

DEVELOPMENT OF LOCAL POSITIONING SYSTEM FOR A PIPE-LESS PLANT

Automation & Robotics
Group Project SS18

Group Members:

Abdulrahman Abouelkhair(198803)
Medhini Rajagopal Balamurugan(198735)
Stefan Rottstegge(191455)
Stephan Vette(198907)

Supervisors:

Afaq Ahmad
Marina Rantanen-Modéer

Abstract

Introduction

The pipe-less plant at the Process Dynamics and Operations group is an experimental setup of Automated Guided Vehicles (AGVs) moving between various stations. The AGVs dynamically change trajectories in operational mode based on a Model Predicative Control (MPC) scheme with the objective to get from one station to the other while at the same time avoiding each other. The current positioning system is based on pattern recognition where the system tracks each AGV based on a unique pattern of LEDs via a camera that overlooks the plant.

Motivation for new positioning system

The vision based positioning system displays some flaws and should be replaced by a system more adapted to the actual operational environment of the experimental plant. The following problems have been identified in the current setup of the system:

- No position feedback in bright day-light conditions
- A “*fish-eye camera lense problem*”, meaning that the position error grows with the distance from the center of the image caused by the distortion a wide angle lense creates
- Problems related to the software implementation restricting the usage of incoming information from the camera

Project objective

The project aimed at first evaluating different potential positioning systems, selecting one of them based on defined metrics and then to develop a proof-of-concept based on the chosen technology for the experimental pipe-less production plant in a model driven fashion. After going through four different alternatives including a triangulation based methods for indoor applications, another pattern recognition based method (such as QR-codes), map-based localization, and Radio-Frequency Identification (RFID), the latter was chosen for further evaluation and implementation.

Theoretical Background

RFID is a versatile technology with multiple application areas, e.g. access control, race tracking and positioning. Automated multi-agent systems are increasingly utilizing RFID for localization as the technology has been proven to have many advantages over vision based positioning systems. It uses electromagnetic fields to automatically identify and track tags attached to objects. There are two potential ways to implement an RFID localization system. One option is based on active RFID transmitters and reader with wide coverage areas that can be placed along the edges of the plant area and on each AGV. The other option is based on comparatively many passive tags, uniformly placed, on the ground of the plant area and active readers on the AGVs. The latter option was chosen for the project based on cost efficiency, system scalability and from literature proven applicability.

Hardware

An RFID system is made up of two parts: a tag and a reader. RFID tags are embedded with a transmitter and a receiver. The RFID component on the tags has two parts: a microchip that stores and processes information, and an antenna to receive and transmit a signal, which partly contains the unique ID of the tag. The hardware components which are added to the AGVs comprise an RFID antenna, an RFID reader and a WiFi module. All the devices are supplied with 5V. The antenna is connected to the reader via a coaxial so called “*SubMiniature version A*”(SMA) cable and the reader communicates via an RX/TX interface. The RFID reader and the WiFi-module are connected via wired serial communication. The WiFi module then transmits the reader data through the local network, using TCP/IP communication. The

system data is lastly received by a PC that represents the control hub of the plant through a framework implemented in C Sharp (C#).

Communication

The WiFi-Module is connected to the same router as the PC on which the system user interface is running. A TCP-Client was established in the C# framework in order to handle incoming RFID data. The WiFi-module continuously sends data and the algorithm calculating AGV position prompts for this data as position and/or orientation of an AGV needs to be computed.

Localization

The implemented positioning algorithm requires the ID and the received signal strength indication (RSSI) of at least three RFID tags to calculate the position of the antenna. The RSSI gives a relation between the detected tag and the distance to it, in other words, a radius. The system has a record of the position of each tag and the ID of each tag hence holds information about the uniquely defined position of the tag. With three positions and the three corresponding radii, one can use trilateration to compute the position of the antenna.

Initialization Procedure

Initially the system cannot know the orientation of the AGV even if it can read enough RFID tags, as the tags only provide the x and y coordinates of the antenna itself (which is located off center on the robot). The main goal of the initializing procedure is to estimate both the starting position and orientation. During the turn, the robot will make a short stop every 45° and estimate the position of the antenna at that point. At the end of the procedure, the algorithm calculates the center of the eight recorded points. It takes two positions plus their corresponding positions at the other side (plus 180°) and computes the intersection of the linear function which goes through the position and its corresponding point. To estimate the orientation the algorithm computes the angle between the estimated position and the position of the antenna at $360^\circ/0^\circ$.

Demonstrator and results

A proof-of-concept for an RFID based localization system has been built in a model-driven fashion. The new system was simulated using Matlab to evaluate its applicability and overcome engineering problems at an early stage of the design phase. An initialization algorithm has been designed and implemented to calculate the starting position and heading of the robot. Simulations show an average position error of 0.5 cm. Analogously, the orientation of an error of around 10° . The system prototype consists of a reader and an area of nine tags (3x3). The measured position error in the experimental setup was on average 2.5 cm. The error of the orientation was on average about 23° . This significant difference to simulated results was caused by two main reasons: Firstly, some tags could not be detected by the reader. Secondly, the test board was quite small as it consisted of so few RFID tags which meant that it was not representative enough of the intended design. To summarize, it can be said that on the one hand a rather low-cost, scalable solution was designed which can work in any area independent for any light conditions. On the other hand, the accuracy of the technology is not very reliable according to the experiments made. This can be improved in further work with a better system setup and an improved localizing algorithm.

Contents

1	Introduction	8
2	Pipeless Plant	9
2.1	Existing setup	9
2.2	Problems with the Existing Setup	10
2.3	Motivation	10
3	Selection Process	11
3.1	Triangulation	11
3.2	Pattern Recognition	15
3.3	RFIS	17
3.4	Map-Based Localization[1]	20
4	Theoretical Background	23
4.1	Radio Frequency Identification	23
4.1.1	RFID System	23
4.1.2	Working Principle	23
4.2	Trilateration	25
4.3	26
5	Hardware	27
5.1	RFID reader and antenna	27
5.2	RFID tag	28
5.3	Wifi Module	29
5.4	Hardware Setup	29
6	Simulation	32
6.1	Emulator	32
6.2	RSSI Measurements with real hardware	33
6.3	Simulation with emulated data	34
6.4	Results	34
7	Implementation	35
7.1	Communication	35
7.2	Initialization procedure	37
7.2.1	Recording and filtering data	41
7.2.2	Analysing data	41
7.2.3	Selection of correct distance related to RSSI	42
7.2.4	Estimation of initial position and orientation	44
7.3	Test setup	45
7.4	Results	47
8	Conclusion	49
9	Future Work	50
9.1	Hardware	50
9.2	Software	50
10	References	51

11 Appendixes	52
11.1 Appendix A: Emulator RFID data (Matlab)	52
11.2 Appendix B: Receiving data from reader via Wifi (C#)	56
11.3 Appendix C: Initialization procedure (C#)	60
11.4 Appendix D: WeMos D1 Mini (Arduino)	78
11.5 Appendix E: Communication Outlay	82

List of Figures

1	Existing setup	9
2	Passive triangulation setup with two cameras	12
3	Active triangulation	12
4	Implementation of passive triangulation	13
5	Ceiling with periodic patterns of lamps acting as landmarks.	15
6	Belief grid of the robot in the plant	16
7	Snapshot of the ceiling	16
8	Passive RFID System	17
9	Active RFID System	17
10	Adaptive Monte Carlo localization	20
11	Global Map	21
12	Local Map	21
13	Robot Orientation	21
14	Correction with global map	21
15	Reader Tag	23
16	RFID System	24
17	Inductive Coupling	24
18	Overview Trilateration	26
19	RFID reader KTS Systeme RFIDM1356-001	27
20	RFID Antenna KTS Systeme PCBA1356_8	28
21	Paper Tag	29
22	Tags on the plant floor	29
23	WeMos D1 Mini WiFi Module	29
24	Robot Hardware Schematic	30
25	Hardware Schematic	30
26	Top of the Robot	31
27	Base of the Robot	31
28	Relation between RSSI and distance antenna to tag	33
29	RFID-WeMos Module Communication	35
30	WeMos Module Network Communication	36
31	Computer Network Communication	36
32	Different possible positions for one antenna position	37
33	Possible hazards/obstacles	38
34	Flow Chart: Initial procedure 360° turn	39
35	Test environment in GUI	39
36	Flow Chart: Analizing measurement points	42
37	Flow Chart: Selection of correct distance and most proper IDs	43
38	Computing the center of the robot	45
39	Orientation of robot in absolute angle	45
40	testing setup for initialization procedure	46
41	Estimated position in x-direction	47
42	Estimated position in y-direction	48
43	Estimated orientation	48
44	Communication Outlay	82

List of Tables

1	Pros and cons points of passive triangulation	14
2	Pros and cons points of active triangulation	14
3	Pros and cons points of Mobile Robot Localization based on Pattern Recognition	16
4	Overview RFID systems	18
5	Pro and cons of active RFID system	19

6	Pro and cons passive RFID system	19
7	Pro and cons of Localization using Ultrasonic Sensor	22
8	Relation between RSSI and distance antenna to tag (data)	33
9	Results Simulation	34
10	Filled array after 360° turn	40
11	String preperation	41
12	Possible shapes of pattern	43
13	Positions of the IDs in the test setup	46

1 Introduction

In today's world, the development and implementation of the positioning system for the autonomous vehicle in a confined space remains to be a major issue and hindrance to a better control system. Though there exists many types of local positioning systems, the precision remains to be still a challenge. This problem becomes critical in a place of no GPS access. This project aims at investigating various methods of indoor localization and to develop a proof-of-concept for the existing pipeless plant setup.

In the past years students and researchers at the Process Dynamics and Operations group at the TU Dortmund have developed this plant with vision based positioning system which need to be replaced to improve the overall efficiency of the system. Both the old and newly implemented techniques are written in C# that sends the position update to the Python based controller code.

In this project, various techniques were discussed and “*Radio Frequency Identification*” was chosen to be the ideal technique which would be further discussed in section 3 and 4. The hardware implementation is explained in section 7. Results of the simulation and experiment is discussed in section 6 and 7.

Based on the experiment, conclusion and future work are given in section 8 and 9 respectively.

2 Pipeless Plant

In chemical industry, pipeless plants are used due to its high flexibility level. In these type of plants, “*Automated Guided Vehicles(AGVs)*” are used to transport the vessel from one processing station to another. Thus, for each and every batch, the AGV transport the vessel to various stations to create an end product, making the pipeless plant multi-product and multipurpose chemical production. In this way, piping and the associated cleaning is eliminated, thus aiding in cost and energy efficiency.

2.1 Existing setup

The pipeless plant framework in TU Dortmund, developed by the Process Dynamics and Operations Group (DYN), consists of four AGVs, two color stations, one mixing station and one storage station. Each station has a role in producing batch of plaster art, for example mixing or filling the product in the vessel. The stations and the AGV are controlled by a Programmable Logic Controller. The vessel on the AGV is moved from one station to another based on the schedule to produce a batch. Regarding the positioning system, the plant uses camera to identify the LED pattern on the AGV. Each AGV has a unique pattern that distinguishes it from another.

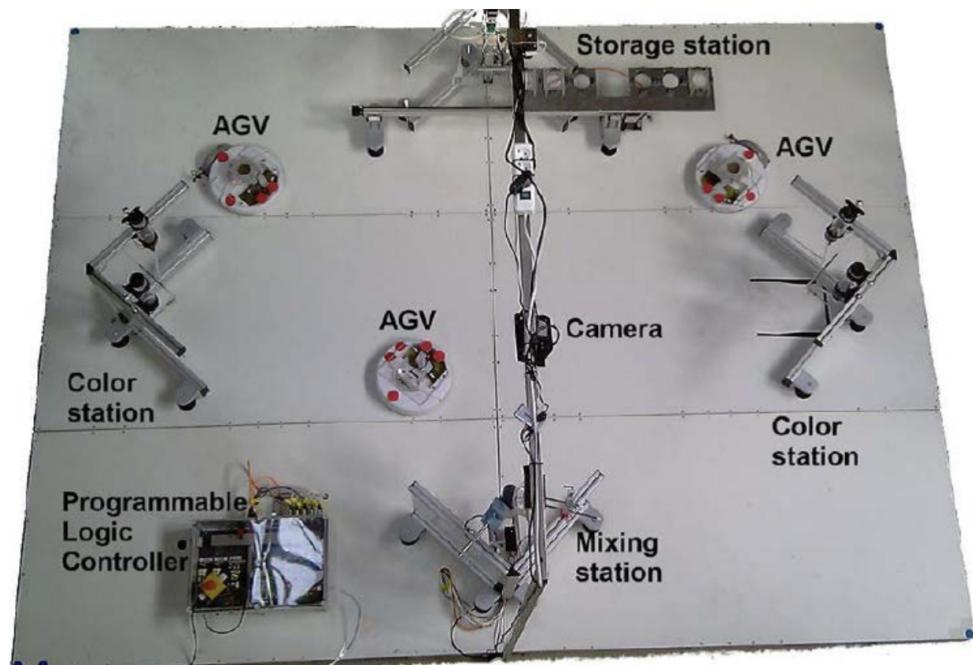


Figure 1: Existing setup

2.2 Problems with the Existing Setup

Since the existing setup uses vision based positioning system, the plant suffers various disadvantages as described below:

- During bright day-light conditions, no position is updated by the camera. This is due to the fact that the threshold of the sunlight and the LED on the AGV becomes equal that the camera fails to detect any pattern, thus affecting the whole system efficiency.
- The camera suffers the so called “*fish-eye camera lense problem*”, meaning that the position error is proportional to distance from the center of the image. This is caused by the distortion a wide angle lens.
- The restriction of usage of incoming information from the camera during software implementation.
- The percentage error and the processing time increases with the increase in number of robots to be localized thus affecting the controller input.

All these cons added up together cause a deterioration in the accuracy of the position of the AGV, which in turn affects the controller leading to a drop in system efficiency.

2.3 Motivation

The disadvantages of the vision based positioning system as discussed above leads to the urge for creating a localization that overcomes all the cons already suffered.

This project aims to research about alternative positioning system and to evaluate with selected method by simulation. The ultimate goal is to develop a positioning system with improved position precision and to compare and develop practical proof-of-concept.

3 Selection Process

Since the main aim of the project is to improve the positioning system of the existing setup, several other techniques were discussed, ending up in four methods namely “*triangulation*”, “*pattern recognition*”, “*radio frequency identification*”, “*map-based localization*”. The pros and cons were listed and the mentioned techniques were compared. The following section deals with a brief description of the above mentioned techniques.

3.1 Triangulation¹

Summary

Since the 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 is divided into 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 angels 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 system setup used in the 18th century nowadays two cameras are installed to perform a geographical method of 3D object-data estimation as shown in fig. 2 [2].

To solve the problem of position estimation, 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 pipesless plant it would be an AGV is found, the projection of a point x in 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). The geometrical location and orientation of the camera and light source in space need to be known. Two possible setups with either a laser point or a stripe as structured light are shown in fig. 3 [3].

To solve the active triangulation problem, the structured light has to point an object which location is desired to estimate. 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 can be estimated.

