this point is found on the 2D image of the camera, a triangulation with basic trigonometrical formulas which are using the properties and parameters of the camera and light source can be performed and the position of the AGV is estimated.

Implementation

One possible way to implement a solution for the passive triangulation is to attach 2 high resolution cameras with USB 3.0 for a fast data transmitting on two edges of the plant being not on each others opposite side as shown in fig. 3.

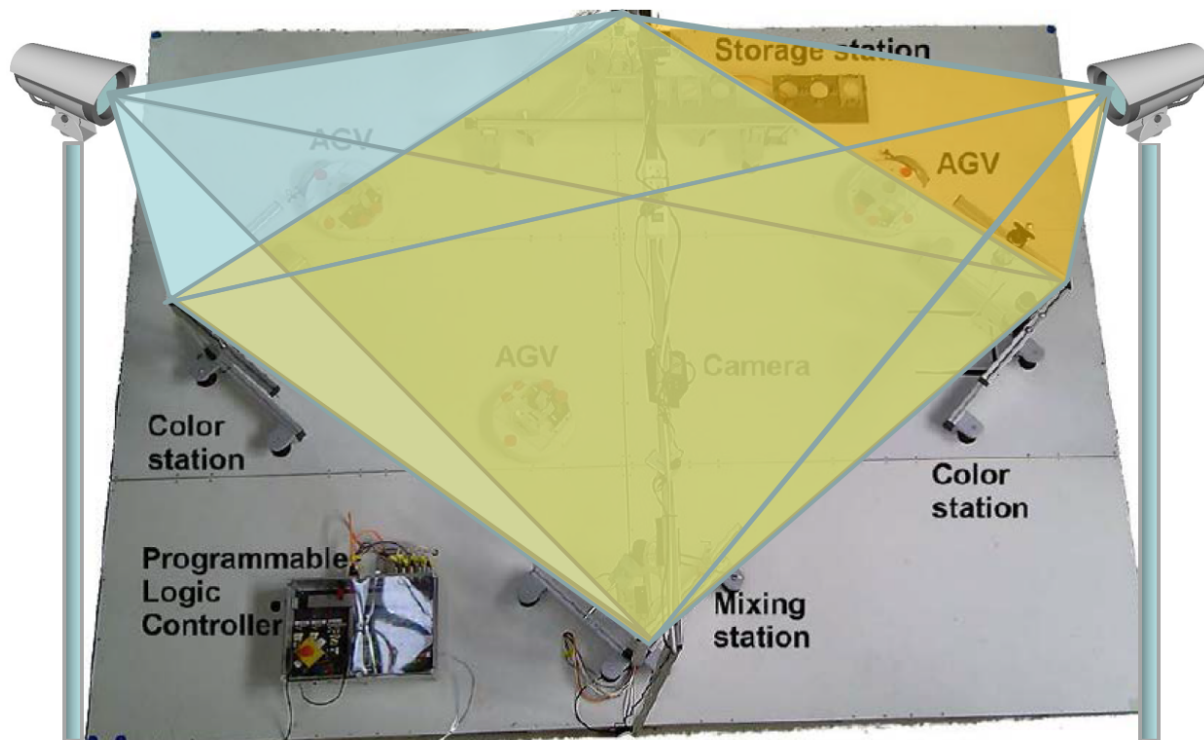


Figure 3: Impmentation of passive triangulation

The left and right camera are sequentially taking pictures which are transmitted to the plants computer where the image processing takes place.

Pro and con

Based on the made research, two tables with advantages and disadvantages of the two RFID systems are created.

Passive Triangulation	
Positive	Negative
Upgrade to USB 3.0 for faster data transmitting possible	Light dependent
Upgrade to a camera with higher resolution to reduce measurement error possible	New concept of orientation may be needed
No Fish-Eye-Lense problem	Limited range of observation
Low cost	

Table 1: Positive and Negative Points of Passive Triangulation

Active Triangulation	
Positive	Negative
Upgrade to USB 3.0 for faster data transmitting possible	New unknown laser technology is needed
Upgrade to a camera with higher resolution to reduce measurement error possible	High costs for several Laser (one per AGV)
Easy detection of laser points on camera image	Laser needs to move while AGVs are moving
	Limited range of observation
	Light dependent

Table 2: Positive and Negative Points of Active Triangulation

3.2 Pattern Recognition

Summary

Implementation

Pro and con

3.3 RFID²

Summary

One of the possible solutions to solve the challenging problem of indoor localization is the use of the Radio-frequency Identification (RFID) technology. The mainly areas of this technology is indeed still supply chains, transport, manufacturing, personnel access, animal tagging, toll collection [reference 4](#), but has also become popular in localizing objects and persons. Where in the main applications only the identification has to be realized, also the strength of the signals is important to estimate the position of a certain object.

The main idea of those systems is that a reader detects a tag and reads its information. The technology can be divided into three main types: passive, semi-passive and active systems. A passive system, like it is been shown in fig. 4, consists of a reader, which is connected to an antenna and a computer and a passive tag.

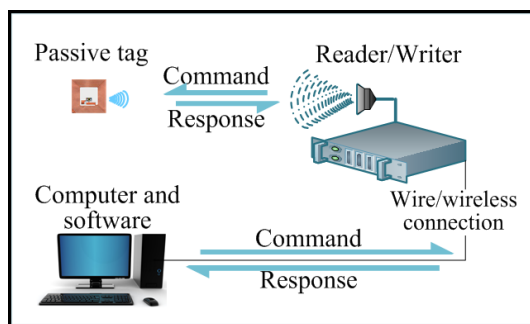


Figure 4: Passive RFID System

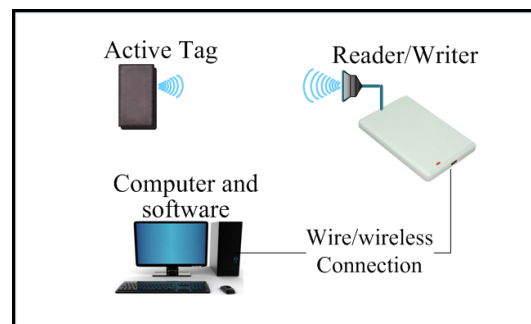


Figure 5: Active RFID System

The system is called passive, because the power supply will be realized by the radio signal of the reader. In case where the tag is in the reading range of the reader, the tags gets enough power to send predefined information (for example ID) back. The active system (see fig.5) in comparison has an active tag which has an own power supply. The semi-passive tag has a battery build in that the the tag has more power to communicate, but is not used to generate radio frequency signals.

Another classification of RFID systems is the frequency of the radio waves. It can reach from 0.135 MHz (Low Frequency) to 5875 MHz (Super High Frequency). The table 3 gives an overview about the systems related to reading ranges, reading rates and the ability to read near metal or water.

It can be seen that the passive systems in general have a smaller reading range then the active systems and has a bigger data rate. But it has also to be take into account, that passive tags a way cheaper then active tags.

²Stephan

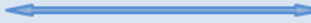

	LF	HF	UHF	SHF
FR (MHz)	< 0.135	3~28	433-435, 860-930	2400~2454 5725~5875
RR(P)	≤ 0.5 m	≤ 3 m	≤ 10 m	≤ 6 m
RR(A)	≤ 40 m	300 m	≤ 1 km	≤ 300 m
TRR	Slower	 Faster		
ARMW	Better	 Worse		
FR: Frequency Range RRP: Typical Reading Range of Passive Tags RRA: Typical Reading Range of Active Tags TRR: Tag Reading Rate ARMW: Ability to Read near Metal or Water				

Table 3: Overview RFID systems

Implementation

There are mainly two different ways to realize a localization system of the AGVs in the pipeless plant. Based on the fact that the plant has a size of 3 by 4 meter, the tracking can be carried out by passive system in which a couple of passive tags on the floor can be used as landmarks. In this case the reader plus the antenna would be placed on the AGV and localize with the help of the detected tags. The other systems consists of three or four reader in each corner of the plant and an active tag on each AGV.

Pro and con

Based on the made research, two tables with advantages and disadvantages of the two RFID systems are created.

Active RFID system	
Pro	Con
Light independent	Prototype more expansive (3 reader + active tags)
Space unlimited	Datarate is related to the amount of detected tags a the same time
Localization only has to be realized in a bigger area - medium accuracy	Anticollision need, cause more AGVs are used at the same time
Wired communication between reader and computer possible	Signal strength can be influenced by environment (metal or water)
Simple algorithm (Trilateration)	

Table 4: Pro and cons of active RFID system

Passive RFID system	
Pro	Con
Light independent	Communication between AGV and computer has to be realized
Space unlimited	Data rate is related to the amount of detected tags a the same time
Localization only has to be realized between four tags (small area) - high accuracy	Anticollision need, cause more tags are detected at the same time
Simple algorithm (Trilateration)	
Prototype cheap (1 reader + passive tags)	

Table 5: Pro and cons passive RFID system

3.4 Map-Based Localization

Summary

Implementation

Pro and con

..

