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Bachelor-Arbeit

Geometric Feature Extraction for Indoor Navigation

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Datum der Abgabe:	11. April 2021

Abstract

The intent of this thesis is to create a system that can detect Walls, Doors and Corners in an indoor office environment. We want to be able to detect these features to be able to automatically detect navigation situations add a semantic aspect to the wheelchairs' driving ability. Concretely, this means we wish to eventually be able to tell the wheelchair to go down the hallway, turn left at the intersection and go in the second door on the right and have the wheelchair know exactly what we mean and execute this. This work expands on the work of [line extraction] which is capable of extracting Walls from a laser scan image. By using these Walls further features can be extracted, such as Doors, Corners, and Corridors.

Contents

List of Symbols

α angle

d distance between two Points

P_n Point n made up of the coordinate tuple (p_{nx}, p_{ny}). The reference frame has the scanner at (0,0). Along positive x axis is the direction the scanner is facing.

r radius of a circle

scanner a laser scanner, optionally attached to a device that can move

"Doors and Corners, this is where they get you." -Josephus Miller (The Expanse)

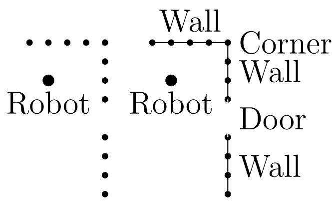
1 Introduction

1.1 Motivation

This work aims to set the foundation to improve the ease of indoor navigation of an electrical wheelchair. It does this by using data provided by a laser scanner that is scanning the environment and processing the scan points to return semantic terms that a human can understand. This list of terms includes *Walls*, *Doors*, *Corners*, and *Corridors*. By having semantic terms be something a computer can understand it is much easier for a human to communicate with the machine. With these defined, future works will be able to take these terms and provide user friendly navigation options, that will make navigating a wheelchair as easy as talking to another person. While the thesis aims to aid electric wheelchair navigation as well, from here on the term 'Robot' will be used, as an electric wheelchair is not actually needed.

1.2 Problem Statement

Given consecutive 2D laser-scan images, it is searched for a method, that extracts semantic features (Walls, Corners, open Doors, Corridors) in a 2D laser scan image.

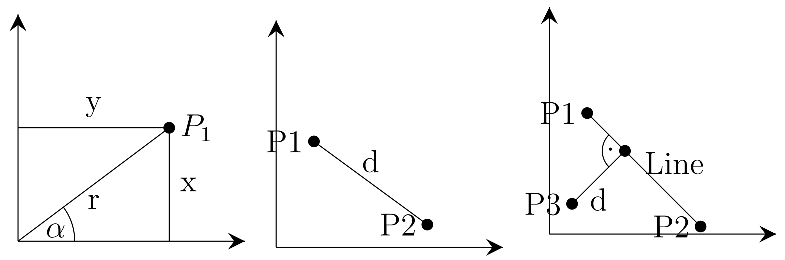


1.3 Basic Formulas

In this section the formulas used throughout this thesis are introduced. These formulas should provide the reader with the tools to fully understand this thesis.

Converting Polar to Cartesian Points

The first formula is that of converting between polar and cartesian coordinates. The reason we want to do this is that a laser scanner returns a list of distances. The length of this list is determined by the angle ranges the Laser scanner is capable of and the



(a) Convert Polar coordinates to Cartesian coordinates

(b) Euclidean Distance between two Points

(c) Euclidean Distance between a Point and a line

Figure 1.1: Basics set 1

angle increment. Where each index of the list relates to the (minimum angle + (angle increment) * index), the value of said index is the distance r_i. This means index i contains the information of α_i and r_i. Figure 1.1a shows an example of how the angle and distance can represent a point in a coordinate system. By using

$$\begin{aligned} x &= r \cdot \cos(\alpha) \\ y &= r \cdot \sin(\alpha) \end{aligned} \tag{1.1}$$

we can extract the x and y coordinates, which can be used easier to apply various algorithms to.