¹Stefan

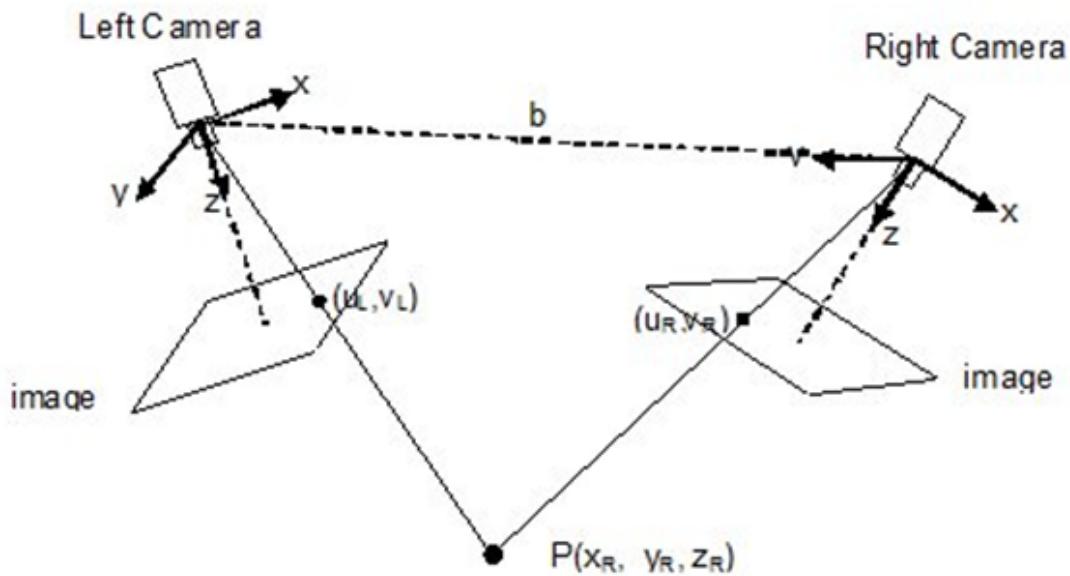


Figure 2: Passive triangulation setup with two cameras

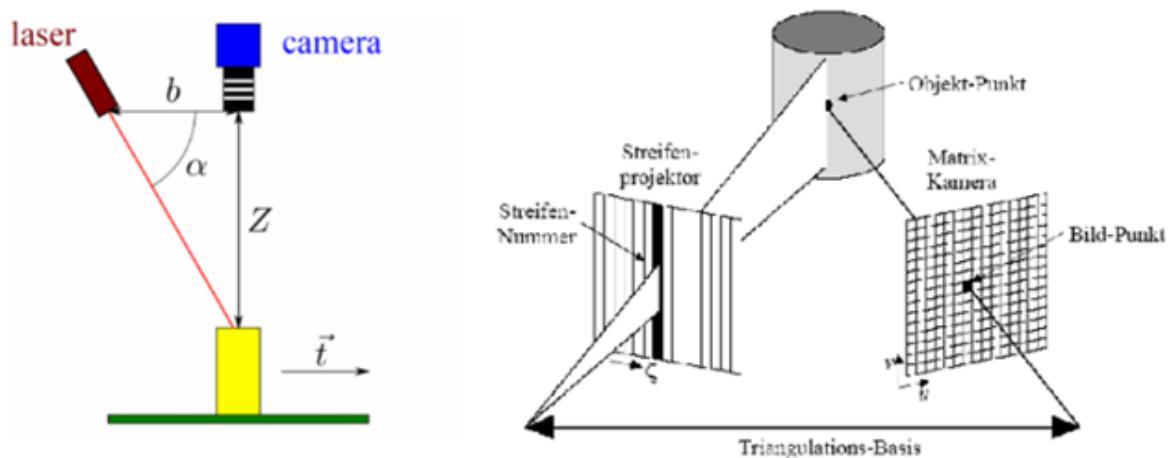


Figure 3: Active triangulation

Implementation

One possible way to implement a solution for the passive triangulation is to attach 2 high resolution cameras with USB 3.0 on two edges of the plant as shown in fig. 4.

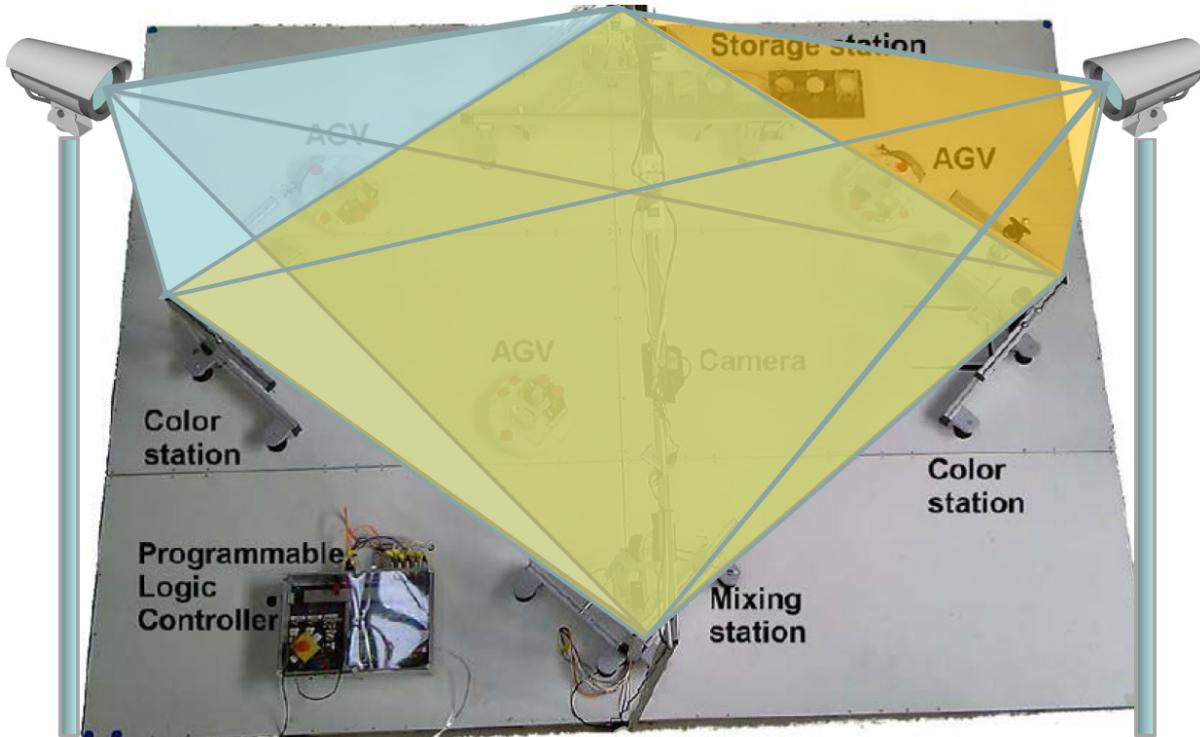


Figure 4: Implementation of passive triangulation

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	
Pro	Con
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: Pros and cons points of passive triangulation

Active Triangulation	
Pro	Con
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 lasers (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: Pros and cons points of active triangulation

3.2 Pattern Recognition

Summary

In this type of localization, estimation of the robot is done in indoor environments using only on-board sensors, namely a web-cam and a compass. The ceiling of the plant is constructed with a pattern of static landmarks whose positions are known a priori. All landmarks are indistinguishable against each other and might additionally be distributed along the ceiling in a periodic pattern. The landmark attached to the ceiling can be lights, QR codes, sensors or other reference points. The ceiling is used, since it is immune to changes. A camera is installed on the robot, which takes snapshots of the ceiling. The robot pose relative to the landmark is calculated with the help of the distance of the landmark to the center of the image and its angle relatively to the direction of the robot motion. An IMU device is additionally used to give the absolute orientation of the robot in the plant. The Markov Localization (ML) algorithm is used to estimate the belief grid of the robot position inside the environment.



Figure 5: Ceiling with periodic patterns of lamps acting as landmarks.

Implementation

The goal is to compute the pose of a mobile robot inside an indoor environment using a camera and an IMU device. As mentioned, Markov Localization is used to create a belief grid of the robot in the plant environment. This is done with the help of the snapshots of the ceiling taken

by the camera. As seen in the figure 6, the blue and black areas have lower belief and green and yellow areas have higher belief. The obtained pattern is evaluated and based on the pattern, the position of the robot is estimated. Thus with the help of the camera and the IMU device, both the position and orientation is obtained.

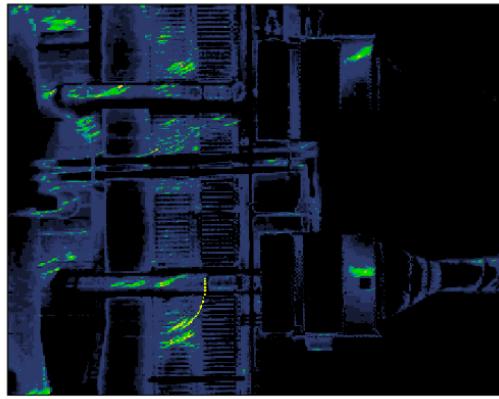


Figure 6: Belief grid of the robot in the plant

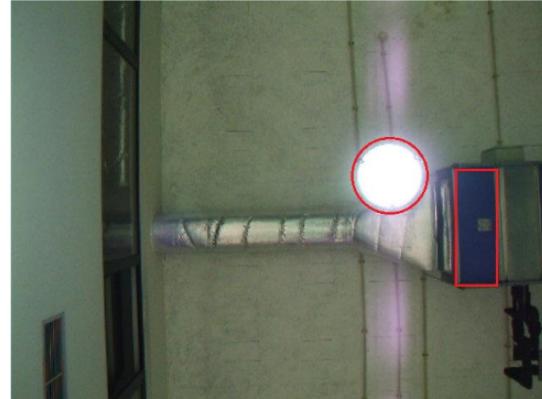


Figure 7: Snapshot of the ceiling

Pro and con

Based on the research, the advantages and disadvantages of Mobile Robot Localization based on Pattern Recognition are created.

Pro	Con
The ceiling is usually immune to changes as a reference and implement landmarks on the ceiling itself	Complex and many changes have to be added to the plant
No Fish-Eye-Lense problem	Cost intensive
	Light dependent

Table 3: Pros and cons points of Mobile Robot Localization based on Pattern Recognition

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 main areas of this technology is indeed still supply chains, transport, manufacturing, personnel access, animal tagging, toll collection [4], but also has 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. 8, consists of a reader, which is connected to an antenna and a computer and a passive tag.

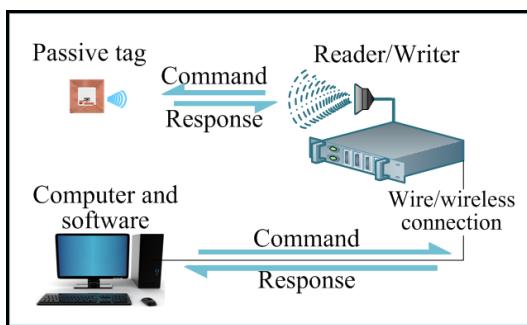


Figure 8: Passive RFID System

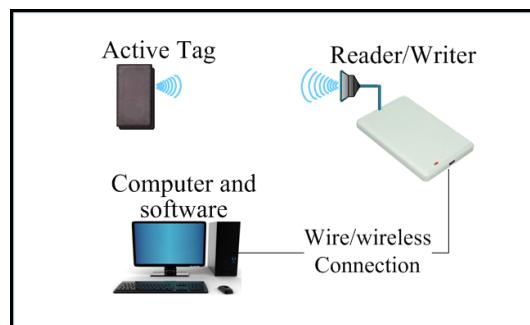


Figure 9: Active RFID System

The system is called passive, because the power supply is realized by the radio signal of the reader. In case where the tag is in the reading range of the reader, the tag gets enough power to send predefined information (for example ID) back. The active system (see fig.9) in comparison has an active tag which has an own power supply. The semi-passive tag has a battery built in that 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 4 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 than the active systems and has a bigger data rate. But it has also to be taken into account, that passive tags are cheaper than 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 4: 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 with a 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 research made, 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	Data rate is related to the amount of detected tags at 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 5: 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 at 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 6: Pro and cons passive RFID system

3.4 Map-Based Localization[1]

Summary

AMCL (Adaptive Monte Carlo Localization) is a probabilistic localization system for a robot moving in 2D. It implements the adaptive (or KLD-sampling) Monte Carlo localization[5][6] approach, which uses a particle filter to track the pose of a robot against a known map.

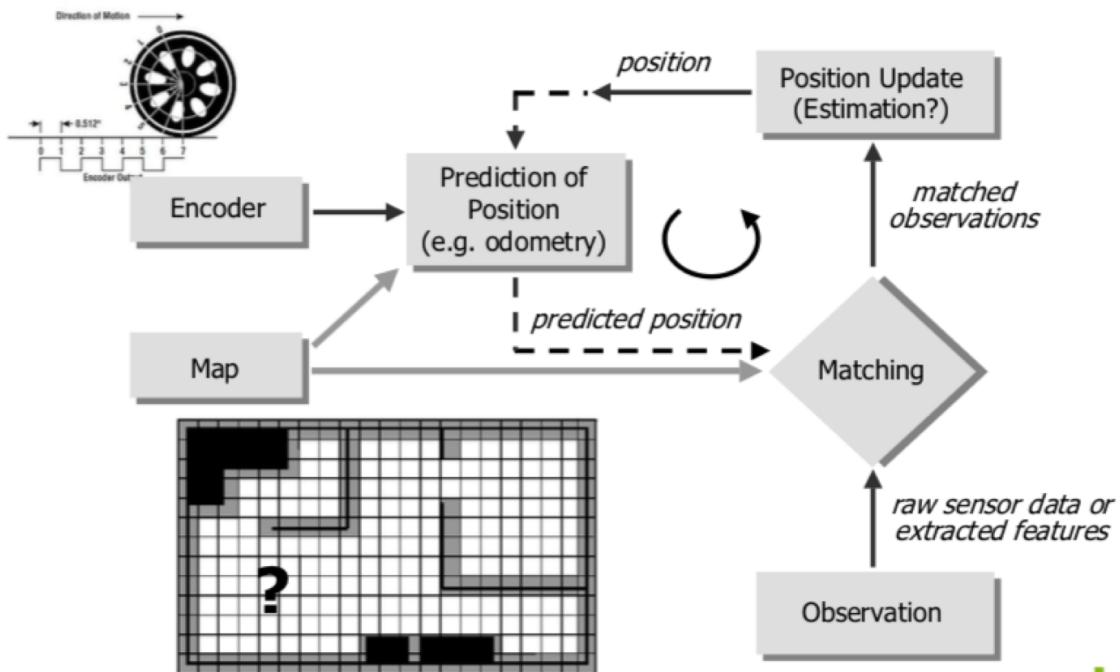


Figure 10: Adaptive Monte Carlo localization

amcl takes in a laser-based map, laser scans, and Odom scan, and outputs pose estimates (see fig.10). On startup, amcl initializes its particle filter according to the parameters provided. Note that, because of the defaults, if no parameters are set, the initial filter state will be a moderately sized particle cloud centered about (0,0,0).

Implementation

To implement such a technique a global and local map should be created as shown in fig. 11 and fig. 12.

- SLAM (Simultaneous Localization and Mapping) is a technique used in mobile robotics in which a robot builds a map of an unknown environment, keeping at the same time track of its localization in this environment.



Figure 11: Global Map

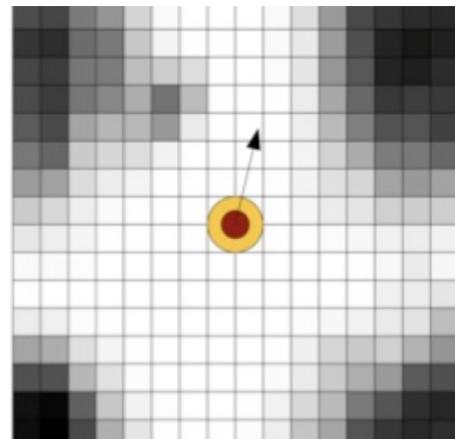


Figure 12: Local Map

- Adaptive Monte Carlo Localization

Given a map of the environment, the goal of the algorithm is for the robot to determine its pose within the environment.

At every time t the algorithm takes as input the previous belief $X_{t-1} = \{x_{t-1}^1, x_{t-1}^2, \dots, x_{t-1}^M\}$, an actuation command u_t , and data received from sensors z_t ; and the algorithm outputs the new belief X_t .

- Orientation Correction

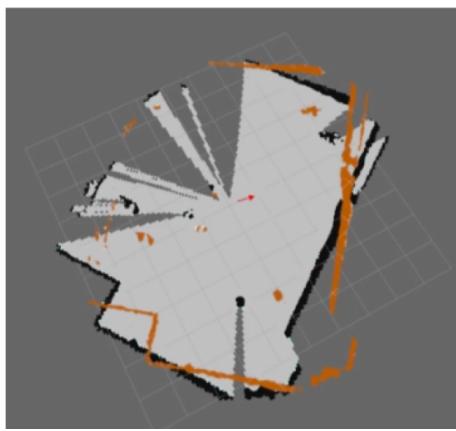


Figure 13: Robot Orientation

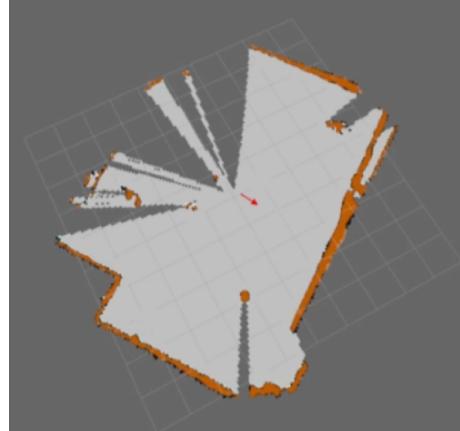


Figure 14: Correction with global map

Initially the robot assumes a position as shown in fig.13, and as it moves it begins to re-correct its estimated orientation using the static obstacle with the global map as a reference as shown in fig. 14.

Pro and con

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

Using Ultrasonic Sensor	
Pro	Con
Cheap €3/each	Scan angle 30°
Easy hardware Installation	Similar landmarks cause localization error
Faster feedback than the previous camera based localization system	High computational effort for large plant
Scan range 4.5 meters	Robots should start at every launch from static home position
Different map based localization algorithms are available	

Table 7: Pro and cons of Localization using Ultrasonic Sensor

4 Theoretical Background

4.1 Radio Frequency Identification

After in depth analysis of various localization methods the Radio Frequency Identification[7][8] was chosen due to its various advantages. This technology involves a reader and a tag which placed on the object needed to be tracked. The reader is continuously sending the radio waves, and when the tag is within the range of the reader, it sends a feedback signal to the reader as shown in fig. 15. The reader can track multiple tags at the same time.