4 Theoretical Background

4.1 Radio Frequency Identification (Abdul)

4.2 Trilateration³

Trilateration is a method to compute the intersection point of three circles/spheres. For this, it is necessary to know the three center of the circles/spheres plus their corresponding radii. The basic idea to estimate the intersection point is to use the mathematical description of a sphere:

$$r^2 = (x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 \quad (1)$$

where $(P_n = (x_n, y_n, z_n))$ is the center of the sphere [1]. A few assumption can be made to simplify (1) for the 2D indoor localization on a floor. First of all, the z-component of all spheres can be neglected. Another assumption is that we define the origin of the first circle as the center of the coordinate system, the second along the x-axis with an distance (d) and the third shifted in x- (i) and y-direction (j), which is illustrated in following fig.

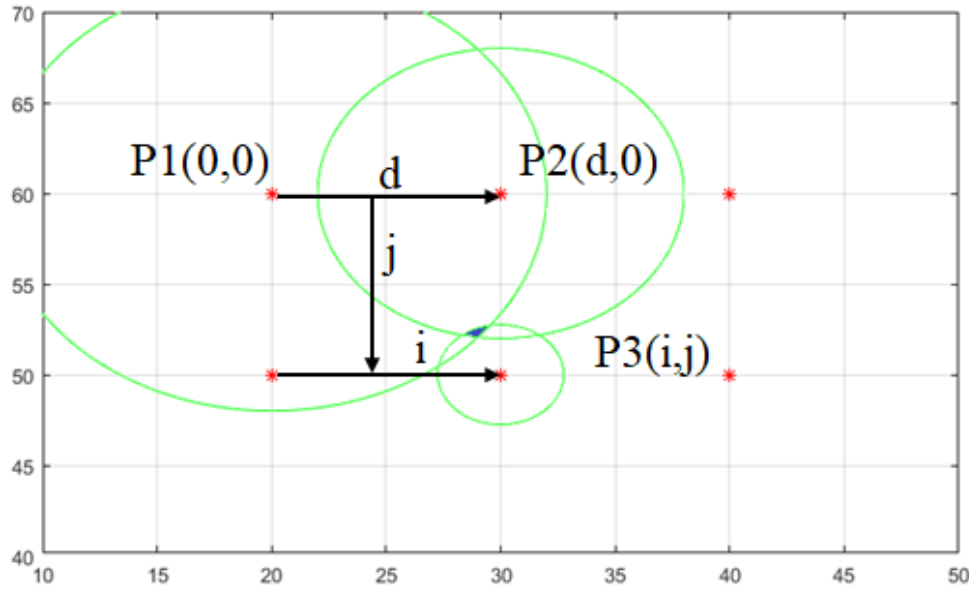


Figure 6: Overview Trilateration

With known positions of the center of the circles d, i and j can be computed in the following

³Stephan

way[1]:

$$d = |P_2 - P_1| \quad (2)$$

$$e_x = \frac{1}{d}(P_2 - P_1) \quad (3)$$

$$a_x = P_3 - P_1 \quad (4)$$

$$i = e_x \cdot a_x \quad (5)$$

$$a_y = (P_3 - P_1) - i * e_x \quad (6)$$

$$e_y = \frac{a_y}{|a_y|} \quad (7)$$

$$j = e_y \cdot a_x \quad (8)$$

It has to be notice that P_1, P_2 and P_3 are 2D vectors, which represents the x- and y-coordinate of the points.

After knowing these values, the relative distance from the origin of the coordinate system can be computed with the help of (1) and the center of the circles $P_1(0,0)$, $P_2(0,d)$ and $P_3(i,j)$ as follows:

$$x_t = \frac{r_1^2 - r_2^2 + d^2}{2 * d} \quad (9)$$

$$y_t = \frac{r_1^2 - r_3^2 + i^2 + j^2}{2 * j} - i * \left(\frac{x_t}{j} \right) \quad (10)$$

The absolute position of the intersection point is computed in following way:

$$P = P_1 + e_x * x_t + e_y * y_t \quad (11)$$

It can be seen, that those equations are using the first two points plus radii to estimate the x-coordinate and first and third point plus the estimated x-coordinate to estimate the y-coordinate.

4.3 ...

5 Hardware⁴

5.1 RFID reader and antenna⁵

The RFID reader from KTS Systeme (see fig.7) is a HF Modul (frequency around 13.56 MHz). It contains a full-fledged microcontroller with a high-performance RFID transceiver IC. It has a 1.27 mm pitch pin-headers for THT mounting. The connection to an external antenna can be realized via a Single ended 50 Ω connection or via Pin Header U.FL. jack, which was used in this project.

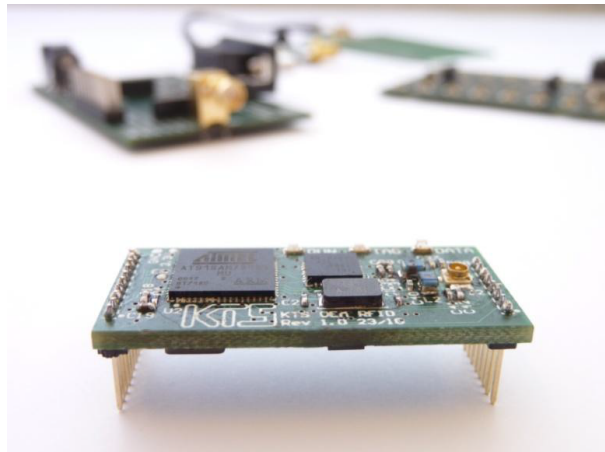


Figure 7: RFID reader KTS Systeme RFIDM1356-001

The communication to other devices is realized via a UART compatible serial interface via pin 6 (RX) and 7 (TX). The power supply is a 5 V DC connection via pin 1 (VCC) and pin 10 (GND). The reader is standardized to ISO 15693 and ISO14443A/B and has the overall dimensions 36 x 16 x 4 mm [LxWxH][2].

The reader has three LEDs:

- Green: Run - Lights when reader receives power
- Yellow: Tag - Lights when a tag is detected
- Red: Data - Lights when data transfer to or from a tag

To configure the reader, KTS Systeme provides also a software (Tag2Image) for free. The reader was configured to scan the environment in an automatic anti collision mode (AT+Scan=AC,RSSI). Anti collision means that multiple tags can be detected at the same time and is highly important in this project. The output of the scan is a continuous information of the Identification (ID) and the Received Signal Strength Indicator (RSSI) of the detected tags. For example means: SCAN:+UID=E00402000018313E,+RSSI=7/6 that the tag with

⁴Stephan and Abdul

⁵Stephan

the ID (in hex) E00402000018313E was detected with a RSSI of 7/6. For the RSSI is the first number the value for the main and the second for the auxiliary receiver channel. In this project only the first number of the RSSI was used. The RSSI is an integer value from 0...7 and gives an information about the distance between the antenna and the detected tag. 0 stands for the maximum reading range which was mentioned to be around 15 cm. A detailed relation was figured out experimental during the project and will be explained later in this report. An AT Command Reference Guide is also available on <http://rfid.kts-systeme.de/downloads/>.

The antenna (fig. 8) is a HF PCB Antenne (PCBA1356_8) also from the company KTS Systeme. It has a dimension of 80 x 80 mm. The connection to the reader is realized by a SMA jack and has a self-impedance of 50Ω . The antenna is designed for passive tags in a frequency range around 13.56 MHz and has a maximum power of 1W.



Figure 8: RFID Antenna KTS Systeme PCBA1356_8

The antenna and the reader are connected with a SMA to U.FL. adapter cable.

5.2 RFID tag ?

5.3 Wifi modul (Abdul ?)

5.4 HW setup?!? (Abdul ?)

6 Simulation⁶

The simulation was carried out to answer important design questions before the real implementation phase. Another idea was also to create artificial RFID reader data to test and simulate the algorithm, which will be explained in chapter 7.