Euclidean Distance between Points

Figure 1.1b shows an example of the Euclidean distance between two points. We determine this distance with the Formula (1.2). An example for where we use this distance function is in the Breakpoint Detection, which is covered in Chapter 2.

$$d(P_1, P_2) = \sqrt{(p_{2x} - p_{1x})^2 + (p_{2y} - p_{1y})^2} \tag{1.2}$$

Euclidean Distance between a Line and a Point

Figure 1.1c offers a visualization for the Formula (1.3). The idea is that we want to find the shortest distance from a point to a Wall. The shortest distance will be perpendicular to the line that is spanned by the Wall start and end.

$$d(P_1, P_2, P_3) = \frac{|(p_{2y} - p_{1y}) \cdot p_{3x} - (p_{2x} - p_{1x}) \cdot p_{3y} + p_{2x} \cdot p_{1y} - p_{2y} \cdot p_{1x}|}{\sqrt{(p_{2y} - p_{1y})^2 + (p_{2x} - p_{1x})^2}} \tag{1.3}$$

Minimum Distance between two Lines

To get the minimum distance between two Lines the distance between the start and end points of one line are compared with the other line. Of these four distances the minimum is then returned,

$$
\begin{aligned}
d_{min}(P_{n-start}, P_{n-end}, P_{n+1-start}, P_{n+1-end}) = \min(\quad & d(P_{n-start}, P_{n-end}, P_{n+1-start}),\\
& d(P_{n-start}, P_{n-end}, P_{n+1-end}),\\
& d(P_{n+1-start}, P_{n+1-end}, P_{n-start}),\\
& d(P_{n+1-start}, P_{n+1-end}, P_{n-end})).
\end{aligned} \tag{1.4}
$$

Angle of a Line

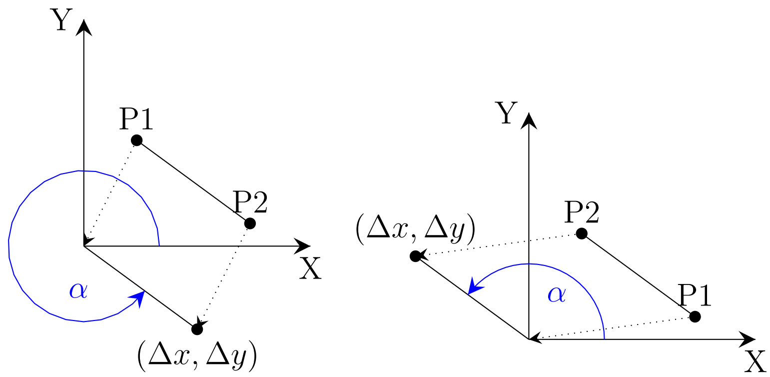


Figure 1.2: Angle between two Points (aka Angle of a line)

The Formula (1.5) uses the two parameter arctan, to determine the angle between two points. The atan2 function <add reference to math.atan2 from python> determines the angle between 0 and a single point. To compensate for this we translate one point to the origin and the second in relation to that. Figure 1.2 shows this process in action.

$$\alpha(P_1, P_2) = \text{atan2}(\Delta y, \Delta x) = \text{atan2}(p_{2y} - p_{1y}, p_{2x} - p_{1x}) \tag{1.5}$$

Angle between two Lines

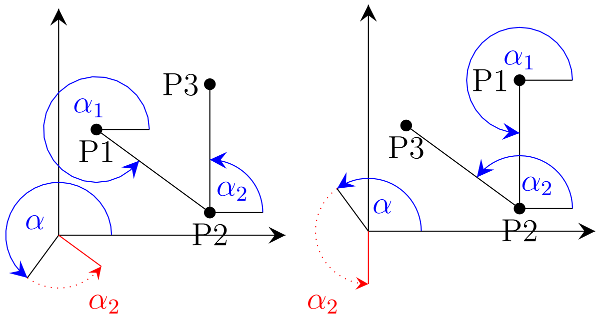


Figure 1.3: Angle α between three Points (i.e. Angle between two lines)

Formula (1.6) involves applying Formula (1.5) twice. This is shown in Figure 1.3. Once again the order of points matters.

$$\alpha(P_1, P_2, P_3) = \alpha_1(P_1, P_2) - \alpha_2(P_2, P_3) \tag{1.6}$$

1.4 Laser Scan Message in ROS

2 Based on Line Extraction in 2D Range Images for Mobile Robotics

To get to the point of determining what a Wall, Door, Corner and Corridor is, the work of BORGES and ALDON 2004 is used. The idea here is to find certain points, called rupture and break points, which are explained in Sections 2.1.1 and 2.1.2. These are used to group segments of connected walls, that we then split at the corners. This provides us with the walls.