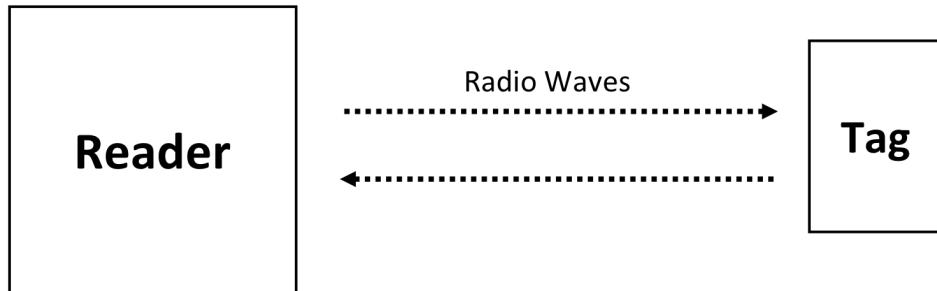


Figure 15: Reader Tag

4.1.1 RFID System

Regarding the tags as shown in fig.16, it can be either

- Active tag: which has its own power supply,
- Passive tag: which relies on the radio waves as its source of energy that come from the reader ,
- Semi-passive tag: which has power supply, but for transmitting the feedback, it relies on the signal coming from reader.

4.1.2 Working Principle

The RFID consists of three main parts:

- Generator: which generates the radio waves.
- A signal detect: which receives the feedback signal from the tag
- Micro-controller: which process the information from the generator and the detector

The tags consists of:

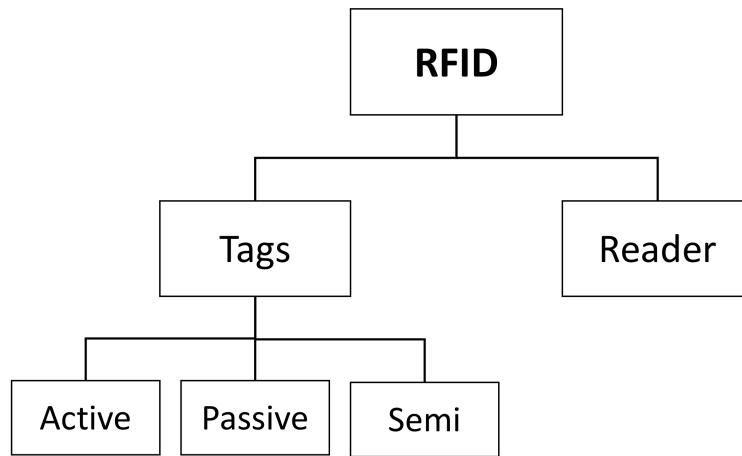


Figure 16: RFID System

- Transponder: that receives radio waves and sends the feedback
- Rectifier Circuit: which stores the energy coming from the wave across the capacitor, and this energy is used as a power supply for the controller as well as the memory

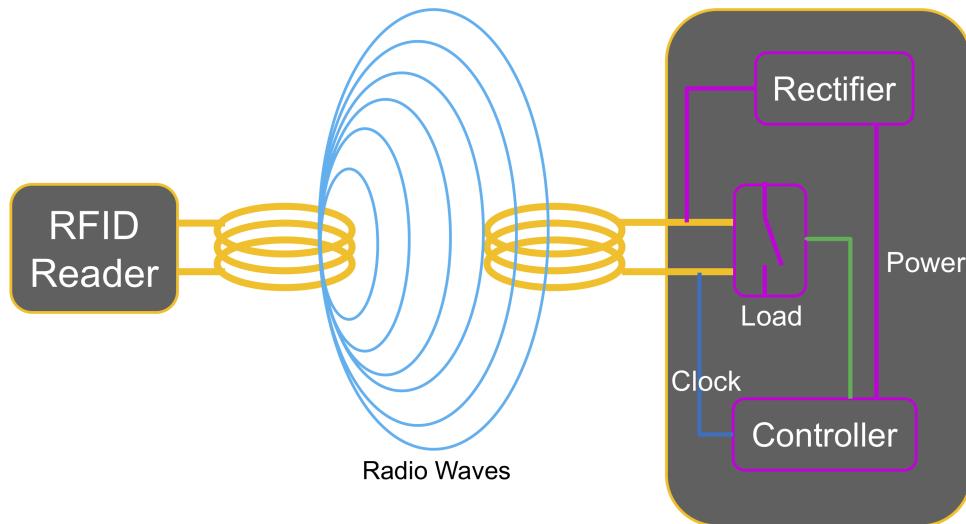


Figure 17: Inductive Coupling

The whole process of sending the information between the tag and the reader is based on principle of "Inductive coupling". The reader is continuously sending radio waves with particular frequency. In this case, the reader and the tag should be close to each other as shown

in fig. 17. The field which is generated by the reader is used to couple with antenna of the tag, and due to the mutual coupling, the voltage is induced across the coil of tag. This voltage, with a particular frequency, is rectified and used as power supply for the controller and is used to derive synchronization clock for the controller.

When the load circuit is connected to the coil, the current starts flowing through the load. Therefore, when the load is switched on and off, the current will be turned on and off respectively leading to the induction of particular voltage in the reader. This method of switching the load is called load modulation. Thus, with the help of load modulation with respect to the data stored in the tag, the value of the induced voltage can be modified, leading to the generation of modulation on carrier frequency, thereby sending the data to the reader.

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 [9]. 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 a distance (d) and the third shifted in x- (i) and y-direction (j), which is illustrated in following fig.

With known positions of the center of the circles d, i and j can be computed in the following way[9]:

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

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

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

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

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

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

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

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

³Stephan

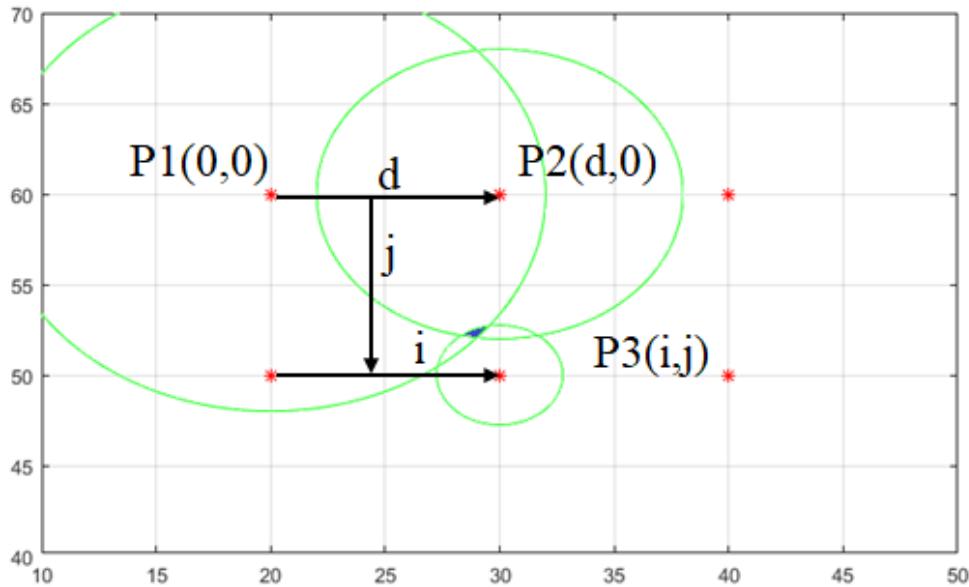


Figure 18: Overview Trilateration

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.19) 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 50Ω connection or via Pin Header U.FL. jack, which was used in this project.

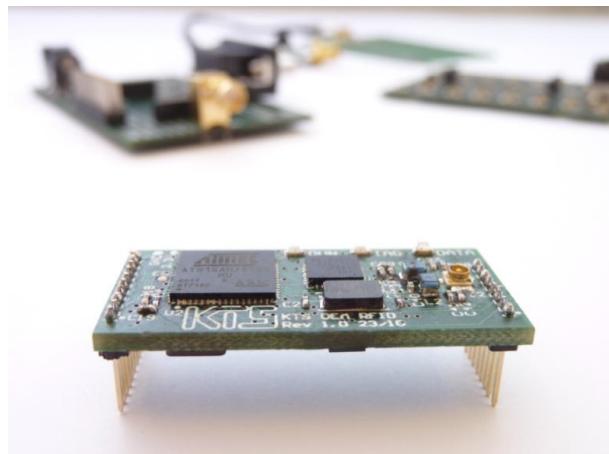


Figure 19: RFID reader KTS Systeme RFIDM1356-001

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][10].

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 also provides 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: SCAN:+UID=E00402000018313E,+RSSI=7/6 means that the tag with

⁴Stephan

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 to 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. 20) 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 20: 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

The tag used in the prototype is of paper type (see fig.21) due to its added advantages as follows:

- cheap, with the cost of 18 cents per tag
- doesn't require power supply
- compact
- easier implementation in the time of plant extension.

It's working principle is based on inductive coupling with an operating frequency of 125-135 kHz and a range of 10cm. The tags are fixed on the floor at known location as shown in fig.22.

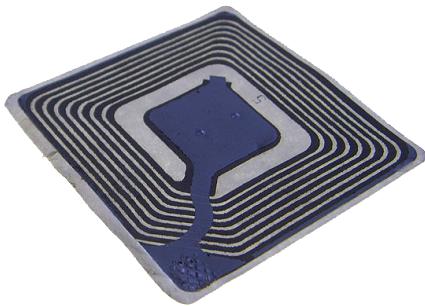


Figure 21: Paper Tag

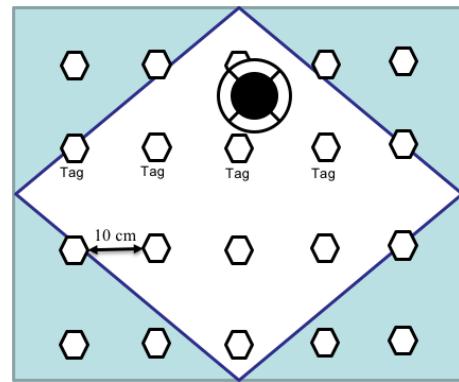


Figure 22: Tags on the plant floor

5.3 Wifi Module

The WiFi module from WEMOS Co.[11] is a mini WiFi board with 4MB flash based on ESP-8266 which is a WiFi microchip with full IP/TCP stack and micro-controller (see fig.23)

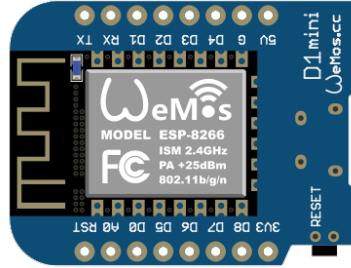


Figure 23: WeMos D1 Mini WiFi Module

- Features
 - 32-bit RISC microprocessor core running at 80 MHz
 - External QSPI flash of 4 MB
 - IEEE 802.11 b/g/n Wi-Fi
 - 16 GPIO pins
 - UART on dedicated pins, plus a transmit-only UART can be enabled on GPIO2
 - 10-bit ADC and I^2C (software implementation)

5.4 Hardware Setup

The in built Micro-controller on the robot receives the sensors data and sends commands to the actuators via serial communication using its first UART pins. (TX/RX) is the process of sending

and propagating an analogue or digital information signal over a physical point-to-point wired connection. It uses its second UART pins to communicate with the built-in WiFi Module. The built-in WiFi Module sends the received sensors data to the Computer and sends the received commands from the computer to the robot micro-controller via Wireless communication (see fig.24). Due to its less complexity, more flexibility and that the robot's in built micro-controller

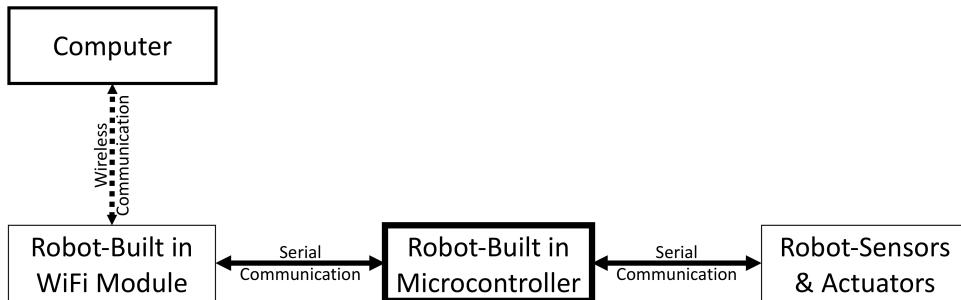


Figure 24: Robot Hardware Schematic

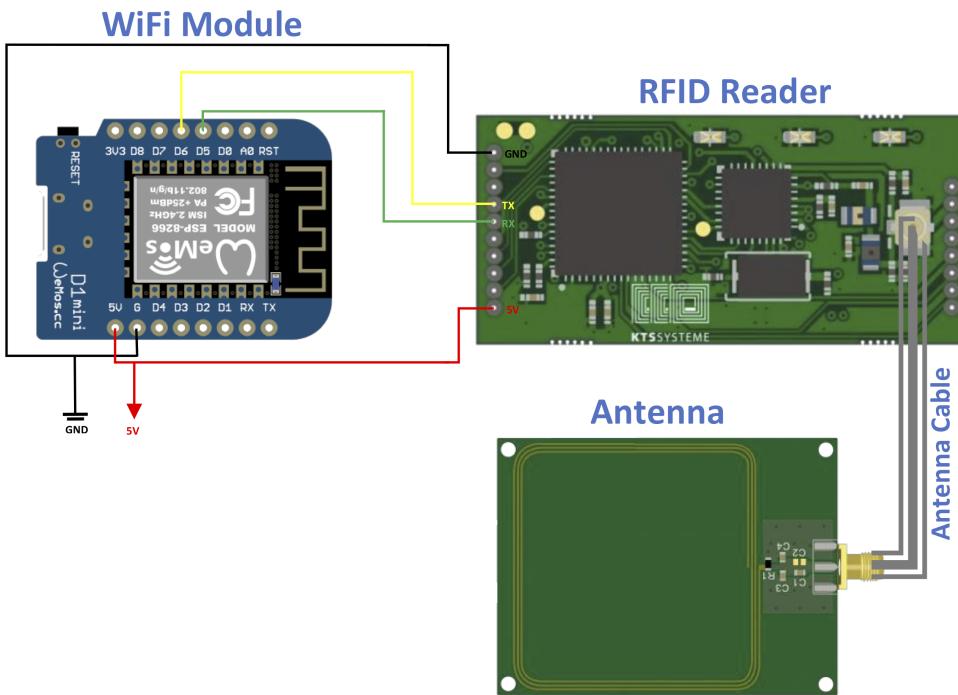


Figure 25: Hardware Schematic

UART pins are in use, a new communication setup were developed for the RFID reader to send the data from the robot to the computer in parallel to the robot hardware setup. As shown in

fig.25) the RFID reader is connected directly to the built-in micro-controller of the WeMos WiFi Module sending it the tags IDs read via serial communication. The WeMos WiFi Module sends the received data through the network. The RFID reader is connected to the antenna which sends and receives the radio waves via SMA antenna cable.

The RFID reader as well as WeMos Module are placed on the top of the robot while the Antenna is fixed to the robot base such that the radio waves would be in direct contact with the tags on the floor.



Figure 26: Top of the Robot



Figure 27: Base of the Robot

6 Simulation⁶

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

To answer the design questions, the simulation has the following 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 around 121 tags are 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 is 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 computes the distance from the center of the antenna to the neighbouring tags at each measurement point. If a tag is closer than the maximal reading distance, the emulator writes 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 is based on the information from the paper [12] and mentioned a consistent increasing of the RSSI while the distance between the tags and the antenna gets smaller.

During own measurements it has been found out that this relation is 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 were 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. 8 and fig. 28 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 8: Relation between RSSI and distance antenna to tag (data)

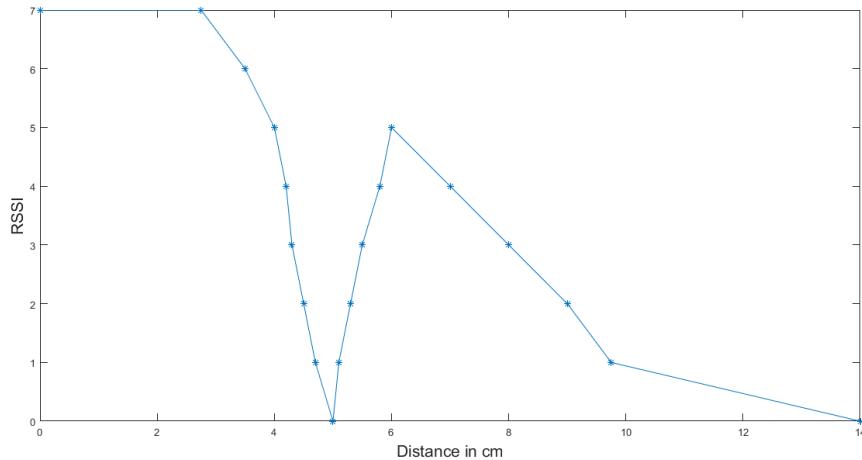


Figure 28: Relation between RSSI and distance antenna to tag

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 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 is created in matlab. The first part of these algorithm is the emulator which simulates the 360° turn and records the tag information. The second part is the solver which is also explained deeper in the chapter 7. 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 9: Results Simulation

As can be seen from tbl. 9, there is a sufficient good match between the estimated position and orientation of the robot for the consistent RSSI data. On the other hand the inconsistent RSSI data results 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

The already existing software is overwritten on the built-in micro-controller of the WeMos WiFi Module which was developed to have a continuous listening to all the data sent from the RFID reader even in case of no tags within the range. The good and bad RFID data readings are as seen in the fig.29.