To answer the design questions, the simulation has these parameter (Appendix 11.1 Line 1-50):

- the size of the simulation space
- distance between the tags
- distance between the first/last row/column of tags and the boarder of the simulation space
- diameter of the robot
- position of the antenna related to the origin of the robot
- the relation between RSSI and the distance antenna and tag
- initial start position and orientation
- difference between the measurement points of the initialization procedure
- optional: cycle time and speed of the robot (for another procedure)
- logging parameter (look of the logged text file)

Foregone tests lead to a distance between the tags of 10 cm. This was founded on the fact that in this case at least 4 tags are detected at the same time (maximum reading range of 14 cm). In this case are around 121 tags needed for every square meter, which turned out to be realistic number for a small plant size.

6.1 Emulator

To create artificial RFID reader data, the emulator was able to write all detected tags together with information about the measuring point into a text file. During the initialization procedure, which was the main focus in this project, the robot turns around 360° and makes measurements every 45°.

The emulator computed at each measurement point the distance from the center of the antenna to the neighbouring tags. If a tag was closer than the maximal reading distance, the emulator wrote the detected ID of the tag together with its RSSI into the text file.

The RSSI is, as explained earlier, an integer value from 0...7. 0 defines in this case a distance from 14 to around 10 cm from the antenna to the tag. In the first version of the emulator the RSSI was on the basis of the information from a paper [3] and mentioned a consistent increasing of the RSSI while the distance between the tags and the antenna gets smaller.

During own measurements has been found out that this relation was inconsistent. Therefore the second version of the emulator was updated and creates more realistic data.

⁶Stephan

6.2 RSSI Measurements with real hardware

The relation of the RSSI is not just related to the distance between the antenna and the tag. It also depends on the orientation of the plain of both components. The tests with the real hardware was performed in a setup where the tags was placed on a floor and the antenna was parallel to the floor at a hight of 1.5 cm. The reason for this was the fact that the antenna should be placed directly under the robot. Tbl. 6 and fig. 9 present the results of the measurements.

RSSI (Received Signal Strength Indicator)	0/0	1/1	2/2	3/3	4/4	5/5	6/6	7/7
Maximal distance antenna to tag [cm]	14	9.8	9	8	7	6	3.5	2.8
Middle distance antenna to tag [cm]	5	5.1	5.3	5.5	5.8	4	-	-
Minimal distance antenna to tag [cm]	-	4.7	4.5	4.3	4.2	-	-	-

Table 6: Relation between RSSI and distance antenna to tag (data)

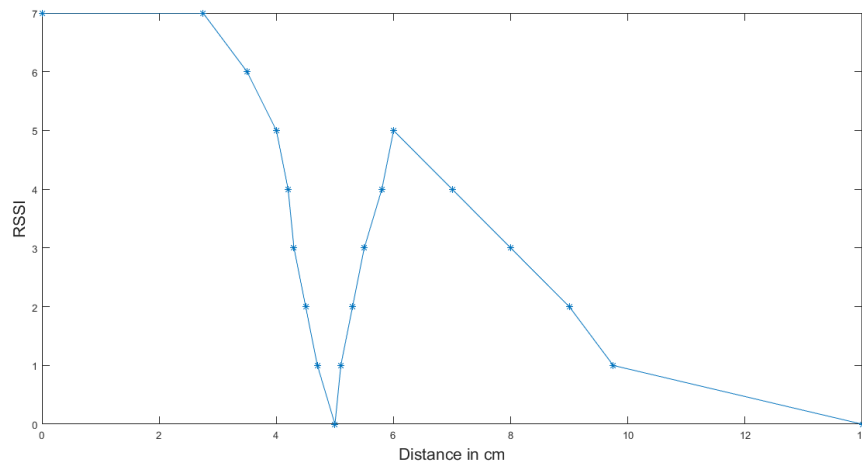


Figure 9: Relation between RSSI and distance antenna to tag

It can be seen that there exists a blind spot at a distance of 5 cm where the RSSI drops to 0. The consequence is now that it is not trivial to build up a relation from the RSSI back to the correct distance.

6.3 Simulation with emulated data

The idea of the final implementation is to estimate the initial position and orientation of the robot. A first version of an algorithm to solve this problem was created in matlab. The first part of these algorithm was the emulator which simulated the 360° turn and recorded the tag information. The second part was the solver which is also explained deeper in the chapter 7.

The first version of the solver which estimates the initial position and orientation based on the consistent RSSI data was quickly build up. After observing an inconsistent behaviour of the RSSI the simulation as well as the solver were updated.

6.4 Results

The application of the emulated data on the solver indicates the following results:

	Avg. accuracy position (x-, & y-direction) [mm]	Avg. Accuracy orientation [°]
Data mentioned in paper	2	<1
Own recorded data (blind spot)	10	20

Table 7: Results Simulation

As can be seen from tbl. 7, there is a sufficient good match between the estimated position and orientation of the robot for the consistent RSSI data. On the other hand results the inconsistent RSSI data in significant differences in the estimation of the position and orientation of the robot. The reason for this is the higher complexity of the algorithm to first estimate the correct distances related to RSSI values and then start to estimate the position based on those distances.

A small error in the estimation of the position of the antenna at the first measurement point leads also to a big error in the computed orientation of the robot.

7 Implementation

7.1 Communication (Abdul and/or Stefan)

7.2 Initialization procedure (Stephan and Stefan)

In the start-up phase, before running the pipe less plant with its AGVs the correct position and orientation of each and every vehicle is not known . Even though the controller is able to compute the position of the AGVs antenna in each point of time ($t=0$ included), several AGV positions in the plants operation space can be described by one single antenna position. In fig. 10 four possible AGV positions with one common antenna position are pointed out.

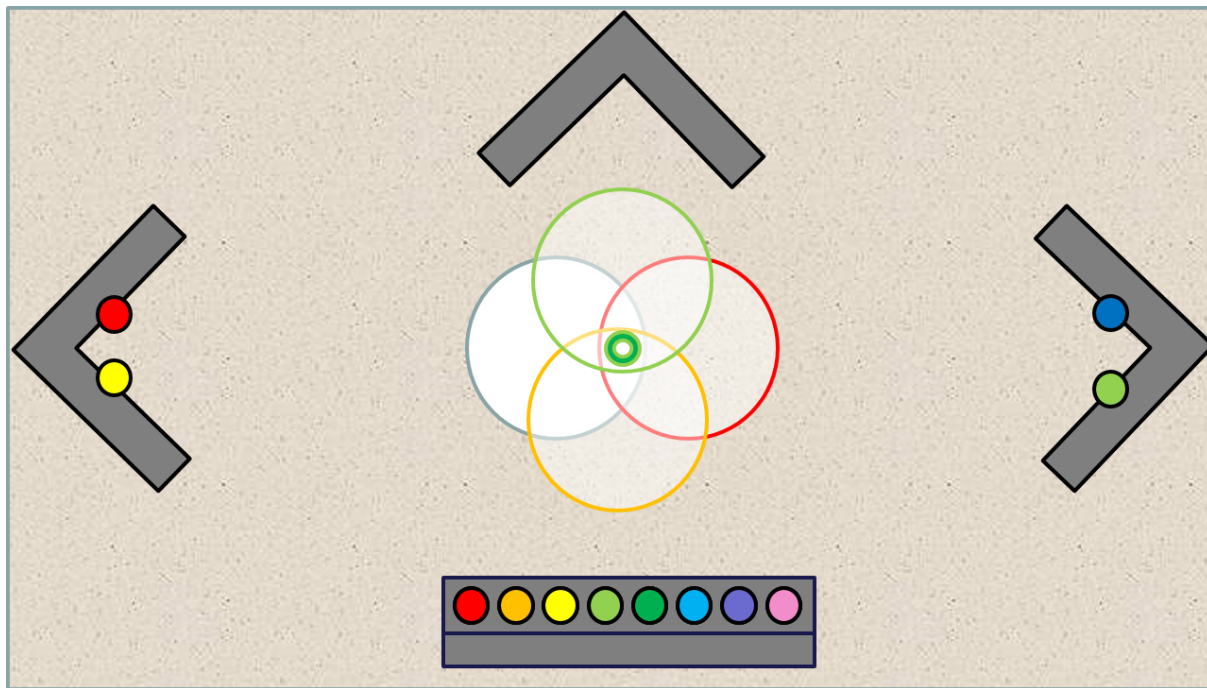


Figure 10: Different possible positions for one antenna position

Since this information is crucial for the plant, a procedure was set up to determine the starting positions of each and every AGV at time $t=0$. According to the fact, that the position and orientation of a single AGV is unknown at time $t=0$, some potential are taken into account. For instance, the plant contains several obstacles like the mixing stations, vessel storage, charging stations, plant edges and even other vehicles as represented in fig. 11.