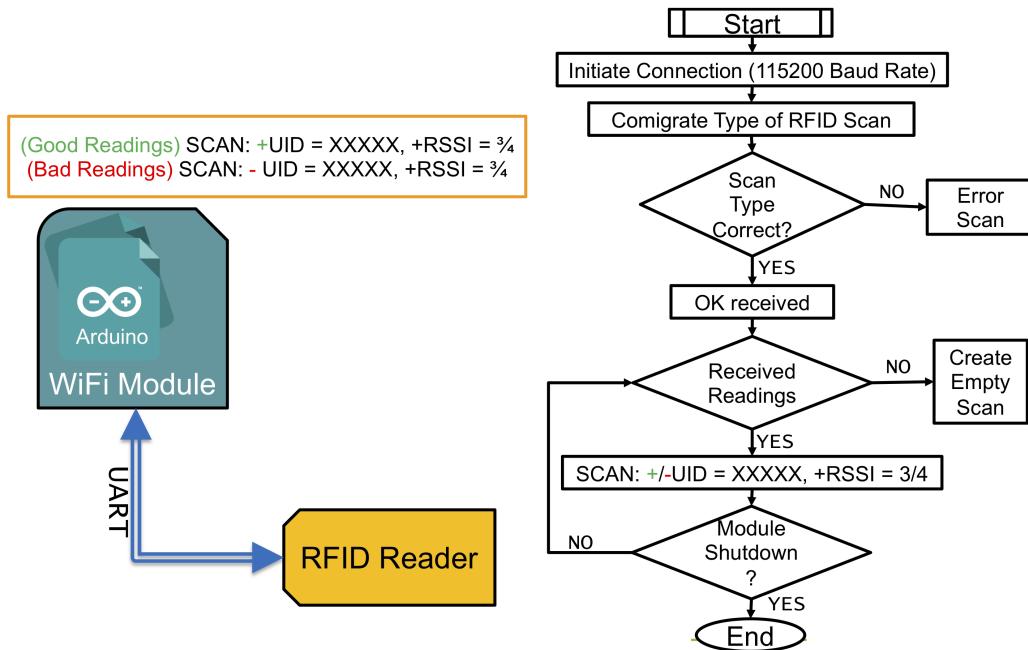


Figure 29: RFID-WeMos Module Communication

A TCP-IP communication is established within the network on the WeMos WiFi Module that start publishing the data which has been received from the reader. This communication is killed if and only if in the case of robot shutdown as shown in fig.30.

While on the other side on computer GUI (Graphical User Interface), the same type of communication is established (which should be in same network), and should grasp all the data that has been published by the WeMos WiFi module even if it no data is sent. This communication can be stopped from the GUI if needed as shown in fig.31.

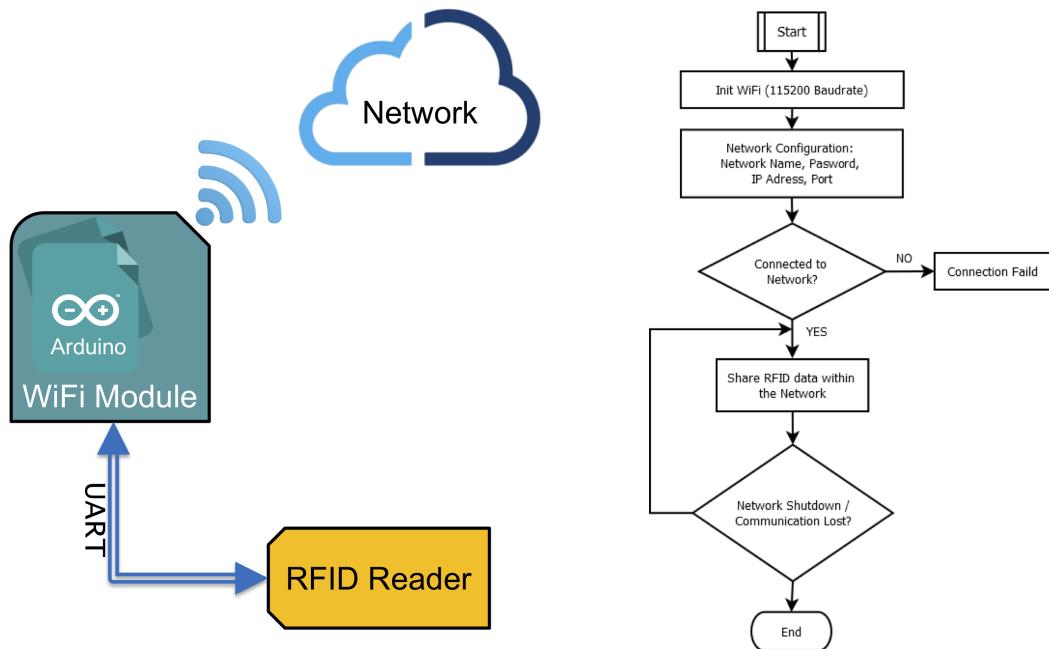


Figure 30: WeMos Module Network Communication

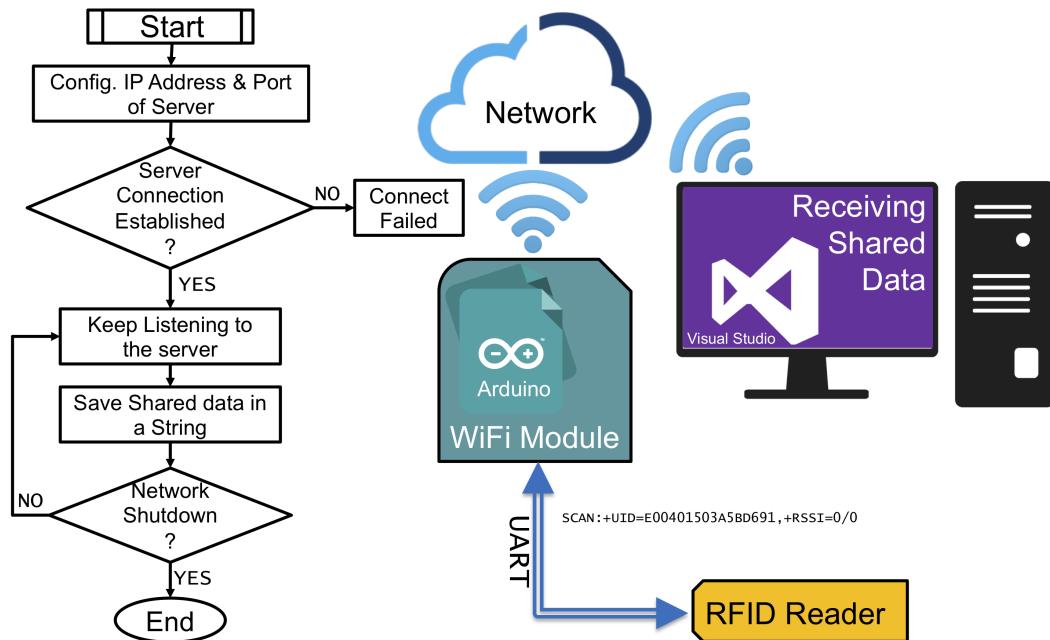


Figure 31: Computer Network Communication

7.2 Initialization procedure ⁷

In the start-up phase, before running the pipeless 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. 32 four possible AGV positions with one common antenna position are pointed out.

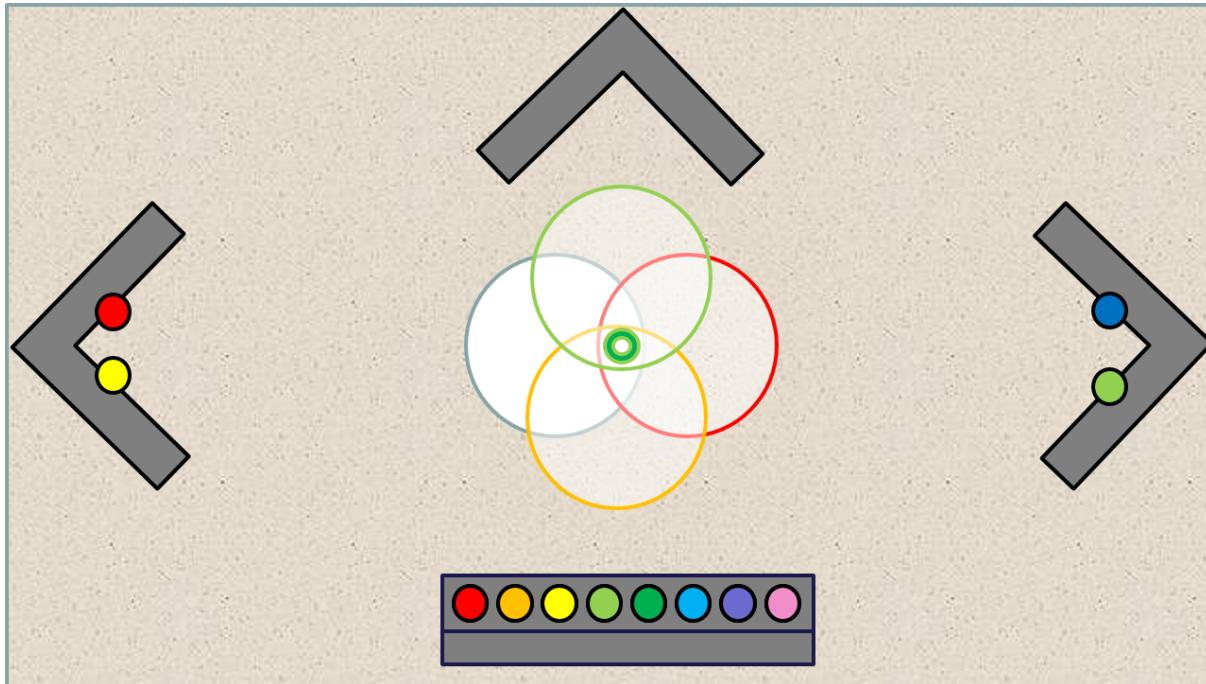


Figure 32: Different possible positions for one antenna position

Since the position information is crucial for the plant, a procedure was set up to determine the starting positions of each and every AGV. According to the fact, that the position and orientation of a single AGV is unknown at the beginning, 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. 33.

⁷Stephan and Stefan

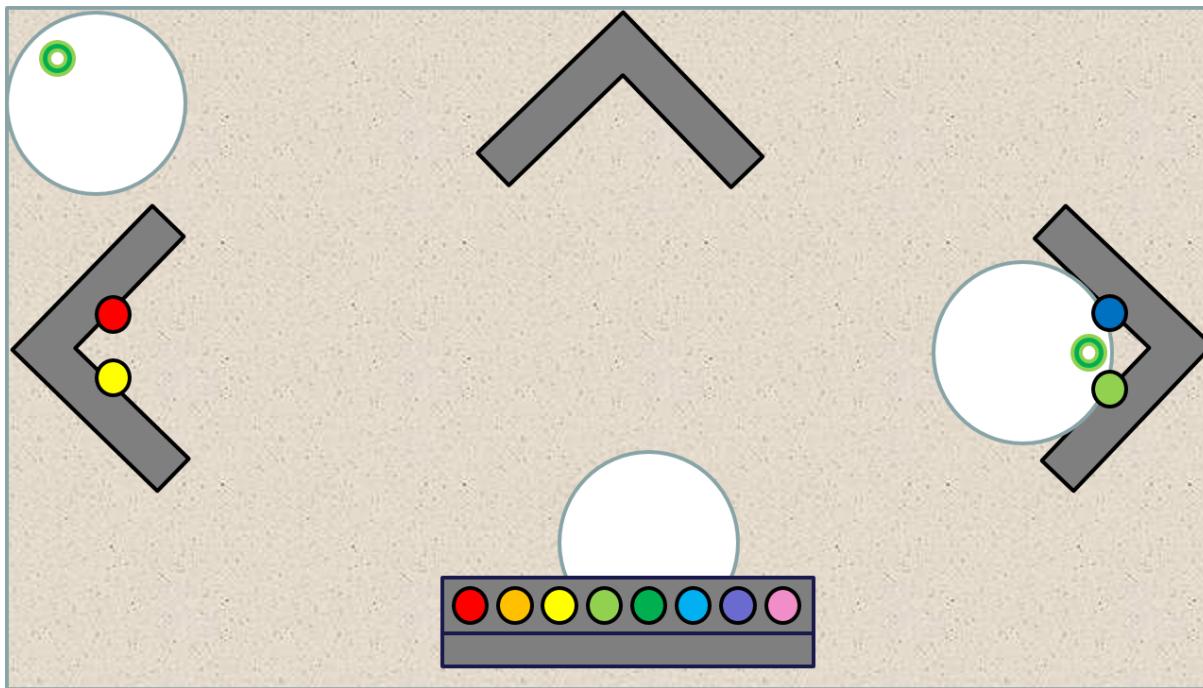


Figure 33: Possible hazards/obstacles

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 z axis without a change of the AGVs center point in x and y direction. 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 z 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. 34 illustrates a sequential flow chart which describes the movement and data processing during the initialization procedure.

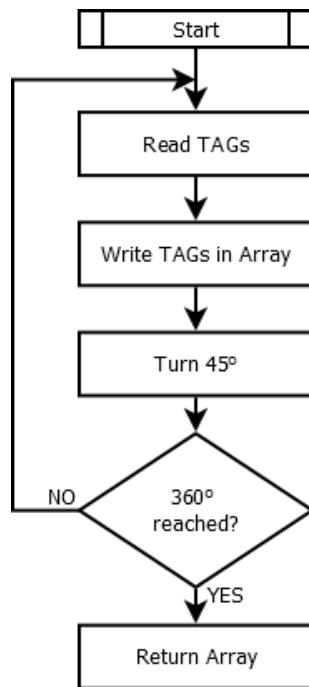


Figure 34: Flow Chart: Initial procedure 360° turn

The initialization procedure for AGV No. 1 is created and can be started in the GUI in the test environment. In the first place an integer number is given to the field called Sleepetime. This integer number is interpreted in milliseconds and describes the time of rotation. Even though a time for a complete turn of 45° 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 in fig. 35.

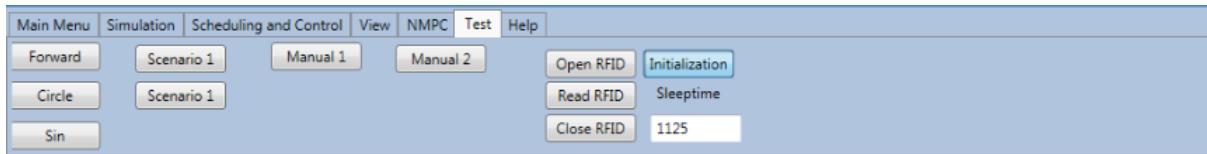


Figure 35: Test environment in GUI

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[10]. 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. Experiences have shown, that a measuring time between one and two seconds delivers the best results. During this time every 100 ms new measurement information are taken. In order to save the single TAG information of each and every measuring point an initially empty array with 14 columns and 8 rows is created. The number of rows is derived by the fact that measurements are taken at every 45° .

$$Rows = 360^\circ / 45^\circ = 8 \quad (12)$$

$$(13)$$

The first seven columns in the array are filled by the received TAG IDs and the last seven entries are filed 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.

$$Columns = max.no.oftags * 2 = 7 * 2 = 14 \quad (14)$$

$$(15)$$

Once the received data is saved in its corresponding row, the AGV turns around 45° to place the antenna at the next measuring point. An 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 10.

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 10: Filled array after 360° turn

7.2.1 Recording and filtering data⁸

To read the ID 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. In this mode packages of strings with a length of 35 characters are received 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 seperate the useful parts which are processed in the localization algorithm.

With exception of the information each and every string contains, the structure itsevle is always the same. In the first five characters the substring “SCAN:” is detected 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 the 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 received information the measurments are filtered by the “+” and the measurements in which a “-” is included are ignored in the further processes. After the indicator for complete and in complete readings a introduction to the ID is indicated by “UID= ” and cut out of the string. The next 16 characters defines the unique identification of the specific TAG. As a last useless string, which has to be cut out, with the structure “.RSSI= ” is found directly after the ID. As a result the 16 character hexadecimal ID and its respective RSSI are seperated from the received string. Since the ordered tag IDs differ each other just in the last three numbers these numbers are transformed in a decimal number before UID and RSSI are used for further computations.

String Transformation	
Complete	Incomplete
SCAN:+UID=E00401503A5BD691,+RSSI=0/0	SCAN:-UID=E00401503A5BDAE4
UID=E00401503A5BD691,+RSSI=0/0	
E00401503A5BD691 0/0	
1681 0	

Table 11: String preperation

7.2.2 Analysing data⁹

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 other measurement point in one set needs to have a distance of 180° to the first.

⁸Stefan

⁹Stefan

In terms to get the adequate sets of measurement points the array is analyzed row by row. The stepwise workflow is visualized in fig. 36.

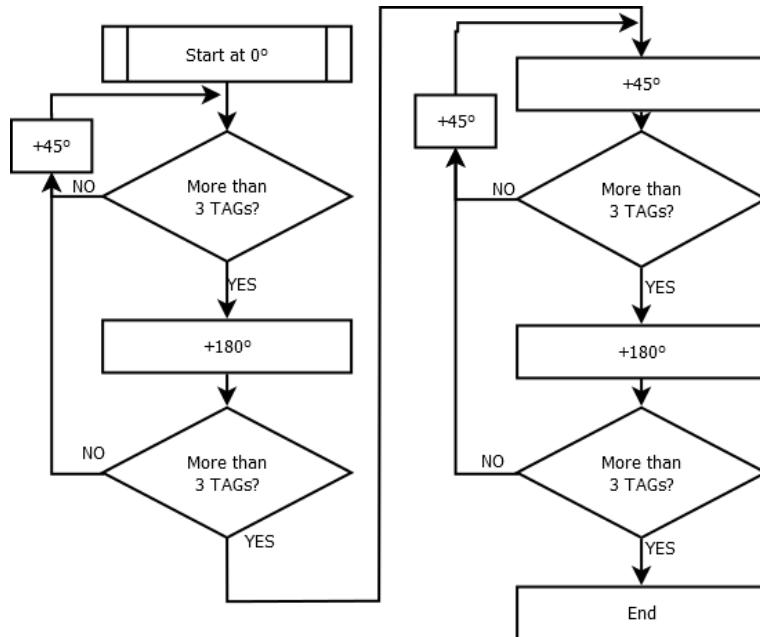


Figure 36: Flow Chart: Analizing measurment points

Initially the first row which represents the measurement at the point 0° is checked in terms of the number of readable tags. If this specific number is higher or equal three 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, the first valid set of two measurement points is found. If, on the other hand, the number of readable TAGs are less than three, which means that the triangulation algorithm cannot be performed, the current measurement point is ignored and the next measurement point is evaluated. Each of this sets of two measurement points is saved as a 1×2 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 RSSI¹⁰

In a first step the multiple occurring data points (see [tbl.8](#)) are divided into three groups (max, middle and min) where max means the maximal possible distance related to one RSSI and so on.

10 Stephan

The measurements have 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. 37:

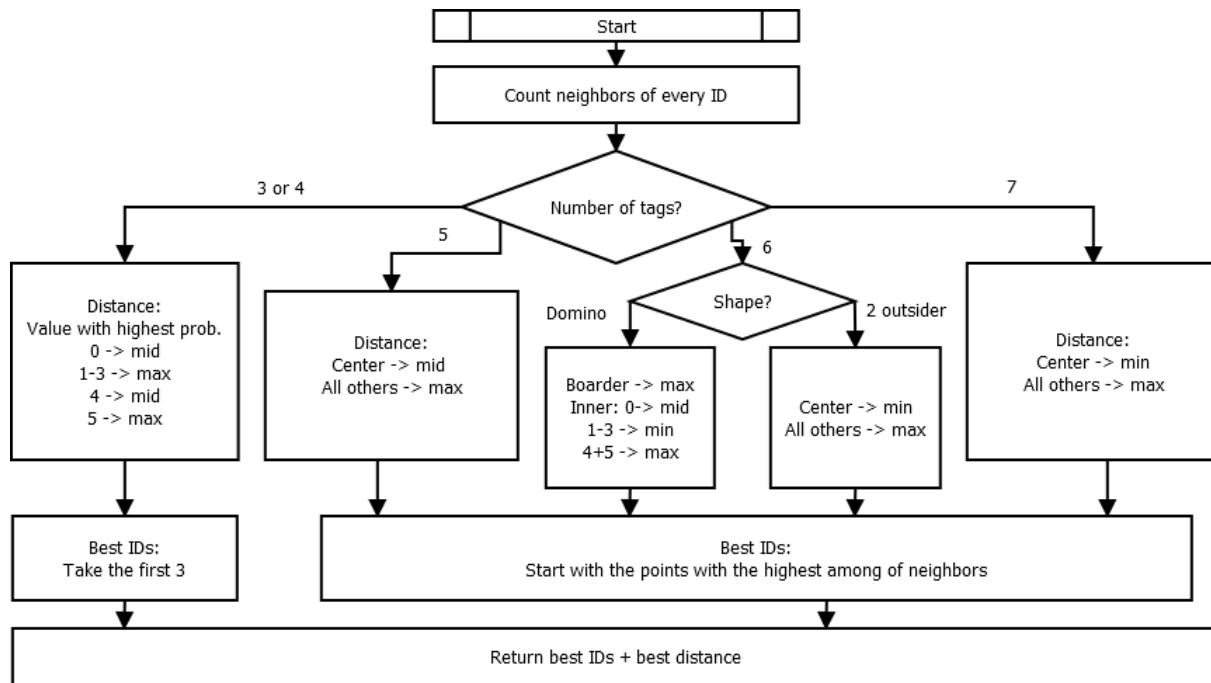


Figure 37: Flow Chart: Selection of correct distance and most proper IDs

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 in this scenario several numbers (4-7) of detected tags are possible. The different shapes can be found in thetbl. 12.

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

Table 12: Possible shapes of pattern

Going back to the flow chart fig.37 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, a tag with 3 neighbours in a pattern of 5 tags, is 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 4 detected tags are leading 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

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

leads 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 ¹¹

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.38 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 equations:

$$x = \frac{(x_1y_2 - y_1x_2)(x_3 - x_4) - (x_1 - x_2)(x_3y_4 - y_3x_4)}{(x_1 - x_2)(y_3 - y_4) - (y_1 - y_2)(x_3 - x_4)} \quad (16)$$

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

Theoretically all eight measuring points are 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

¹¹Stephan

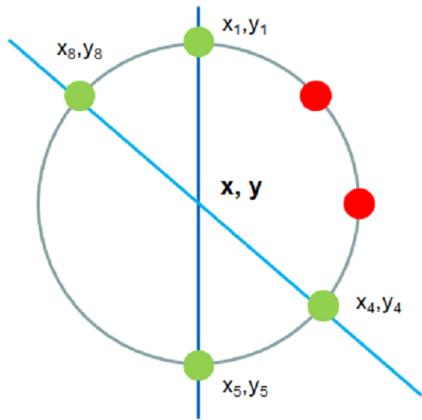


Figure 38: Computing the center of the robot

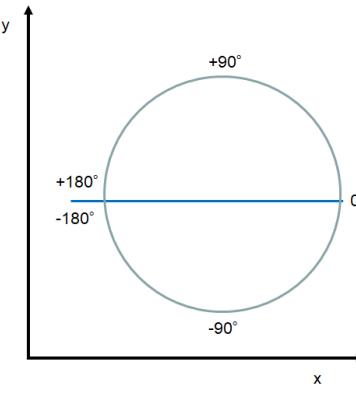


Figure 39: Orientation of robot in absolute angle

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.39.

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 setup¹²

In order to verify the validity of the initialization procedure, experiments with the components mentioned in chapter 5 were carried out. The beginning of these experiments were the reconstruction of one of the AGVs with this HW setup. After all components were added to the AGV the power supply was realized 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.40 gives an overview of the test setup and shows that also 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.13.

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.

¹²Stephan

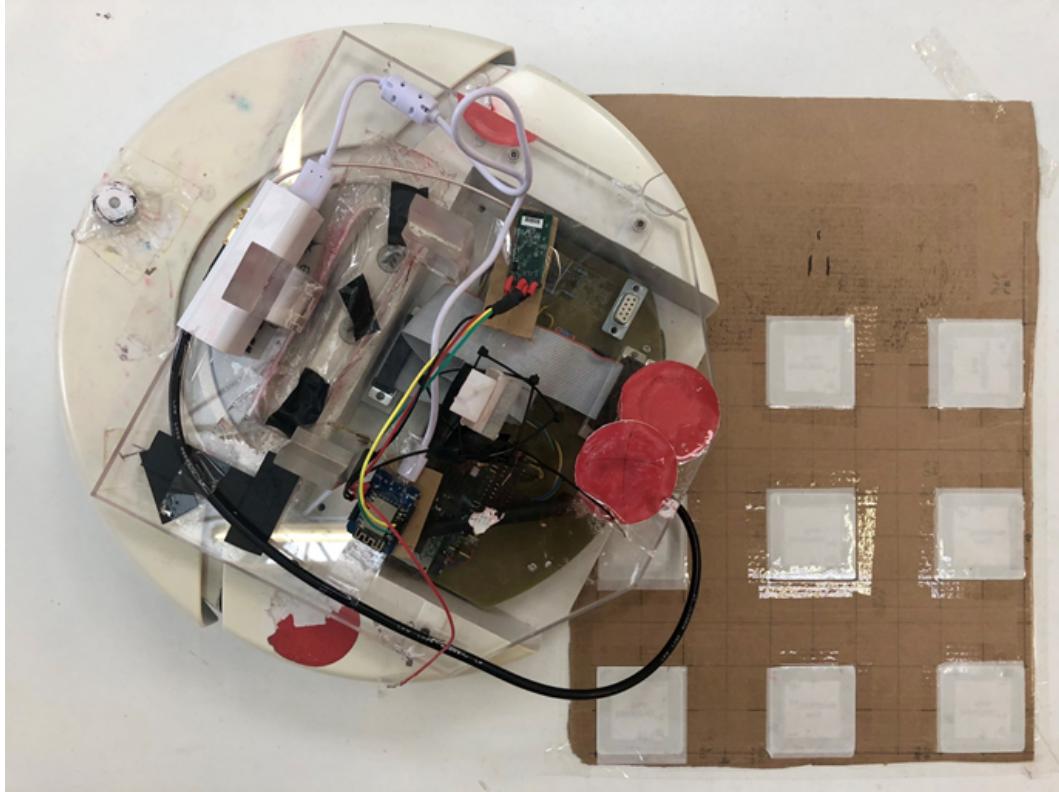


Figure 40: testing setup for initialization procedure

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 13: 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 1125 ms and is highly correlated to the battery status of the AGV.

7.4 Results¹³

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.41 and fig.42 illustrate the actual measurement results and the desired position in x- and y-direction.

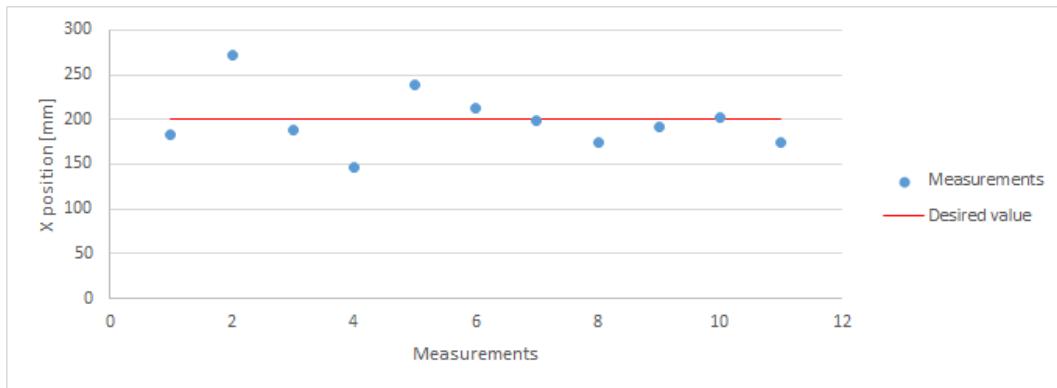


Figure 41: Estimated position in x-direction

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.41, 42 and 43).

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.

¹³Stephan

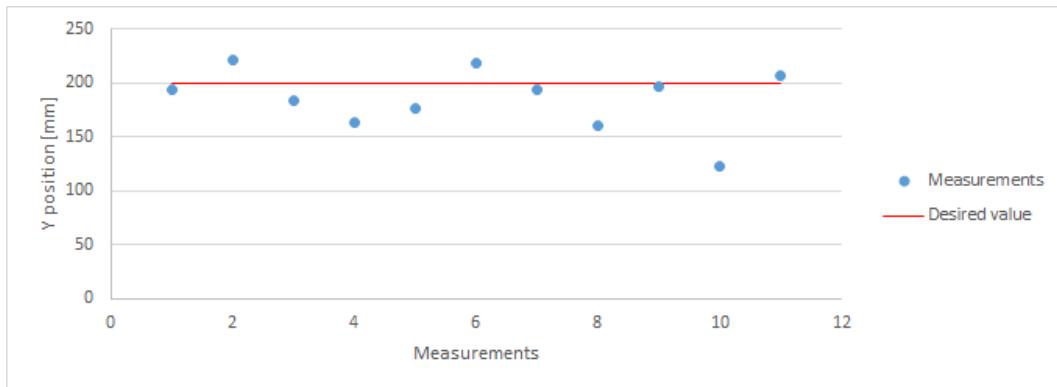


Figure 42: Estimated position in y-direction

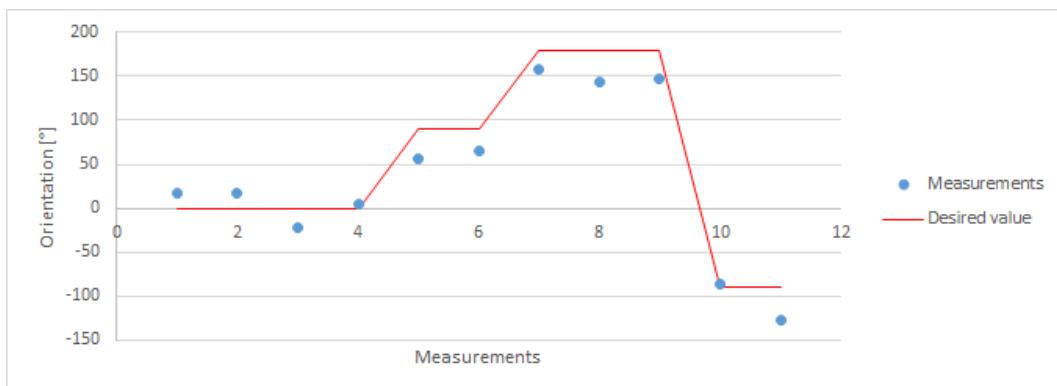


Figure 43: Estimated orientation

8 Conclusion¹⁴

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 to find an alternative tracking solution. During the project group phase different localization technologies were evaluated. With respect to the outcome researches about triangulation, map-based-localization, pattern recognition and localization via radio frequency identification the last RFID based localization of the AGV with passive tags as landmarks turned out to be the most promising among those four. With information of a similar project realized by the FH Dortmund a model to evaluate sample data and a localization algorithm was created in Matlab. The results of the simulation were promising and therefore used during the decision making process about the actual hardware setup. With a demonstration board with the size of 30 cm x 30 cm the initialization procedure algorithm was implemented in which the AGV performs a 360° turn and estimates its position and its orientation based on measurements during this movement. With respect to this solution it can be said that it is possible to assemble a reader on an AGV and detect passive tags with its antenna in a range of 14 cm. It also has been found out that an inconsistent realization between the reviewed signal strength (RSSI) of the detected TAGs and the distance based on the RSSI is not generally trivial and was only solved in a rather simple and unreliable way during the project. Based on the results computed by the initialization procedure, it can be concluded that it is 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°. Compared to the former localization set up this solutions, especially with respect to the orientation error, are not perfectly satisfying and just minimal requirements are fulfilled. The received data from the RFID reader have furthermore clearly shown that the anti-collision algorithm used by the reader leads to an unknown amount of time until each and every TAG in the detection area is identified. Summed up a model based demonstrator was realized which on the one hand does not improve the accuracy of the localization of the plant under good light conditions especially with respect to the orientation but on the other hand a promising technology for indoor localization with light independence, respectively cheap costs and highly scalability was found.

¹⁴Stephan and Stefan

9 Future Work¹⁵

After a proof-of-concept for an RFID based localizatin 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 zentralized power supply a 12 V to 5 V converter can be installed and connected to the reader and wifi module.
- As a first setup a demonstration area of 3 x 3 tags was build. In this rather small area the initializaion procedure was developed, but a real time localization while a path is followed by an AGV was not possible since the 30cm x 30cm was simply to small. For futrue research in terms of localizaion on a specified path 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 Robot No. 1 is the only AGV which is equipped with the RFID technology. To run the plant with multible AGVs the remaining robots needs to be upgraded.

9.2 Software

- During the initalizatin procedure a 360° turn is performed. The desired turn around 45° is realized by a driving time of 1125 ms. But it needs to be said that this movement is highly dependend 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 of the parameter time.
- As an alternative localization technology was found several code lines in the current code 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 realiable and the accuracy especially with respect to the orientation is not satisfying so far. As an improvement the triangulation algorithm has to be optimized and or a second RFID-antenna has to be added under the AGV to reduce measurment errors.