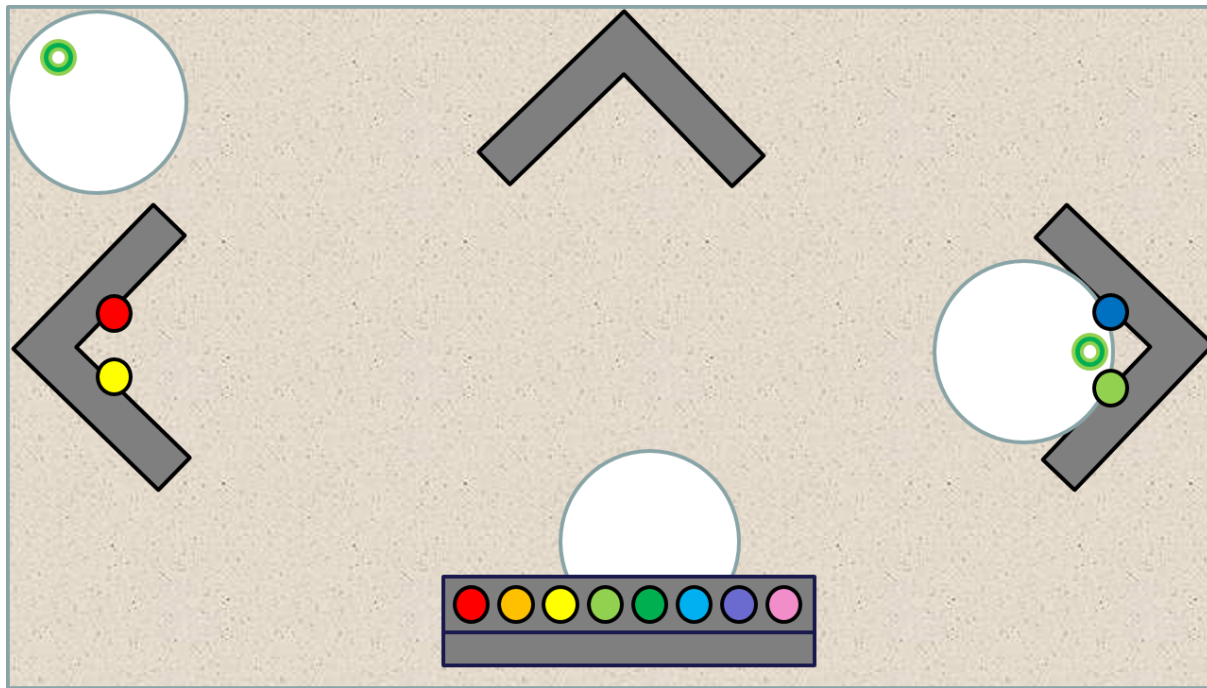


Figure 11: Possible hazards/obstacles

With respect to these potential hazards collisions during the initialization procedure have to be avoided. This is realized by taking advantage out of the AGVs ability to turn around its own axis without a change of the AGVs center point x and y position. This ability of the AGV leads the way that each and every robot performs an initialization turn of 360° in which measurements are taken every 45° to estimate the specific positions and orientations of the AGVs. Furthermore, the decision process of the antenna position under the robot is dominated by the fact that the position of the center point does not change during a turn around its own axis. During the 360° turn the intervals in which the measurements have to be taken need to be known by the controller. The determination of these measurement points can be computed in two different ways. On the one hand the encoders of the AGV-wheels can be used to estimate the performed rotation. On the other hand, the time of a complete turn can be measured and used as a parameter in the procedure. In terms of simplicity the second option is used in the initialization procedure. fig. 12 represents a sequential flow chart which describes the movement and data processing during the initialization procedure.

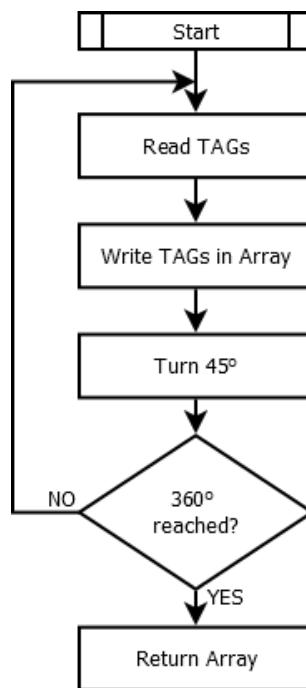


Figure 12: Flow Chart: Initial Procedure 360 degree turn

An initialization procedure for AGV No. 1 was created and is started in the GUI in the Test environment. In the first place an integer number is given to the field called Sleeptime. This integer number is interpreted as milliseconds and describes the time of rotation. Even though a time for a complete turn of 360° has been found at around 1125ms it has to be said that this time strongly depends on the battery charge of the AGV. After the desired turning time is given to the GUI the initialization is started by pushing the button Initialization, located over the input box 13.

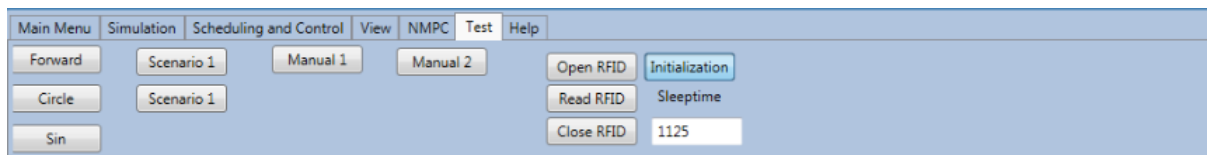


Figure 13: Test environment in GUI

In the second step after the procedure was started all the available IDs and their respective RSSI in the current reading range of the RFID-Reader are read. The reading is performed

in the Automatic Scan mode of the RFID reader. With the included timestamp for every measurement a delay of minimum 30ms between each and every TAG-Information was detected. With respect to this delay the antenna has to stop a specific period of time at each measuring point to deliver correct data of all the reachable TAGs. Experience has shown, that a measuring time between one and two seconds, in which every 100ms measurements are taken, the best results are delivered. In order to save the single TAG information of each and every measuring point an initially empty Array with 14 rows and 8 columns was created. The number of rows is derived by the fact that measurements are taken at every 45° .

$$Rows = 360/45 \quad (12)$$

$$Rows = 8 \quad (13)$$

The first seven entries of a row in the array is filled by the received TAG IDs and the last seven entries are filled by the respective RSSI.

The number of columns is derived by the fact that at each and every measurement point in the used test environment, information of maximal seven TAGs can be read.

$$Columns = max.no.ofTAGs * 2 \quad (14)$$

$$Columns = 7 * 2 \quad (15)$$

$$Columns = 14 \quad (16)$$

Once the received data is saved in its corresponding row, the AGV turns around 45° to place the antenna at the next measuring point. A AGV turn is realized by setting the velocity of the right and left wheel in different directions. During the turning sections the velocity is set to 100 mm/s or rather -100 mm/s. This procedure of reading information, writing information in the initialization array and turning 45° to the next measuring point is repeating itself until a 360° turn is performed. After a successful initialization turn the corresponding Array of measurement information can look like the example in table 8.

4	1	5	2	3			0	0	1	7	0		
5	3						2	3					
3	5						2	2					
9	8	6	5				1	1	1	2			
9	7	8	6	4	5		2	0	6	0	0	2	
4	7	5	8				0	2	3	3			
5	4	7	8	1			2	5	0	0	0		
2	4	1	5				0	2	2	0			

Table 8: Filled Array after 360 degree turn

7.2.1 Recording and filtering data (Stefan)

To read the UID and RSSI of all the TAG laying in the reading range the RFID-Reader is set to its Automatic mode and its Anticollision is switched on. During this mode packages of strings with a length of 35 characters are reviewed by the plans computer. Even though these 36 character strings contain all the information of the TAG which is needed some effort has to be taken to separate the useful parts which are processed in localization algorithm.

With exception of the information each and every string contains, the structure itself is always the same. In the first five characters the substring “SCAN:” are found and deleted for the further process. The first important character is found in the sixth slot of the string. Here either a “+” or a “-” is written. With help of this sixth slot it is distinguished if the current reading is either a complete or incomplete one. In order to guarantee the correctness of the reviewed information the measurements are filtered by the “textit+” and the measurements in which a “-” is included are ignored in the further processes. After the indicator for complete and in complete readings an introduction to the UID is indicated by “UID= ” and cut out of the string. The next 16 characters define the unique identification of the specific TAG. As a last useless information which has to be cut out a string with the structure “.RSSI=” is found directly after the UID. As a result the sixteen character hexadecimal UID and its respective RSSI are separated from the reviewed string. Since the ordered TAG UIDs differ each other just in the last three numbers these numbers are transformed in a decimal number before UID and RSSI is used for further computations.