¹⁵Stefan

10 References

References

- [1] Yihuan Zhang Liang Wang and Jun Wang. Map-based localization method for autonomous vehicles using 3d-lidar. *IFAC (International Federation of Automatic Control) Hosting by Elsevier*, 50, 2017.
- [2] Dr.-Ing. habil. Dipl.-Ing. Dipl.-Ing. Joerg Wollnack. Prinzip der dreidimensional messenden videometrischen messsysteme.
- [3] Jeremie Houssineau, Daniel Clark, Spela Ivezkovic, Chee Sing Lee and Jose Franco. A unified approach for multi-object triangulation, tracking and camera calibration.
- [4] Yuntian Brian Bai, Suqin Wu, Hongren Wu, and Kefei Zhang. Overview of rfid-based indoor positioning technology, 2012.
- [5] Jun Liu Baoxian Zhang and Haoyao Chen. Amcl based map fusion for multi-robot slam with heterogenous. *IEEE International Conference on Information and Automation (ICIA)*, 6, 2013.
- [6] ROS. Amcl, 2018.
- [7] Hanifa SHAH Kamran AHSAN and Paul KINGSTON. Rfid applications: An introductory and exploratory study. *International Journal of Computer Science Issues*, 7(3), 2010.
- [8] Vinita Sharma Ms.Neha Kamda and Sudhanshu Nayak. A survey paper on rfid technology, its applications and classification of security/privacy attacks and solutions. *IRACST - International Journal of Computer Science and Information Technology & Security*, 6(4), 2016.
- [9] 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.
- [10] KTS Systeme. Rfid plug module rfidm1356, 2017.
- [11] WEMOS. Wemos d1 mini, 2018.
- [12] 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 = 11;     % 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
            % mode=2: tracking only changes in the RSSI signals
33 mode_hex = 0; % activate or deactivate hex ID
34
35 % For the name of the txt file
36 measuementeNumber = num2str(11); % Number of measurement
37 % Two possibilities for the content of the txt file
38 % 1. Without filtering. Exactly like the reader creates data
39 % text0 = '<\r>';
40 % text1 = 'OK';
41 % text2 = 'SCAN:+UID=';
42 % text3 = '+RSSI=';
43
44 % 2. Filtered data. Without unusable information.
45 text0 = ',';
46 text1 = ',';
47 text2 = ',';
48 text3 = ',';
49
50 %% Error check
51 if mod(11/d1,1) ~= 0
52     error('Length of platform not dividable by distance between tags');
53 elseif mod(12/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(gamma1), sin(gamma1)];
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',measuementeNumber,'.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',gamma1); % 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_StartngProc_like_reader_real_data',measuementeNumber,'.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(gamma1), sin(gamma1)];
131 figure(2)
132 for l=0:360/angle1
133     deltaR_temp = deltaR * l;
134     xUpdateAnt = robStart(1) + d3 * cos(gamma1 + deltaR_temp);
135     yUpdateAnt = robStart(2) + d3 * sin(gamma1 + deltaR_temp);
136     plot(x1, y1, 'LineWidth',2)
137     hold on
138     xlim([-5 (11+5)]);
139     ylim([-5 (12+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 (11+5)]);
146     ylim([-5 (12+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),
172                     text4);
173     end
174 end

```

```

                text0);
171    end
172        fprintf( ' %d %d %ld\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),
184                     text3 ,k(end) ,text0);
185         elseif mode_hex == 0
186             fprintf(fileID , '%d %s%d%s%d%s\n' ,l*angle1 ,text2 ,m ,text3 ,k(end) ,
187                     text0);
188         end
189         fprintf(' %d %d %8d,\n' ,l*angle1 ,m,k(end));
190     elseif mode == 1
191         if mode_hex == 1
192             fprintf(fileID , '%d %s%s%s%d%s\n' ,l*angle1 ,text2 ,dec2hex(m, 16),
193                     text3 ,k(end) ,text0);
194         elseif mode_hex == 0
195             fprintf(fileID , '%d %s%d%s%d%s\n' ,l*angle1 ,text2 ,m ,text3 ,k(end) ,
196                     text0);
197         end
198         fprintf(' %d %d %ld,\n' ,l*angle1 ,m,k(end));
199     end
200     streamDataRSSIold = streamDataRSSI;
201     pause(cycleT/1000)
202     timeStep = timeStep + 1;
203 end
204 savefig('Figure2.fig');
205 fclose(fileID);
206 %% Results
207 %% figure(3) % plot for the max value of every tag
208 %% dataRSSInoT = reshape(max(dataRSSI),[numTagsX,numTagsY]);
209 %% plot3(Tagx,Tagy,dataRSSInoT,'*');
210 %% xlabel('Length platform in cm')
211 %% ylabel('Width platform in cm')
212 %% title('Max RSSI signal of every tag')
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')

```

11.2 Appendix B: Receiving data from reader via Wifi (C#)

```
1 %using System;
2 using System.Collections.Generic;
3 using System.Linq;
4 using System.Text;
5 using System.Windows;
6 using System.IO;
7 using System.Threading;
8 using System.Net;
9 using System.Net.Sockets;
10 using MULTIFORM_PCS.ControlModules.SchedulingModule;
11 using MULTIFORM_PCS.ControlModules.FeedForwadModule;
12 using MULTIFORM_PCS.ControlModules.RoutingModule.PathAndVelocityPlanning.
    DataTypes;
13 using MULTIFORM_PCS.ControlModules.CameraModule.CameraForm;
14 using MULTIFORM_PCS.ControlModules.CameraControl.CameraControlClass;
15 using System.Windows.Threading;
16 using System.Diagnostics; // Process
17 using System.Globalization;
18 using Emgu.CV.WPF;
19 using System.Threading.Tasks;
20 using System.Collections.Concurrent;
21
22 namespace MULTIFORM_PCS.ControlModules.RFID
23 {
24     public class receive
25     {
26         public string[] availablearray=new string[1];
27         public void connect()
28         {
29             try
30             {
31                 Console.WriteLine("Connecting");
32                 TcpClient tcpClient = new TcpClient("192.168.0.100", 8883);
33                 if (tcpClient.Connected)
34                 {
35                     Console.WriteLine("Connected to server");
36                 }
37             }
38             catch (Exception e)
39             {
40                 Console.WriteLine("Connection Failed");
41             }
42         }
43
44         public void reading(CancellationToken ct)
45         {
46             if (ct.IsCancellationRequested == true)
47             {
48                 ct.ThrowIfCancellationRequested();
```

```
49
50
51     Console.WriteLine("Connecting");
52     TcpClient tcpClient = new TcpClient("192.168.0.100", 8883);
53
54     if (tcpClient.Connected)
55     {
56         Console.WriteLine("Connected to server");
57     }
58
59     using (StreamReader STR = new StreamReader(tcpClient.GetStream()))
60     {
61         string recieve;
62         char[] trash = new char[16];
63         char[] UID = new char[3];
64         char[] RSSI = new char[3];
65         long milliseconds, seconds, minutes;
66         string UID_, RSSI_, RSSI___;
67         string[] array = new string[1];
68
69         List<string> RSSI__;
70         int UID_DEC=0;
71         int RSSI_int = 0;
72
73         while ((recieve = STR.ReadLine()) != null && !ct.
74                 IsCancellationRequested)
75         {
76             if (ct.IsCancellationRequested)
77             {
78                 try
79                 {
80                     ct.ThrowIfCancellationRequested();
81                 }
82                 catch (AggregateException e)
83                 {
84                 }
85             }
86
87             if (recieve.Contains("+"))
88             {
89
90                 List<string> Worte = recieve.Split(new string[] { "OK",
91                     "<\\r>", "\\n", "", "SCAN:+UID=", "+RSSI=" },
92                     StringSplitOptions.RemoveEmptyEntries).ToList();
93                 string Wort = string.Join("", Worte.ToArray());
94
95                 using (StringReader sr = new StringReader(Wort))
96                 {
97                     sr.Read(trash, 0, 13);
98                     sr.Read(UID, 0, 3);
99                     UID_ = new string(UID);
```

```
97             sr.Read(trash, 0, 1);
98             sr.Read(RSSI, 0, 1);
99             RSSI_ = new string(RSSI);
100            try
101            {
102                UID_DEC = Int32.Parse(UID_, System.Globalization.
103                               NumberStyles.HexNumber);
104            }
105            catch (Exception e)
106            {
107            }
108        }
109
110        RSSI__ = RSSI_.Split(new string[] { "," },
111                               StringSplitOptions.RemoveEmptyEntries).ToList();
112        RSSI___ = string.Join("", RSSI__.ToArray());
113        try
114        {
115            RSSI_int = Int32.Parse(RSSI___);
116        }
117        catch (Exception e)
118        {
119
120            milliseconds = DateTimeOffset.Now.Millisecond;
121            seconds = DateTimeOffset.Now.Second;
122            minutes = DateTimeOffset.Now.Minute;
123            array[0] = minutes + " " + seconds + " " + milliseconds
124            + " " + UID_DEC + " " + RSSI_int;
125            //File.AppendAllText(AppDomain.CurrentDomain.
126            //BaseDirectory + "\\pythonfiles\\python_1robot\\"
127            //RFID_Data.log", minutes + " " + seconds + " "
128            + milliseconds + "\t UID: " + UID_ + " RSSI: " +
129            RSSI___ + "\r");
130            //File.AppendAllText(AppDomain.CurrentDomain.
131            //BaseDirectory + "\\pythonfiles\\python_1robot\\"
132            //RFID_Data_original.log", hour + ":" + minutes + ":" +
133            + seconds + ":" + milliseconds + "\t" + recieve + "\r");
134            //Console.WriteLine(minutes + " " + seconds + " "
135            + milliseconds + "\t" + " " + UID_ + " " + RSSI___);
136        }
137        this.availablearray[0] = array[0];
138    }
139}
140
141
142
143
144    public void disconnect()
145    {
```

```
136     TcpClient tcpClient = new TcpClient();
137     tcpClient.Connect("192.168.0.100", 8883);
138     tcpClient.Close();
139
140 }
141 }
142 }
```

11.3 Appendix C: Initialization procedure (C#)

```
1 %using System;
2 using System.Collections.Generic;
3 using System.Linq;
4 using System.Text;
5 using MULTIFORM_PCS.ControlModules.CameraModule.CameraForm;
6 using System.Threading;
7 using MULTIFORM_PCS.GUI;
8 using MULTIFORM_PCS.Gateway.ConnectionModule;
9 using MULTIFORM_PCS.ControlModules.RFID;
10 using System.Threading.Tasks;
11 using System.Collections;
12
13 namespace MULTIFORM_PCS.ControlModules.MPCModule
14 {
15     public class Position
16     {
17         public int X = 0;
18         public int Y = 0;
19     }
20
21     public class PositionD
22     {
23         public double X = 0;
24         public double Y = 0;
25     }
26
27     class Init
28     {
29         public static void initialize(Int32 time)
30         {
31             int messungen = 100;
32             //Gateway.ConnectionModule.ConnectionCTRLModule.getInstance().
33             setCTRLForRobot(0, 0.0, 100.0, 0.0, 8.0, 0.0, 0.0, 3.0);
34             receive initial = new receive(); //Create a new instance of
35             class Receive
36             var tokenSource = new CancellationTokenSource();
37             var token = tokenSource.Token;
38             Init compare = new Init();
39             string[] rfid_signals = new string[messungen];
40             int currentRobot = 0;
41             int[] RobotAssingment = new int[] { 0, 1, 3 };
42             Gateway CTRLModule.getInstance().camCtrl.
43                 processFrameAndUpdateGUI();
44             RobotDiscription[] RobotArray = new RobotDiscription[] { Gateway
45                 .CTRLModule.getInstance().camCtrl.RobotA, Gateway CTRLModule
46                 .getInstance().camCtrl.RobotB,
47                 Gateway CTRLModule.getInstance().camCtrl.RobotC };
48             double[][] velocity1 = new double[RobotArray.Length][];
49             string[,] Signals = new string[messungen,8];
```

```

45         velocity1[currentRobot] = new double[] { 0, 0 }; //Starts the
46         Robot
47         Gateway.CTRLModule.getInstance().getRobotRemoteCTRL(
48             RobotAssingment[currentRobot]).forward(velocity1[
49                 currentRobot], 0, 0, 0); //Sends velocity to Robot
50         //Opening a new Task which works in the background to read data
51         //from RFID Antenna
52         Task t = Task.Factory.StartNew(() => initial.reading(token));
53         Thread.Sleep(1000);
54         for (int i = 0; i < 8; i++)      //9 Because of 8 measurements
55             every 45 degree
56         {
57             for (int j = 0; j < messungen; j++)      //in this for loop we
58                 find all the reachable TAGs
59             {
60                 Signals[j, i] = initial.availablearray[0];
61                 Thread.Sleep(100);
62             }
63             velocity1[currentRobot] = new double[] { 100, -100 }; ////
64             Starts the Robot
65             Gateway.CTRLModule.getInstance().getRobotRemoteCTRL(
66                 RobotAssingment[currentRobot]).forward(velocity1[
67                     currentRobot], 0, 0, 0); //Sends velocity to Robot
68             Thread.Sleep(time); //time the robot needs for a 45 degree
69             turn
70             velocity1[currentRobot] = new double[] { 0, 0 }; //Stops
71             the Robot
72             Gateway.CTRLModule.getInstance().getRobotRemoteCTRL(
73                 RobotAssingment[currentRobot]).forward(velocity1[
74                     currentRobot], 0, 0, 0); //Sends velocity to Robot
75         }
76
77         tokenSource.Cancel();    //close the reading Thread
78         try
79         {
80             Task.WaitAll(t);
81         }
82         catch (AggregateException e)
83         {
84         }
85         finally
86         {
87             tokenSource.Dispose();
88         }
89         Console.WriteLine("END\r\n");
90
91         Array[] Liste = new Array[8];    //List of arrays each array in the
92         array contains the data of a special position (45°, 90°,...)
93         string[,] Init_array = new string[8, 14]; //Array filled with
94         signal strengthes and ID of every degree position
95         string temp_ID="begin", temp_RSSI; //Substrings of Data

```

```
81         int counter;      //Counter for the row in the Init_Array
82         Console.WriteLine("");
83
84         for (int j = 0; j < 8; j++)
85         {
86             counter = 0;
87             for (int i = 0; i < messungen; i++)
88             {
89                 try
90                 {
91                     temp_ID = Signals[i, j].Substring(Signals[i, j].Length -
92                                         6, 4);    //seperation of UID in the string
93                     if (temp_ID == "2788")
94                     {
95                         temp_ID = "1";
96                     }
97                     if (temp_ID == "1414")
98                     {
99                         temp_ID = "2";
100                    }
101                    if (temp_ID == "3060")
102                    {
103                        temp_ID = "3";
104                    }
105                    if (temp_ID == "1673")
106                    {
107                        temp_ID = "4";
108                    }
109                    if (temp_ID == "1925" || temp_ID == "1025")
110                    {
111                        temp_ID = "5";
112                    }
113                    if (temp_ID == "1681")
114                    {
115                        temp_ID = "6";
116                    }
117                    if (temp_ID == "1146")
118                    {
119                        temp_ID = "7";
120                    }
121                    if (temp_ID == "2780")
122                    {
123                        temp_ID = "8";
124                    }
125                    if (temp_ID == "1933")
126                    {
127                        temp_ID = "9";
128                    }
129                catch (AggregateException e)
130                {
```

```

131             Console.WriteLine("Array incomplete");
132         }
133
134         temp_RSSI = Signals[i, j].Substring(Signals[i, j].Length -
135             1, 1); //seperation of RSSI in the string
136         if (temp_ID != Init_array[j, 0] && temp_ID != Init_array[j,
137             1] && temp_ID != Init_array[j, 2] && temp_ID !=
138             Init_array[j, 3] && temp_ID != Init_array[j, 4] &&
139             temp_ID != Init_array[j, 5] && temp_ID != Init_array[j,
140             6] && temp_ID != Init_array[j, 7]) //check if the UID
141             already exists in the Init_array
142             {
143                 //Filling Init_Array
144                 Init_array[j, counter] = temp_ID;
145                 Init_array[j, counter + 7] = temp_RSSI;
146                 counter++;
147             }
148         }
149
150         int rowLength = Init_array.GetLength(0);
151         int colLength = Init_array.GetLength(1);
152         string str;
153         string headline = " | " + "ID 1" + " | " + "ID 2" + " | " + "ID 3" + "
154             | " + "ID 4" + " | " + "ID 5" + " | " + "ID 6" + " | " + "ID 7" +
155             " | " + "ST 1" + " | " + "ST 2" + " | " + "ST 3" + " | " + "ST 4" +
156             " | " + "ST 5" + " | " + "ST 6" + " | " + "ST 7" + " | ";
157         System.Console.WriteLine(headline);
158
159         for (int k = 0; k < rowLength; k++)
160         {
161             str = " | " + Init_array[k, 0] + " | " + Init_array[k, 1] + "
162                 | " + Init_array[k, 2] + " | " + Init_array[k, 3] + "
163                 | " + Init_array[k, 4] + " | " + Init_array[k, 5] + "
164                 | " + Init_array[k, 6] + " | " + Init_array[k, 7] + "
165                 | " + Init_array[k, 8] + " | " + Init_array[k, 9] + "
166                 | " + Init_array[k, 10] + " | " + Init_array[k, 11] +
167                 " | " + Init_array[k, 12] + " | " + Init_array[k, 13]
168                 + " | ";
169             System.Console.WriteLine(str);
170         }
171
172         // Solver
173         // Different Positions
174         Position Starting = new Position();
175         Position Antennal1 = new Position();
176         Position Antenna2 = new Position();
177         Position Antenna3 = new Position();
178         Position Antenna4 = new Position();
179
180         //Initialization for Position estimation

```

```
166         float m1 = 0.000f;
167         float m2 = 0.000f;
168
169         float RobStartx_f1 = 0.000f;
170         float RobStarty_f1 = 0.000f;
171
172         double angle;
173         double angleTemp;
174
175         int null_counter = 0;
176         int[] check_row = new int[8];
177         for (int m = 0; m < rowLength; m++)
178     {
179             null_counter = 0;
180             for (int n = 0; n < 7; n++)
181             {
182                 if (Init_array[m, n] == null)
183                 {
184                     null_counter++;
185                 }
186             }
187             check_row[m] = 7 - null_counter; //Array of elements with
188                                         //the number empty places of each init_array row
189             System.Console.WriteLine("The number of elements at " + m *
190                                         45 + "° is: \t" + check_row[m]);
191
192             bool solution_found = false; //true if initialization process
193                                         //is solvable
194             bool solution1_found = false; //true if one possible point is
195                                         //found
196             bool solution2_found = false; //true if two possible points
197                                         //are found
198             int count = 0;
199             int[] solution1 = new int[2]; //Array with the both degree
200                                         //numbers of solution 1
201             int[] solution2 = new int[2]; //Array with the both degree
202                                         //numbers of solution 2
203             while (solution_found == false)
204     {
205                 while (solution1_found == false)
206                 {
207                     if (check_row[count] >= 3)
208                     {
209                         if (check_row[count + 4] >= 3)
210                         {
211                             solution1[0] = count;
212                             solution1[1] = count + 4;
213                             break;
214                         }
215                         if (count >= 2) //if we reach the 180 degree
216                                         //there will be no solution for this
217                     }
218                 }
219             }
220         }
221     }
222 }
```

```
                                initialization turn
209
210    {
211        System.Console.WriteLine("NO SOLUTION FOUND!!!")
212        ;
213        break;
214    }
215    count++;
216
217    System.Console.WriteLine(count);
218    count = count + 1;
219    while (solution2_found == false)
220    {
221        if (check_row[count] >= 3)
222        {
223            if (count >= 8)
224            {
225                Console.WriteLine("Out of Range Exception caused
226                                in Array: " + count);
227            }
228            if (check_row[count + 4] >= 3)
229            {
230                solution2[0] = count;
231                solution2[1] = count + 4;
232                solution_found = true;
233                break;
234            }
235            if (count >= 3) //if we reach the 180 degree
236                there will be no solution for this
237                initialization turn
238            {
239                System.Console.WriteLine("NO SOLUTION FOUND!!!")
240                ;
241                break;
242            }
243        }
244    }
245    System.Console.WriteLine("Solution No. 1 found at: " +
246        solution1[0] * 45 + " degree -- " + solution1[1] * 45 +
247        " degree");
248    System.Console.WriteLine("Solution No. 2 found at: " +
249        solution2[0] * 45 + " degree -- " + solution2[1] * 45 +
        " degree");
}
// Providing the distance with the highest probability
```

```
250 // Input: # of tags, all IDs of the tags
251 // Output: best fitting IDs (e.g. [3 4 5] if 3rd, 4th and 5th
252 //          are best ones)
253 //          the correct distance <-> RSSI signal (e.g. [2 1 3]
254 //          for middle, max and min)
255 int[,] best_arr1 = new int[2, 3];
256 int[,] best_arr2 = new int[2, 3];
257 int[,] best_arr3 = new int[2, 3];
258 int[,] best_arr4 = new int[2, 3];
259
260 int[] temp_input1 = new int[7];
261 int[] temp_input2 = new int[7];
262 int[] temp_input3 = new int[7];
263 int[] temp_input4 = new int[7];
264
265 int[] temp_inputRSSI1 = new int[7];
266 int[] temp_inputRSSI2 = new int[7];
267 int[] temp_inputRSSI3 = new int[7];
268 int[] temp_inputRSSI4 = new int[7];
269
270 for (int i = 0; i < 8; i++)
271 {
272     for (int j = 0; j < 14; j++)
273     {
274         if (Init_array[i, j] == null)
275         {
276             Init_array[i, j] = "0";
277         }
278     }
279
280     for (int m = 0; m < 7; m++)
281     {
282         temp_input1[m] = Int32.Parse(Init_array[solution1[0], m]);
283         temp_input2[m] = Int32.Parse(Init_array[solution1[1], m]);
284         temp_input3[m] = Int32.Parse(Init_array[solution2[0], m]);
285         temp_input4[m] = Int32.Parse(Init_array[solution2[1], m]);
286
287         temp_inputRSSI1[m] = Int32.Parse(Init_array[solution1[0], m
288                                         + 7]);
289         temp_inputRSSI2[m] = Int32.Parse(Init_array[solution1[1], m
290                                         + 7]);
291         temp_inputRSSI3[m] = Int32.Parse(Init_array[solution2[0], m
292                                         + 7]);
293         temp_inputRSSI4[m] = Int32.Parse(Init_array[solution2[1], m
294                                         + 7]);
295     }
296
297     best_arr1 = CorrectID_Distance(temp_input1, temp_inputRSSI1,
298                                   check_row[solution1[0]]);
299     best_arr2 = CorrectID_Distance(temp_input2, temp_inputRSSI2,
```

```

294     check_row[solution1[1]]));
best_arr3 = CorrectID_Distance(temp_input3, temp_inputRSSI3,
    check_row[solution2[0]]);
best_arr4 = CorrectID_Distance(temp_input4, temp_inputRSSI4,
    check_row[solution2[1]]);

296
297 // Position of the antennae
298 Antenna1 = Trilateration(IDtoPOS(Int32.Parse(Init_array[
    solution1[0], best_arr1[0, 0]]), IDtoPOS(Int32.Parse(
    Init_array[solution1[0], best_arr1[0, 1]]),
    IDtoPOS(Int32.Parse(Init_array[solution1[0],
        best_arr1[0, 2]]), Int32.Parse(
        (Init_array[solution1[0], best_arr1[0, 0] + 7]),
        Int32.Parse(Init_array[solution1[0],
            best_arr1[0, 1] + 7]), Int32.Parse(
            Init_array[solution1[0], best_arr1[0, 2] + 7]),
            best_arr1[1, 0], best_arr1[1, 1],
            best_arr1[1, 2]));

300
301
302 Antenna2 = Trilateration(IDtoPOS(Int32.Parse(Init_array[
    solution1[1], best_arr2[0, 0]]), IDtoPOS(Int32.Parse(
    Init_array[solution1[1], best_arr2[0, 1]]),
    IDtoPOS(Int32.Parse(Init_array[solution1[1],
        best_arr2[0, 2]]), Int32.Parse(
        (Init_array[solution1[1], best_arr2[0, 0] + 7]),
        Int32.Parse(Init_array[solution1[1],
            best_arr2[0, 1] + 7]), Int32.Parse(
            Init_array[solution1[1], best_arr2[0, 2] + 7]),
            best_arr2[1, 0], best_arr2[1, 1],
            best_arr2[1, 2]));

304
305
306 Antenna3 = Trilateration(IDtoPOS(Int32.Parse(Init_array[
    solution2[0], best_arr3[0, 0]]), IDtoPOS(Int32.Parse(
    Init_array[solution2[0], best_arr3[0, 1]]),
    IDtoPOS(Int32.Parse(Init_array[solution2[0],
        best_arr3[0, 2]]), Int32.Parse(
        (Init_array[solution2[0], best_arr3[0, 0] + 7]),
        Int32.Parse(Init_array[solution2[0],
            best_arr3[0, 1] + 7]), Int32.Parse(
            Init_array[solution2[0], best_arr3[0, 2] + 7]),
            best_arr3[1, 0], best_arr3[1, 1],
            best_arr3[1, 2]));

308
309
310 Antenna4 = Trilateration(IDtoPOS(Int32.Parse(Init_array[
    solution2[1], best_arr4[0, 0]]), IDtoPOS(Int32.Parse(
    Init_array[solution2[1], best_arr4[0, 1]]),
    IDtoPOS(Int32.Parse(Init_array[solution2[1],
        best_arr4[0, 2]]), Int32.Parse(
        (Init_array[solution2[1], best_arr4[0, 0] + 7]),
        Int32.Parse(Init_array[solution2[1],
            best_arr4[0, 1] + 7]), Int32.Parse(
            Init_array[solution2[1], best_arr4[0, 2] + 7]),
            best_arr4[1, 0], best_arr4[1, 1],
            best_arr4[1, 2]));

```

```

314             Init_array[solution2[1], best_arr4[0, 1]])),
315             IDtoPOS(Int32.Parse(Init_array[solution2
316             [1], best_arr4[0, 2]])), Int32.Parse(
317             Init_array[solution2[1], best_arr4
318             [0, 0] + 7]),
319             Int32.Parse(Init_array[solution2[1],
320             best_arr4[0, 1] + 7]), Int32.Parse(
321             Init_array[solution2[1], best_arr4
322             [0, 2] + 7]),
323             best_arr4[1, 0], best_arr4[1, 1],
324             best_arr4[1, 2]);
325
326             Console.WriteLine("1st Antenna " + Antenna1.X + " and " +
327             Antenna1.Y);
328             Console.WriteLine("2nd Antenna " + Antenna2.X + " and " +
329             Antenna2.Y);
330             Console.WriteLine("3rd Antenna " + Antenna3.X + " and " +
331             Antenna3.Y);
332             Console.WriteLine("4th Antenna " + Antenna4.X + " and " +
333             Antenna4.Y);

334             //Console.ReadKey();
335             // Alternative estimation of the centre of the robot + position
336             //m1 = ((float)Antenna2.Y - (float)Antenna1.Y) / ((float)
337             //    Antenna2.X - (float)Antenna1.X);
338             //m2 = ((float)Antenna4.Y - (float)Antenna3.Y) / ((float)
339             //    Antenna4.X - (float)Antenna3.X);
340             //RobStartx_fl = (1 / (m1 - m2)) * (m1 * (float)Antenna1.X - m2
341             //    * (float)Antenna3.X - (float)Antenna1.Y + (float)Antenna3.Y)
342             ;
343             //RobStarty_fl = m1 * (RobStartx_fl - (float)Antenna1.X) + (
344             //    float)Antenna1.Y;

345             //Starting.X = (int)RobStartx_fl;
346             //Starting.Y = (int)RobStarty_fl;

347             Starting.X = (((Antenna4.X - Antenna3.X) * (Antenna2.X * Antenna1.Y -
348             Antenna1.X * Antenna2.Y) - (Antenna2.X - Antenna1.X) * (Antenna4.X *
349             Antenna3.Y - Antenna3.X * Antenna4.Y)) /
350                 ((Antenna4.Y - Antenna3.Y) * (Antenna2.X -
351                 Antenna1.X) - (Antenna2.Y - Antenna1.Y)
352                 * (Antenna4.X - Antenna3.X)));
353             Starting.Y = (((Antenna1.Y - Antenna2.Y) * (Antenna4.X *
354             Antenna3.Y - Antenna3.X * Antenna4.Y) - (Antenna3.Y -
355             Antenna4.Y) * (Antenna2.X * Antenna1.Y - Antenna1.X *
356             Antenna2.Y)) /
357                 ((Antenna4.Y - Antenna3.Y) * (Antenna2.X -
358                 Antenna1.X) - (Antenna2.Y - Antenna1.Y)
359                 * (Antenna4.X - Antenna3.X)));
360
361             Console.WriteLine("Robotstarting Position at:" + Starting.X + "
362             Starting.Y);

```

```
    mm, " + Starting.Y + "mm");  
339  
340     // Computing the orientation of the Robot  
341     //angle = (Math.Atan2(y, x)) * (180 / Math.PI);  
342     angleTemp = (Math.Atan2((Antenna1.Y - Starting.Y), (Antenna1.X -  
         Starting.X)) * (180 / Math.PI));  
343     Console.WriteLine("Angle temp " + angleTemp);  
344     angle = angleTemp - (double)(solution1[0]*45.0); // in deg  
345     Console.WriteLine("Angle wrong direction " + angle);  
346     if (angle <= 0.0)  
347     {  
348         angle = angle + 180;  
349     }  
350     else  
351     {  
352         angle = angle - 180;  
353     }  
354  
355     Console.WriteLine("Robotangle: " + angle + "°");  
356  
357 }  
358  
359 // Procedure and function  
360 // Method to compute the norm of a vector  
361 public static double Norm(PositionD p) // get the norm of a vector  
362 {  
363     return (Math.Pow(Math.Pow(p.X, 2) + Math.Pow(p.Y, 2), 0.5));  
364 }  
365  
366 //Methode to compute the position based on the ID in [cm], Output in [mm  
367 //]  
367 public static Position Trilateration(Position point1, Position point2,  
    Position point3, int rit, int r2t, int r3t, int bestr1, int bestr2,  
    int bestr3)  
368 {  
369     //double[] dist = new double[] { 10.5, 10.0, 9.5, 9.0, 8.0, 6.0,  
      5.0, 4.0 }; // FH paper  
370     double[,] dist = new double[3, 8] { { 14, 9.75, 9.0, 8.0, 7.0, 6.0,  
      3.5, 2.75 },  
371                                         { 5.0, 5.1, 5.3, 5.5, 5.8, 4.0,  
      3.5, 2.75 },  
372                                         { 5.0, 4.7, 4.5, 4.3, 4.2, 4.0,  
      3.5, 2.75 } }; //  
// Approximation of our  
// measurements  
373  
374     Position resultPose = new Position();  
375     PositionD ex = new PositionD();  
376     PositionD ey = new PositionD();  
377     PositionD aux = new PositionD();  
378     PositionD auy = new PositionD();
```

```
379     PositionD aux2 = new PositionD();
380     double r1;
381     double r2;
382     double r3;
383     r1 = dist[bestr1, r1];
384     r2 = dist[bestr2, r2];
385     r3 = dist[bestr3, r3];
386
387     // For testing purpose
388     //Console.WriteLine("1st radius " + r1);
389     //Console.WriteLine("2nd radius " + r2);
390     //Console.WriteLine("3rd radius " + r3);
391
392     //Console.WriteLine("1st point " + point1.X + " " + point1.Y);
393     //Console.WriteLine("2nd point " + point2.X + " " + point2.Y);
394     //Console.WriteLine("3rd point " + point3.X + " " + point3.Y);
395
396     //unit vector in a direction from point1 to point 2
397     double p2p1Distance = Math.Pow(Math.Pow(point2.X - point1.X, 2) +
398         Math.Pow(point2.Y - point1.Y, 2), 0.5);
399     ex.X = (point2.X - point1.X) / p2p1Distance;
400     ex.Y = (point2.Y - point1.Y) / p2p1Distance;
401     aux.X = point3.X - point1.X;
402     aux.Y = point3.Y - point1.Y;
403     //signed magnitude of the x component
404     double i = ex.X * aux.X + ex.Y * aux.Y;
405     //the unit vector in the y direction.
406     aux2.X = point3.X - point1.X - i * ex.X;
407     aux2.Y = point3.Y - point1.Y - i * ex.Y;
408     ey.X = aux2.X / Norm(aux2);
409     ey.Y = aux2.Y / Norm(aux2);
410     //the signed magnitude of the y component
411     double j = ey.X * aux.X + ey.Y * aux.Y;
412     //coordinates
413     double x = (Math.Pow(r1, 2) - Math.Pow(r2, 2) + Math.Pow(
414         p2p1Distance, 2)) / (2 * p2p1Distance);
415     double y = (Math.Pow(r1, 2) - Math.Pow(r3, 2) + Math.Pow(i, 2) +
416         Math.Pow(j, 2)) / (2 * j) - i * (x / j);
417     //result coordinates
418     double finalX = 10 * (point1.X + x * ex.X + y * ey.X);
419     double finalY = 10 * (point1.Y + x * ex.Y + y * ey.Y);
420     resultPose.X = (int)(finalX);
421     resultPose.Y = (int)(finalY);
422
423     return resultPose;
424 }
425
426 // Methode to compute the position based on the ID in [mm]
427 public static Position IDtoPOS(int ID)
428 {
429     Position FinalPos = new Position();
```