String Transformation	
Complete	Incomplete
SCAN:+UID=E00401503A5BD691,+RSSI=0/0	SCAN:-UID=E00401503A5BD4E4
UID=E00401503A5BD691,+RSSI=0/0	
E00401503A5BD691 0/0	
1681 0	

Table 9: String preparation

7.2.2 Analysing data (Stefan)

In the next step of the Algorithm the previous described filled Array is analyzed. To estimate the position and orientation of the AGV the Array has to include two valid sets of each two valid measuring points. During this analyzation the single measurement point-sets are validated in terms of following restrictions:

- 1.: At the two valid measurement point each contains at least three TAGs
- 2.: The two measurement points in one set need to have a distance of 180° to each other.

In terms to get the adequate sets of measurement points the array is analyzed row by row. The stepwise workflow is vizialized in fig. 14.

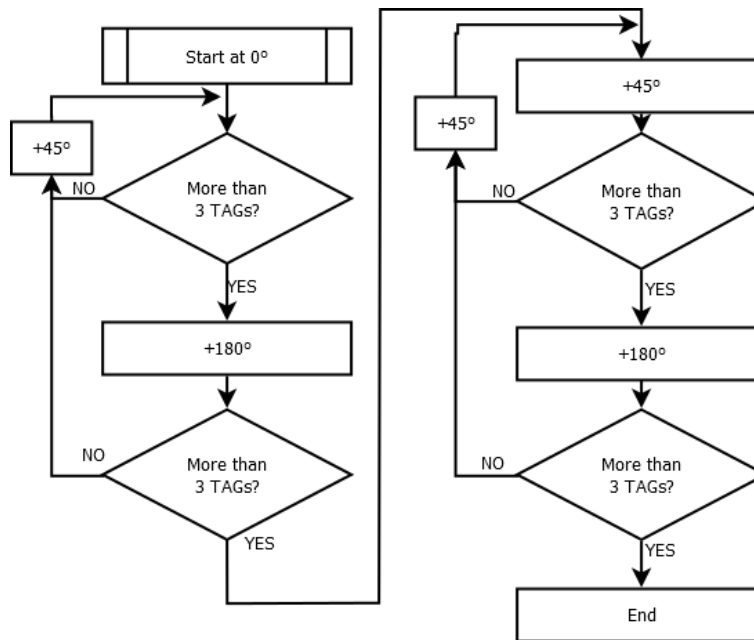


Figure 14: Flow Chart: Analyzing Measurement Points

Initially the first row which represents the measurement at the point zero degree is checked in terms of the numbers of readable TAGs. If this specific number is higher or equal tree the transition is acknowledged as true and the same query will be performed at the measurement point with a distance of 180°to the former measurement point. If this next measurement point can be described as valid as well the first valid set of two measurement points is found. If, on the other hand, the number of readable TAGs are less than 3, which means that the triangulation algorithm cannot be performed, the current measurement point is ignored and the next point with a distance of 45°is evaluated. Each of this sets of two measurement points [degree] is saved as a 1x2 Array called Solution 1 and Solution 2 is used for the estimation of the position of the measurement points which is explained in the section 7.2.4 Estimation of initial position and orientation.

7.2.3 Selection of correct distance related to RSSI footnoteStephan

In a first step the multiple occurring data points (see tbl.6) are divided into three groups (max, middle and min) where max means the maximal possible distance related to one RSSI and so on.

The measurements has shown that it is not trivial to define the correct distance related to most

of the RSSI. The involved algorithm selects the correct distance out of the multiple possible solutions and is shown in fig. 15:

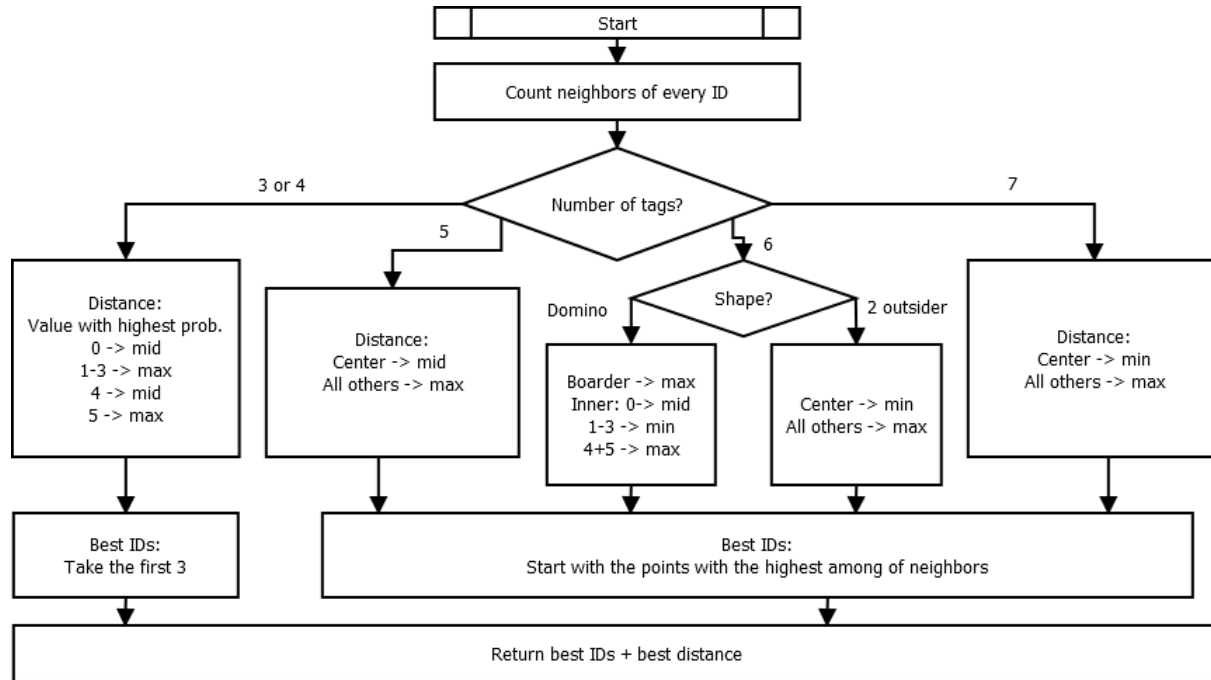


Figure 15: Flow Chart: Selection of correct distance and most proper IDs

To distinguish between the multiple possible solution for one RSSI, the algorithm defines the shape of the pattern of tags based on the number of tags at each measurement and the number of the neighbours each tag has. At each measurement point are in this scenario several numbers (4-7) of detected tags possible. The different shapes can be found in the tbl. 10.

Number of detected tags	4	5	6 (Domino)	6 (2 alone)	7
Unique shapes					

Table 10: Possible shapes of pattern

Going back to the flow chart fig.15 the first step is to count the number of neighbours each tag has. With this information, the position of the tag in the pattern can be detected. For example is a tag with 3 neighbours in a pattern of 5 tags the center of this pattern.

After the number of tags at each measurement point and the position of each tag are defined, the selection of the correct distance will be performed based on the highest probability. To know the highest probabilities an analysis of measurements with emulated data has been done.

As an example are leading 4 detected tags to the fact that the position of the antenna should be very close to the center of this square. If in this case a RSSI of 4 is detected, the middle value (5.8 cm) will be taken.

Afterwards the most suitable three IDs will be selected, in case where more than three are detected. The algorithm takes at first the ID with the highest amount of neighbours, because these tags are close to the position of the antenna and have probably a value of 6 or 7 and are uniquely defined. In the case where several tags with the same number of neighbours, the first ID (number increasing) will be taken.

The return of the function is an array (2x3) with the indices of the chosen IDs and the correct distance. The correct distance will be indicated by the number 0,1 and 2. 0 means the maximal, 1 the middle and 2 the minimum possible value related to one RSSI. For example leads

$$\begin{bmatrix} 3 & 2 & 4 \\ 2 & 0 & 0 \end{bmatrix}$$

to the choice of the maximal value of the RSSI of the fourth detected ID and the minimum value of the RSSI of the third and the fifth ID in the recorded array at this measurement point.

7.2.4 Estimation of initial position and orientation ⁷

As mentioned in chapter 7.2, the main idea to estimate the initial position is to find the intersection point, which lies in the middle of the measurement points.

To compute this position, the algorithm uses trilateration at every suitable measurement point to estimate its position. For trilateration are three defined positions plus three radii necessary, which are available after the selection of the correct distance and proper IDs.

As follows from the fig.16 shown above, the intersection point is found by computing two linear functions which go through two corresponding points (blue lines). The center of the robot is then the intersection of those two linear functions and can be computed by the following equation:

$$x = \frac{(x_1y_2 - y_1x_2)(x_3 - x_4) - (x_1 - x_2)(x_3y_4 - y_3x_4)}{(x_1 - x_2)(y_3 - y_4) - (y_1 - y_2)(x_3 - x_4)} \quad (17)$$

$$y = \frac{(x_1y_2 - y_1x_2)(y_3 - y_4) - (y_1 - y_2)(x_3y_4 - y_3x_4)}{(x_1 - x_2)(y_3 - y_4) - (y_1 - y_2)(x_3 - x_4)} \quad (18)$$

Theoretical are all eight measuring points suitable points (at least four IDs found). But for the case that the real measurements differ from the theory, the algorithm just needs four suitable

⁷Stephan

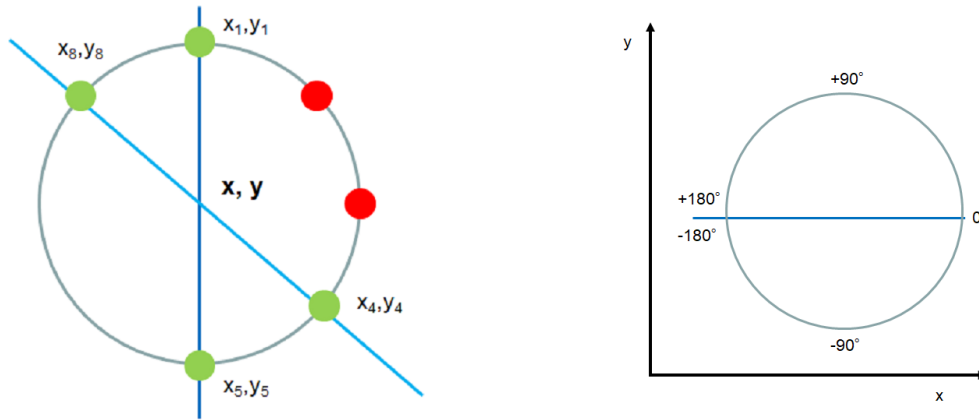


Figure 16: Computing the center of the robot Figure 17: Orientation of robot in absolute angle

points.

After the initial position as well as the positions of 4 measurement points are known, the algorithm computes the orientation based on those information. The relative angle between the center and the first measurement point will be computed with the $\arctan2$ function and leads to an orientation $-180^\circ < \Theta \leq 180^\circ$ as shown in fig.17.

To compute the absolute angle, the angle of the measurement point has to be subtracted and 180° has to be added. This is caused by the fact that the antenna is placed on the back of the robot and the absolute orientation should be the direction of the front. After this computation, the initial position and orientation of the robot are known.

7.3 Test setup⁸

In order to verify the validity of the initialization procedure, we carried out experiments with the components mentioned in chapter 5. The beginning of these experiments were the reconstruction of one of the AGVs with this HW setup. After we added all components to the AGV we realized the power supply via a powerbank and the USB connection of then wifi modul. The plan is to replace this in the future with a direct connection to the battery of the AGV. Fig.18 gives an overview of the test setup and shows also that for the prototype, the reader and the wifi modul was just stuck with Sellotape on the upper layer of the AGV.

The test platform was a field of 9 tags which were stuck on a piece of carton. The IDs and its positions are shown in tbl.11.

The reason for the small setup was the fact that until the end of the project only 10 tags were available. One of the following steps should be to extend the platform with more tags.

⁸Stephan

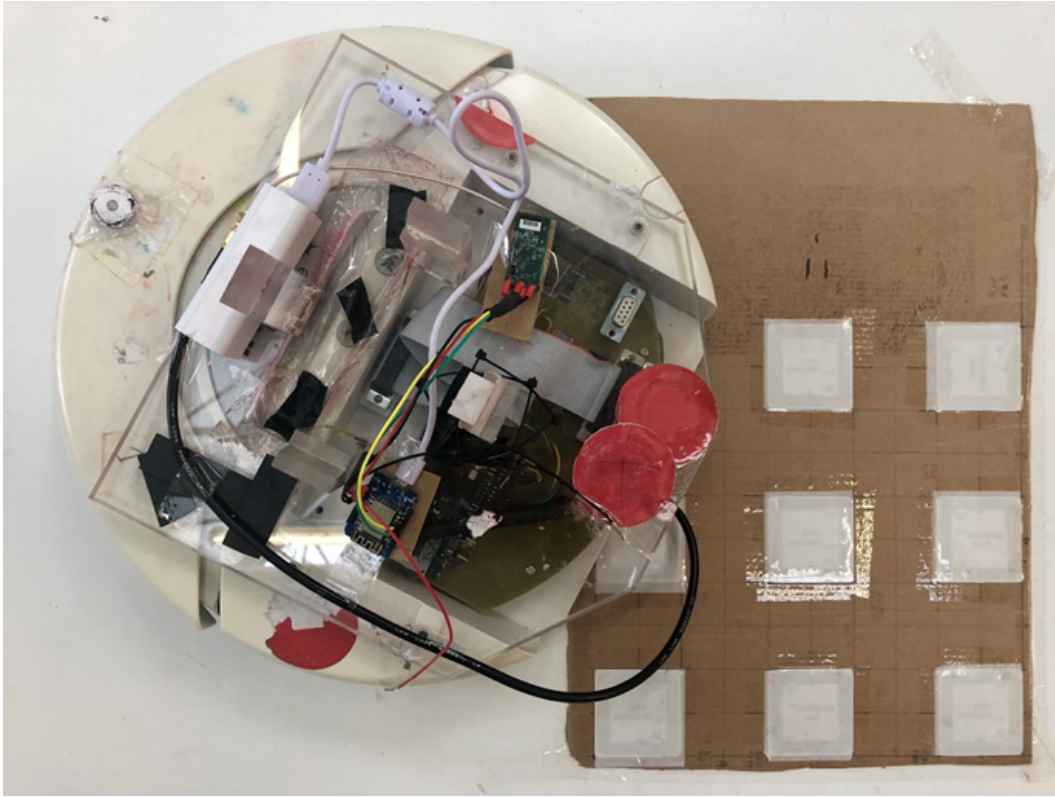


Figure 18: testing setup for initialization procedure

X-dir. [mm]	0	100	200	0	100	200	0	100	200
Y-dir. [mm]	0	0	0	100	100	100	200	200	200
ID tag [hex]	AE4	689	47A	586	785	ADC	BF4	691	78D
ID tag [dec]	2788	1673	1146	1414	1925	2780	3060	1681	1933

Table 11: Positions of the IDs in the test setup

The initialization procedure was started via the GUI. A time value was added in the GUI to perform the 45° turns. This number was **around 1150 ms** and is highly correlated to the battery status of the AGV.

7.4 Results⁹

A couple of tests on the test setup (previous section) were performed to compare the good results created with the simulated data with real measurements. The result of the position estimation was directly plotted in the console. The initial position was 200 mm in x- and y-direction and a varying orientation (0°, 90°, 180° and -90°). Fig.19 and fig.20 illustrate the actual measurement results and the desired position in x- and y-direction.

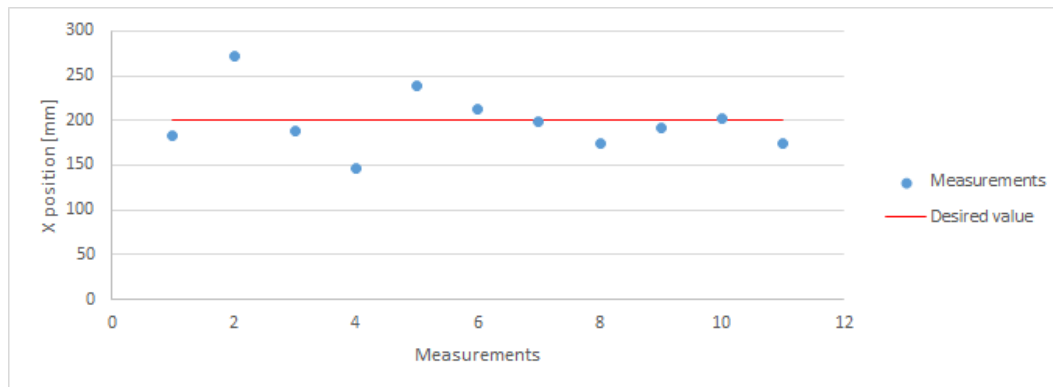


Figure 19: Estimated position in x-direction

The average of the absolute error of the position in x-direction was 24.5 mm. The minimum and maximum error were 2 mm and 72 mm.