```
427         int[] posx = new int[9] { 10, 10, 10, 20, 20, 20, 30, 30, 30 };
428         int[] posy = new int[9] { 10, 20, 30, 10, 20, 30, 10, 20, 30 };
429         // For a 3x3 testing field
430         FinalPos.X = posx[ID - 1];
431         FinalPos.Y = posy[ID - 1];
432         return FinalPos;
433     }
434
435     // Find neighbours of the IDs
436     public static int[] FindNeig(int[] arrID, int numTags)
437     {
438         // Init
439         int[] neighbours = new int[numTags];
440         int[] tempNeig = new int[4];
441
442         // Find the number of neighbours
443         for (int m = 0; m < numTags; m++)
444         {
445             // Init
446             neighbours[m] = 0;
447
448             // Take actual ID and compute the possible neighbours
449             tempNeig[0] = arrID[m] - 11;
450             tempNeig[1] = arrID[m] - 1;
451             tempNeig[2] = arrID[m] + 1;
452             tempNeig[3] = arrID[m] + 11;
453
454             for (int v = 0; v < 4; v++)
455             {
456                 foreach (int tempinput in arrID)
457                 {
458                     if (tempinput == tempNeig[v])
459                     {
460                         neighbours[m] += 1;
461                     }
462                 }
463             }
464         }
465         return neighbours;
466     }
467
468     // Methode to compute the best IDs and correct distances
469     public static int[,] CorrectID_Distance(int[] arr, int[] arrRSSI, int
470     numTags)
471     {
472         // Inputs
473         /* arr = Array of all IDs
474          * arrRSSI = Array of all RSSI
475          * numTags = Int with the num of tags found
476          */
477         // Init
```

```
477     int[,] best = new int[2, 3];
478     int[] dist = new int[numTags];           // Array which contain the
479     best distance (max(0),middle(1),min(2))
480     int[] neighbours = new int[numTags];
481     int i = 0;
482     int p = 4;
483
484     // Compute the neighbours
485     neighbours = FindNeig(arr, numTags);
486
487     // Switch case for the different possible shapes
488     switch (numTags)
489     {
490         case 3:
491             Console.WriteLine("3 Tags -----");
492             for (int l = 0; l < neighbours.GetLength(0); l++)
493             {
494                 if (neighbours[l] == 0)          // Detect outlier and
495                     boarder
496                 {
497                     dist[l] = 1;                // stay max
498                 }
499                 else if (neighbours[l] <= 3)    // Detect outlier and
500                     boarder
501                 {
502                     dist[l] = 0;                // stay max
503                 }
504                 else if (neighbours[l] == 4)    // Detect the inner,
505                     change it to min/middle
506                 {
507                     dist[l] = 1;                // change it to middle
508                 }
509                 else if (neighbours[l] > 4)    // Detect the inner,
510                     change it to min/middle
511                 {
512                     dist[l] = 0;                // change it to middle
513                 }
514                 // all other numbers are at the boarder
515             }
516             // Select the best 3 readings
517             i = 0;
518             p = 4;
519             while (i < 3)                  // Start for the first ID
520             {
521                 for (int h = 0; h < neighbours.GetLength(0); h++) // looks for a fitting
522                 {
523                     if (neighbours[h] == p && i < 3) // hit must be
524                         same value and less then 3 hits
525                     {
526                         best[0, i] = h;            // index of the
```

```

521             best ID
522             best[1, i] = dist[h];           // info about
523             max, mid and min of this ID
524             i += 1;
525         }
526         else if (i >= 3)
527         {
528             break;
529         }
530     }
531     break;
532 /*
-----*/
533 case 4:
534     Console.WriteLine("4 Tags -----");
535     for (int l = 0; l < neighbours.GetLength(0); l++)
536     {
537         if (neighbours[l] == 0)          // Detect outlier and
538             boarder
539         {
540             dist[l] = 1;                // stay max
541         }
542         else if (neighbours[l] <= 3)    // Detect outlier and
543             boarder
544         {
545             dist[l] = 0;                // stay max
546         }
547         else if (neighbours[l] == 4)    // Detect the inner,
548             change it to min/middle
549         {
550             dist[l] = 1;                // change it to middle
551         }
552         else if (neighbours[l] > 4)    // Detect the inner,
553             change it to min/middle
554         {
555             dist[l] = 0;                // change it to middle
556         }
557         // all other numbers are at the boarder
558     }
559     // Select the best 3 readings
560     i = 0;
561     p = 4;
562     while (i < 3)                  // Start for the first ID
563     {
564         for (int h = 0; h < neighbours.GetLength(0); h++) // looks for a fitting
565         {
566             if (neighbours[h] == p && i < 3) // hit must be

```

```

563                         same value and less then 3 hits
564             {
565                 best[0, i] = h;                                // index of the
566                 best ID
567                 best[1, i] = dist[h];                      // info about
568                 max, mid and min of this ID
569                 i += 1;
570             }
571             else if (i >= 3)
572             {
573                 break;
574             }
575         p -= 1;
576     }
577
578     break;
579 /*
580 */
581 case 5:
582     Console.WriteLine("5 Tags -----");
583     for (int l = 0; l < neighbours.GetLength(0); l++)
584     {
585         if (neighbours[l] <= 2)           // Detect outlier and
586             boarder
587         {
588             dist[l] = 0;                  // stay max
589         }
590         else if (neighbours[l] == 3)      // Detect the inner,
591             change it to min/middle
592         {
593             dist[l] = 1;                  // change it to middle
594         }
595         // all other numbers are at the boarder
596     }
597     // Select the best 3 readings
598     i = 0;
599     p = 4;
600     while (i < 3)                      // Start for the first ID
601     {
602         for (int h = 0; h < neighbours.GetLength(0); h++) // looks for a fitting
603         {
604             if (neighbours[h] == p && i < 3) // hit must be
605                 same value and less then 3 hits
606             {
607                 best[0, i] = h;                // index of the
608                 best ID
609                 best[1, i] = dist[h];        // info about
610                 max, mid and min of this ID
611             }
612         }
613     }

```

```
603             i += 1;
604         }
605         else if (i >= 3)
606     {
607         break;
608     }
609     p -= 1;
610 }
611 break;
612
613 /*
614 -----
615 */
616 case 6:
617     Console.WriteLine("6 Tags -----");
618     switch (neighbours.Sum())
619     {
620         case 12: // Shape with 2 outliers
621             Console.WriteLine("2 Outliers");
622             for (int l = 0; l < neighbours.GetLength(0); l++)
623             {
624                 if (neighbours[l] <= 2)          // Detect outlier
625                     and boarder
626                 {
627                     dist[l] = 0;                  // stay max
628                 }
629                 else if (neighbours[l] == 4)    // Detect the
630                     inner, change it to min/middle
631                 {
632                     if (arrRSSI[l] <= 3)
633                     {
634                         dist[l] = 2;              // change it to
635                         min
636                     }
637                 }
638             // all other numbers are at the boarder
639         }
640         break;
641     case 14: // Shape like a domino
642         Console.WriteLine("Domino");
643         for (int l = 0; l < neighbours.GetLength(0); l++)
644         {
645             if (neighbours[l] <= 2)          // Detect outlier
646                     and boarder
647             {
```

```

647                     dist[1] = 0;           // stay max
648     }
649     else if (neighbours[1] == 3)      // Detect the
650         centre, change it to min
651     {
652         dist[1] = 2;           // change it to min
653     }
654     // all other numbers are at the border
655     }
656     break;
657     default:
658         Console.WriteLine("Default case");
659         break;
660     }
661     // Select the best 3 readings
662     i = 0;
663     p = 4;
664     while (i < 3)                  // Start for the first ID
665     {
666         for (int h = 0; h < neighbours.GetLength(0); h++) // looks for a fitting
667         {
668             if (neighbours[h] == p && i < 3) // hit must be
669                 same value and less than 3 hits
670             {
671                 best[0, i] = h;           // index of the
672                 best ID
673                 best[1, i] = dist[h]; // info about
674                 max, mid and min of this ID
675                 i += 1;
676             }
677             else if (i >= 3)
678             {
679                 break;
680             }
681         }
682     }
683     break;
684 /*
685 -----
686 */
687 case 7:
688     Console.WriteLine("7 Tags -----");
689     for (int l = 0; l < neighbours.GetLength(0); l++)
690     {
691         if (neighbours[l] <= 3)      // Detect outlier and
692             boarder
693         {
694             dist[l] = 0;           // stay max

```

```
690 }
691     else if (neighbours[1] == 4)      // Detect the centre,
692         change it to min
693     {
694         dist[1] = 2;                  // change it to min
695     }
696     // all other numbers are at the boarder
697 }
698 // Select the best 3 readings
699 i = 0;
700 p = 4;
701 while (i < 3)                      // Start for the first ID
702 {
703     for (int h = 0; h < neighbours.GetLength(0); h++) // looks for a fitting
704     {
705         if (neighbours[h] == p && i < 3) // hit must be same value and less then 3 hits
706         {
707             best[0, i] = h;           // index of the best ID
708             best[1, i] = dist[h];    // info about max, mid and min of this ID
709             i += 1;
710         }
711         else if (i >= 3)
712         {
713             break;
714         }
715         p -= 1;
716     }
717     break;
718 default:
719     Console.WriteLine("Default case");
720     break;
721 }
722 foreach (int ee in best)
723 {
724     Console.WriteLine(ee);
725 }
726 return best;
727 }
728 }
729 }
```

11.4 Appendix D: WeMos D1 Mini (Arduino)

```
1 #include <SoftwareSerial.h>
2 #include <ESP8266WiFi.h>
3 #include <ESP8266HTTPClient.h>
4 #include <string.h>
5 #include <ArduinoJson.h>
6
7
8 //how many clients should be able to telnet to this ESP8266
9 #define MAX_SRV_CLIENTS 2
10
11 // Definig Wifi address, password, host and port
12 //const char* ssid      = "UPC113C854 A.Abouelkhair";      // write SSID between "( here )"
13 //const char* password = "rnU3cu6dzpkA";                      // write Password between "( case sensitiv)"
14 //const char* ssid      = "iPhone";                            // write SSID between "( here )"
15 //const char* password = "boody123";                          // write Password between "( case sensitiv)"
16 const char* ssid     = "iRobot";                            // write SSID between "( here )"
17 const char* password = "nopipes123";                        // write Password between "( case sensitiv)"
18 //const char* ssid     = "DORTMUND-DEMO-AP";                  // write SSID
19 //const char* password = "R0b0tn1K";                          // write Password between "( case sensitiv)"
20
21 // Starting Wifi Server and client with Port 8883
22 WiFiServer server(8883);
23 WiFiClient serverClients[MAX_SRV_CLIENTS];
24
25 // Variables Declaration
26 unsigned long previousMillis = 0;
27 const long interval = 10;
28 unsigned long currentTime;
29
30 /* RFID Intialization */
31 SoftwareSerial RFID(14, 12, false, 256);      //RX,TX = D5,D6 (Wemos UART1)
32
33
34
35
36 void setup() {
37     // put your setup code here, to run once:
38
39     /* Beginning Serial Communication with RFID with baud rate 115200 */
40     RFID.begin(115200);
41     // delay(10);
```

```
42 // Beginning Serial Communication with baud rate 115200
43 Serial.begin(115200);
44 // delay(10);
45 Serial.println();
46
47
48 Serial.println();
49 Serial.print("Connecting to ");
50 Serial.println(ssid);
51
52 // Time is used so the device does not stuck in
53 // connecting to Wifi forever
54 currentTime = millis();
55 unsigned long previousTime = currentTime;
56 while (WiFi.status() != WL_CONNECTED) {
57     delay(500);
58     Serial.print(".");
59     currentTime = millis();
60     if ((currentTime - previousTime) > 12000) {
61         break;
62     }
63 }
64
65
66 WiFi.mode(WIFI_STA);
67 WiFi.begin(ssid, password);
68 uint8_t i = 0;
69 while (WiFi.status() != WL_CONNECTED && i++ < 20) delay(500);
70 if (i == 21) {
71     Serial.print("Could not connect to"); Serial.println(ssid);
72     while (1) delay(500);
73 }
74 server.begin();
75 server.setNoDelay(true);
76
77
78 // Getting the MAC address and saving it
79 if (WiFi.status() == WL_CONNECTED) {
80     Serial.println("");
81     Serial.println("WiFi connected");
82     Serial.print("IP address: ");
83     Serial.println(WiFi.localIP());
84     Serial.println("Port: 8883");
85 }
86
87 /* AUTO Send AT Command to the RFID */
88 RFID.write("AT+Scan=OFF\r");
89 // RFID.write("AT+Scan=AC,RSSI\r");
90 RFID.write("AT+Scan=AC,RSSI\r");
91
92 // delay(10);
```

```
93
94
95  }
96
97
98 void loop() {
99     // put your main code here, to run repeatedly
100
101    // while(RFID.available())
102    //
103    //     char read= RFID.read();
104    //     Serial.print(read);
105    //     delay(10);
106    //
107
108    /*Send commands Through Wifi*/
109    sendCommandsWiFi();
110
111    /* send AT Commands to RFID through serial monitor */
112    //Example: AT+Scan=AC,RSSI           "Without /r"
113    // Comment the next command if you are using AUTO command send
114    sendCommandsRFID();
115
116
117 }
118
119
120
121 void sendCommandsWiFi()
122 {
123
124     unsigned long currentMillis = millis();
125     uint8_t i;
126     //check if there are any new clients
127     if (server.hasClient()) {
128         for (i = 0; i < MAX_SRV_CLIENTS; i++) {
129             //find free/disconnected spot
130             if (!serverClients[i] || !serverClients[i].connected()) {
131                 if (serverClients[i]) serverClients[i].stop();
132                 serverClients[i] = server.available();
133                 continue;
134             }
135         }
136         //no free/disconnected spot so reject
137         WiFiClient serverClient = server.available();
138         serverClient.stop();
139     }
140
141     //do every 2ms edit from time interval in Declaration
142     // if (currentMillis - previousMillis >= interval)      //
143     // { //
```

```
144 //     previousMillis = currentMillis;  //
145     for (i = 0; i < MAX_SRV_CLIENTS; i++)
146     {
147         if (serverClients[i] && serverClients[i].connected())
148         {
149             delay(20);
150             RFID.write("AT+A\r");
151             while(RFID.available()>0)
152             {
153                 char read = RFID.read();
154                 serverClients[i].print(read);
155             }
156         }
157     }
158 }
159 // } //
160 }
161 }
162
163
164 void sendCommandsRFID()
165 {
166     /* send AT Commands to RFID through serial monitor */
167     //Example: AT+Scan=AC,RSSI           "Without \r"
168     while (Serial.available() > 0) {
169         RFID.write(Serial.read());
170     }
171 }
172 }
```

11.5 Appendix E: Communication Outlay

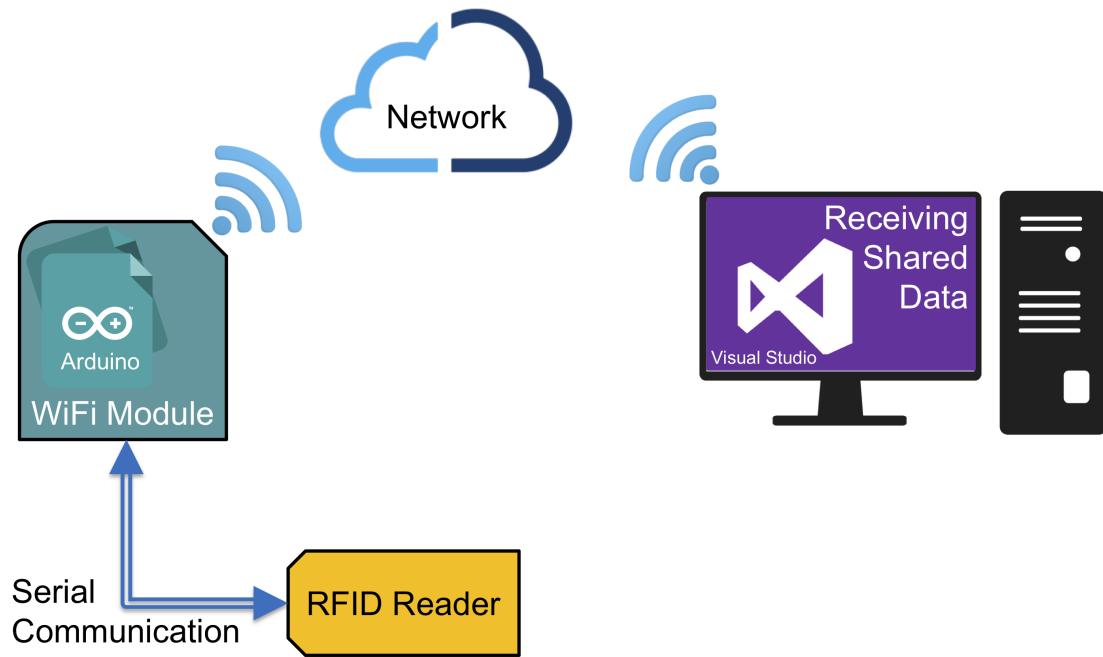


Figure 44: Communication Outlay