The average of the absolute error of the estimation of the position in y-direction is with 23.3 mm, a minimum error of 3 mm and an maximum error of 77 mm very similar to the results from the estimation of the x-direction. The computation of the overall error of the position has an average derivation of 37.5 mm and a minimum and maximum error of 6.3 mm and 77 mm.

For the estimation of the orientation, the average of the absolute error was 23° with a minimum and a maximum value of 3.9° and 37.5°. The measurements also shows that an estimation of the position with a big error not necessarily leads to a big error in the estimation of the orientation (see measurement 4 in fig.19,20 and 21).

An extension of the results could also be an analyse of the estimated positions of the antenna at the measurement points. Those points were also plotted in the console.

⁹Stephan

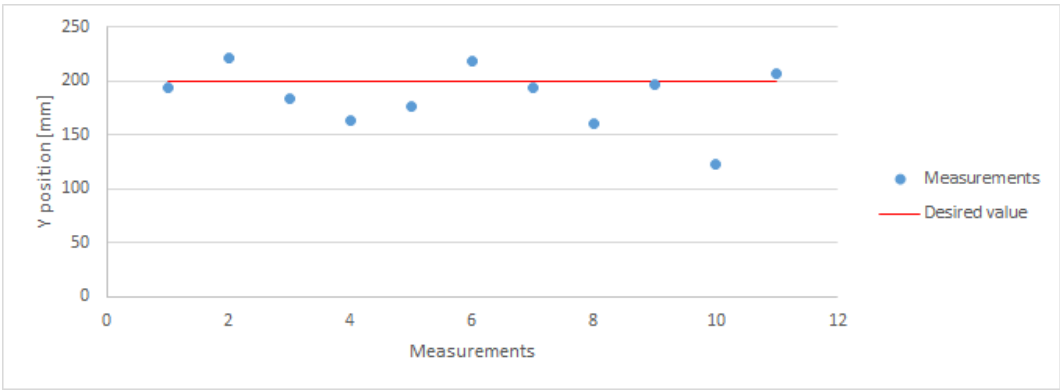


Figure 20: Estimated position in y-direction



Figure 21: Estimated orientation

8 Conclusion¹⁰

The developed localization solution was for the pipeless plant, a prototype of a chemical production plant which has a size of 3 by 4 meter. In this plant the vessel will be transported by AGVs from one station to another. In the actual setup only a camera, which is installed above the plant, was used to detect the AGVs and estimate their positions. The problem with this technology is the bad detection of the LED pattern from the AGVs during bright light conditions and also the space limitation. Another big disadvantage was the big computation effort which made the system also very slow. The main task of this project was now to find an alternative tracking solution. After the decision for a RFID system with passive tags as landmarks a prototype was build to verify the good solutions from the simulations. The implemented procedure was an initialization algorithm in which the the AGV makes an 360° turn and estimates its position and its orientation based on measurements during these turn. This project has shown that it is possible to put a reader on an AGV and detect passive tags with a reader and an antenna in an detection area of 14 cm. It has also been found out that there is inconsistent relation between the received signal strength (RSSI) of the detected tags and the distance between the tag and the reader. This leads to the fact that the estimation of the distance based on the RSSI is not trivial and was only solvable in a very simple and inaccurate way during the project. Based on the results from the initialization procedure, it can be concluded that it possible to estimate the position of the AGV with an average accuracy of around 2.5 cm and an estimation error of the orientation of around 23° . This is not a very good results and fulfils only the minimal requirements. This project has also clearly shown that the anti-collision algorithm of the reader gives very inefficient results and leads to an unknown amount of time until all tags in the detection area are identified. It was not possible to develop a running and faultless system, but is has been demonstrated that the system is light independent and space unlimited. Summing up all results, it can be concluded that the system is a promising technology for the indoor localizing on the small plant and gets rid of a lot of the current disadvantages.

¹⁰Stephan

9 Future Work

After a proof-of-concept for an RFID based localization system has been build and a first demonstration set-up has been build the disadvantages and limitations of the prototype were evaluated. According to these results several points of improvement and extension were found and categorized into a hardware and a software section.

9.1 Hardware

- The AGVs are feed by an included 12V battery which provides the power for all included electronical devices. This 12V power supply is available on board and is suggested to be used. Currently the WiFi-Module and the RFID-Reader are fed by an external powerbank since a 5V power supply is needed. In terms of one centralized power supply a 12 V to 5 V converter can be installed and connected to the new hardware.
- As a first set-up a demonstration area of 3 x 3 TAGs was developed. In this rather small area initialization procedure was developed but a real time localization while a trajectory is followed by an AGV was not possible since the 30cm x 30cm was simply too small. For future research in terms of localization on a specified trajectory additional TAGs can be included to the area of operation. Since the RFID concept is highly scalable the only change that needs to be made in the algorithm is the insertion of the additional TAG into the lookup table.
- Currently the only Robot No. 1 is the only AGV which is equipped with the RFID technology. To run the plant with multiple AGVs the remaining robots need to be upgraded.

9.2 Software

- During the initialization procedure a 360 degrees turn is performed. The degrees are divided by the change of degree over time. But it needs to be said that this movement is highly dependent on disturbances like changing battery charge and plant underground. For the future developers it is suggested to use the encoders of the robot wheels as a determination of the orientation instead the parameter time.
- As an alternative localization technology was found several code lines in the VisualStudio can be deleted since the camera and image processing is simply not used anymore. With a clean code an improvement of processing time will be achieved.
- As a last point it can be said that even though a localization with RFID is now possible the results are not 100 percent reliable and the accuracy especially with respect to the orientation is not satisfying so far. As an improvement the triangulation algorithm is to be optimized and or a second RFID-Antenna is to be added under the AGV to reduce measurement errors.

10 References

References

- [1] Pablo Cotera, Miguel Velazquez, David Cruz, Luis Medina, and Manuel Bandala. Indoor robot positioning using an enhanced trilateration algorithm. *International Journal of Advanced Robotic Systems*, 13(3):110, 2016.
- [2] KTS Systeme. Rfid plug module rfidm1356, 2017.
- [3] Christof Rohrig, Daniel Hess, and Frank Kunemund. Rfid-based localization of mobile robots rfid-based localization of mobile robots using the received signal strength indicator of detected tags.

11 Appendixes

11.1 Appendix A: Emulator RFID data (Matlab)

```

1 %% -----
2 % Description:  Emulator, which creates txt file like the reader
3 %              RSSI related to the real measurements
4 %              For the Initialization procedure, turn around 360°
5 % Date:        12.06.2018
6 % Created by:  Stephan Vette
7 % -----
8 %% RFID signal emulator
9 clear all
10 clc
11 close all
12 % Initializing
13 l1 = 100; % length of the plant, x [cm]
14 l2 = l1; % width of the plant, y [cm]
15 d1 = 10; % distance between tags [cm]
16 d2 = 0; % distance last tag <-> boarder [cm]
17 r1 = 14; % radius of the reading range of every tag
18 r2 = [r1, 9.75, 9.0, 8.0, 7.0, 6.0, 5.8, 5.5, 5.3, 5.1, 5.0, 4.7, 4.5, 4.3, 4.2, 4.0,
        3.5, 2.75, 0]; % distances at certain RSSI
19 r4 = [0, 1, 2, 3, 4, 5, 4, 3, 2, 1, 0, 1, 2, 3, 4, 5, 6, 7, 7]; % array with the
        different RSSI values
20
21 r3 = 33/2; % radius of the robot
22 d3 = 10; % distance between origin robot and origin antenna [cm]
23
24 angle1 = 45; % angle between the measurement points in the init procedure
25
26 gammal = deg2rad(22.5); % Start orientation of robot [rad]
27 robStart = [22.5, 51.5]; % Start position of robot in x, y [cm]
28
29 robSpeed = 0.1; % Speed robot [m/s]
30 cycleT = 100; % Cycletime in [ms]
31
32 mode = 1; % mode=1: tracking all available tags, which are nonzero
33 % mode=2: tracking only changes in the RSSI signals
34 mode_hex = 0; % activate or deactivate hex ID
35
36 % For the name of the txt file
37 measuementNumber = num2str(11); % Number of measurement
38 % Two possibilities for the content of the txt file
39 % 1. Without filtering. Exactly like the reader creates data
40 % text0 = '<\r>';
41 % text1 = 'OK';
42 % text2 = 'SCAN:+UID=';
43 % text3 = '+RSSI=';
44
45 % 2. Filtered data. Without unusable information.
46 text0 = ' ';
47 text1 = ' ';
48 text2 = ' ';
49 text3 = ' ';
50 %% Error check
51 if mod(l1/d1,1)~=0
52     error('Length of platform not dividable by distance between tags');
53 elseif mod(l2/d1,1)~=0

```

```

54     error('Length of platform not dividable by distance between tags');
55 end
56
57 %% Computing position of antenna
58 numTagsX = (l1-2*d2)/d1 +1;
59 numTagsY = (l2-2*d2)/d1 +1;
60 numTags = numTagsX * numTagsY;
61 antPos = robStart + d3 * [cos(gammal), sin(gammal)];
62
63 %% Display the setup, write important information into a seperate txt file
64 d1_str = num2str(d1);
65 l1_str = num2str(l1);
66 l2_str = num2str(l2);
67 numTags_str = num2str(numTags);
68
69 msg0 = ['Your plane is ',l1_str,'cm x ',l2_str,'cm.'];
70 msg1 = ['You chose a distance of ',d1_str,'cm and need ', numTags_str,' Tags!'];
71 disp(msg0);
72 disp(msg1);
73 nameTxt = ['NumTags',measumeenteNumber,'.txt'];
74 fileNumTags = fopen(nameTxt,'w');
75 fprintf(fileNumTags,'%6d\n',numTags); % Write the number of tags in file
76 fprintf(fileNumTags,'%6d\n',l1); % Write the size of the plant in file
77 fprintf(fileNumTags,'%6.4f\n',gammal); % Write the starting angle
78 fprintf(fileNumTags,'%6d\n',robStart(1)); % Write the starting pos
79 fprintf(fileNumTags,'%6d\n',robStart(2)); % Write the starting pos
80 fclose(fileNumTags);
81
82
83 %% Drawing environment
84 figure(1)
85 x1 = [0 l1 l1 0 0];
86 y1 = [0 0 l2 l2 0];
87 plot(x1, y1, 'LineWidth',2)
88 xlim([-5 (l1+5)]);
89 ylim([-5 (l2+5)]);
90 hold on
91
92 % Position of the tags
93 ID = 1:numTags;
94 [Tagx,Tagy] = meshgrid(d2:d1:l1-d2,d2:d1:l2-d2);
95 plot(Tagx,Tagy,'r*')
96 % Circles
97 radiipl = ones(numTagsX,1)*r1;
98 for k=1:numTagsX
99     tempx = Tagx(1:end,k);
100     tempy = Tagy(1:end,k);
101     temppos = horzcat(tempx,tempy);
102     viscircles(temppos,radiipl,'Color','k','LineStyle',':', 'LineWidth',0.25);
103 end
104 robX = robStart(1);
105 robY = robStart(2);
106 plot(robX,robY,'bO','LineWidth',3);
107 plot(robX,robY,'r:');
108 viscircles([robX,robY],r3,'Color','k','LineWidth',0.25);
109 plot(antPos(1),antPos(2),'bs');
110 xlabel('Length platform in cm')
111 ylabel('Width platform in cm')
112 title({'Position and reading range of tags'; 'Start-, endpoint and path of the robot'});

```

```

113 hold off
114 pause(1)
115
116 %% Animation and loggin
117 xUpdateAnt = antPos(1);
118 yUpdateAnt = antPos(2);
119 deltaR = deg2rad(angle1); % A new measurement after every XX°
120 % Txt file name
121 name = ['Meas.StartingProc.like.reader.real.data',measumeNumber, '.txt'];
122 fileID = fopen(name,'w');
123
124 % Data stored in variables
125 dataRSSI = zeros(8,numTags);
126 streamDataRSSI = zeros(1,numTags);
127 streamDataRSSIold = zeros(1,numTags);
128 timeStep = 1; % current measurement step
129
130 % antPos = robStart + d3 * [cos(gammal), sin(gammal)];
131 figure(2)
132 for l=0:360/angle1
133     deltaR_temp = deltaR * l;
134     xUpdateAnt = robStart(1) + d3 * cos(gammal + deltaR_temp);
135     yUpdateAnt = robStart(2) + d3 * sin(gammal + deltaR_temp);
136     plot(x1, y1, 'LineWidth',2)
137     hold on
138     xlim([-5 (l1+5)]);
139     ylim([-5 (l2+5)]);
140     [Tagx,Tagy] = meshgrid(d2:d1:l1-d2,d2:d1:l2-d2);
141     plot(Tagx,Tagy, 'r*')
142     plot(robX,robY, 'bO', 'LineWidth',1);
143     plot(robX,robY, 'r:');
144     plot(xUpdateAnt,yUpdateAnt, 'bs');
145     xlim([-5 (l1+5)]);
146     ylim([-5 (l2+5)]);
147     viscircles([robX,robY],r3, 'Color','b', 'LineWidth',0.5);
148     for k=1:numTagsX
149         tempX = Tagx(1:end,k);
150         tempY = Tagy(1:end,k);
151         tempPos = horzcat(tempX,tempY);
152         viscircles(tempPos,radiipl, 'Color','k', 'LineStyle',':', 'LineWidth',0.25);
153     end
154 hold off
155
156 % Creating measurements
157 antPosnew=[xUpdateAnt,yUpdateAnt];
158 for m = 1:numTags % m = current number of tag
159     m_str = num2str(m);
160     tempTag=[Tagx(m),Tagy(m)];
161     tempD = pdist([antPosnew; tempTag], 'euclidean');
162
163     % Display if tag is in range or not
164     if tempD > r1
165         streamDataRSSI(m) = 0;
166         if (streamDataRSSI(m) ~= streamDataRSSIold(m)) && mode == 2
167             if mode_hex == 1
168                 fprintf(fileID, '%d %s%s%s%d%s\n',l*angle1,text2,dec2hex(m, 16),
169                     text3,k(end),text0);
170             elseif mode_hex == 0
171                 fprintf(fileID, '%d %s%d%s%d%s\n',l*angle1,text2,m,text3,k(end),

```



```

                                text0);
171         end
172         fprintf(' %d %d %d\n',l*angle1,m,'0');
173     end
174     elseif tempD <= r1
175         % disp(['Label ',m_str,' in range!!!!!!!!!!!!!!']);
176         % Relation distance <=> RSSI
177         k_temp = find(r2>=tempD);
178         k = r4(k_temp);
179         dataRSSI(timeStep,m) = k(end);
180         streamDataRSSI(m) = k(end);
181         if (streamDataRSSI(m) ~= streamDataRSSIold(m)) && mode == 2
182             if mode_hex == 1
183                 fprintf(fileID, '%d %s%s%s%d%s\n',l*angle1,text2,dec2hex(m, 16),
                                text3,k(end),text0);
184             elseif mode_hex == 0
185                 fprintf(fileID, '%d %s%d%s%d%s\n',l*angle1,text2,m,text3,k(end),
                                text0);
186             end
187             fprintf(' %d %d %d\n',l*angle1,m,k(end));
188         elseif mode == 1
189             if mode_hex == 1
190                 fprintf(fileID, '%d %s%s%s%d%s\n',l*angle1,text2,dec2hex(m, 16),
                                text3,k(end),text0);
191             elseif mode_hex == 0
192                 fprintf(fileID, '%d %s%d%s%d%s\n',l*angle1,text2,m,text3,k(end),
                                text0);
193             end
194             fprintf(' %d %d %d\n',l*angle1,m,k(end));
195         end
196     end
197     end
198     streamDataRSSIold = streamDataRSSI;
199     pause(cycleT/1000)
200     timeStep = timeStep + 1;
201 end
202 savefig('Figure2.fig');
203 fclose(fileID);
204
205 %% Results
206 % figure(3) % plot for the max value of every tag
207 % dataRSSIinoT = reshape(max(dataRSSI),[numTagsX,numTagsY]);
208 % plot3(Tagx,Tagy,dataRSSIinoT,'*');
209 % xlabel('Length platform in cm')
210 % ylabel('Width platform in cm')
211 % title('Max RSSI signal of every tag')
212
213 figure(4) % plot of the RSSI signal which are non zero vs. time
214 dataRSSIsum = sum(dataRSSI);
215 IDclear = find(dataRSSIsum ~= 0);
216 IDstr = string(IDclear);
217 dataRSSIclear = dataRSSI;
218 dataRSSIclear(:, all(~any(dataRSSI), 1)) = []; % and columns
219 plot(dataRSSIclear);
220 xlabel('Measurement points')
221 ylabel('RSSI')
222 ylim([0 360/angle1])
223 legend(IDstr,'FontSize',6);
224 title('RSSI Signal of every non zero tag')

```