2.1 Rupture Detection

The idea of the Rupture Detection is quite simple. If there are Points of the laser scan that exceed the laser scan maximum or a given threshold $d_{rupture\_max}$ there must be a discontinuity in our surrounding area. This can occur for example, when looking down a long hallway or when looking through a doorway. If a point exceeding the $d_{rupture\_max}$ threshold is detected the points before and after it receive the rupture flag. Examples of Rupture Points can be seen in Figure 2.1.

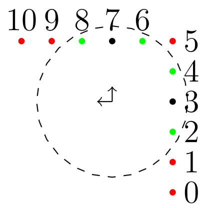


Figure 2.1: The dashed circle indicates the $d_{rupture\_max}$ radius around the Robot. The points in red are ruptured points. Green points gain the rupture flag. Black points gain no flag.

Points 0, 1, 5, 9, and 10 are denoted in red as these are outside of the range of $d_{rupture\_max}$. The result of which is that Point 2 gains the rupture Flag thanks to Points 0 and 1, Points 4 and 6 gain the Flag thanks to 5 and Point 8 gains the Flag thanks to points 9 and 10.

$$d_n > d_{rupture\_max} \tag{2.1}$$

2.2 Breakpoint Detection

The idea of the Breakpoint Detection closely resembles that of the Rupture Point Detection. Where the Rupture Point detection analyzed the distance to the Laser scanners, the Breakpoint Detection analyzes the distances between two consecutive points P_{n-1} and P_n. A Breakpoint occurs, when the distance between the two points is greater than d_{break_max}.

$$d(P_{n-1}, P_n) > d_{break\_max} \tag{2.2}$$

d_{break_max} is defined in Formula (2.3), where λ corresponds to the worst case of incidence angle of the laser scan ray with respect to a line for which the scan points are still reliable and σ is a parameter for tolerance.

$$d_{break\_max} = P_{n-1} \cdot \frac{sin(\Delta\phi)}{sin(\lambda - \Delta\phi)} + (3 \cdot \sigma) \tag{2.3}$$

The distance of d_{break_max} is exceeded for example, when we are dealing with two separate walls, or when an object, such as a pillar, is obstructing a wall, but is not directly connected to that wall. Examples of break points are shown in Figure 2.2

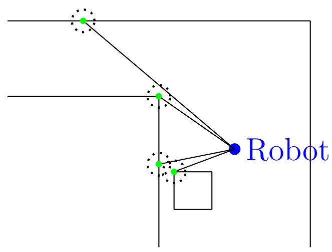


Figure 2.2: Breakpoints are shown in green and d_{break_max} is indicated by the dotted circles around each Point

Should a Breakpoint occur between points P_{n-1} and P_n both need the Breakpoint flag to be set true.

2.3 Line Extraction

After having found the Rupture and Breakpoints we can group the points into continuous wall segments. These segments are not necessarily individual walls as the breakpoint detection is not suited for corner detection. The first step of this is to group Points together until one either has a Rupture or Breakpoint associated with it. Once this happens this segment will be considered a continuous segment and sent into the Iterative Endpoint Fit, which is explained next. Now that the first segment is taken care of we continue where we left off, working our way in the same way through all the available Points to group the Points into connected segments that tend to be Walls.

2.4 Iterative Endpoint Fit

The Iterative Endpoint Fit process takes one Wall segment and breaks it up at the Corners, should these be in the segment. The way it does this is by taking the first and last Point and connecting these with a line. Now every Point between the first and last point is checked for the maximum distance to the line. Should the Point that this process finds exceed a certain length we split the segment at this Point and rerun the process on both segments, until we end up with only straight lines.

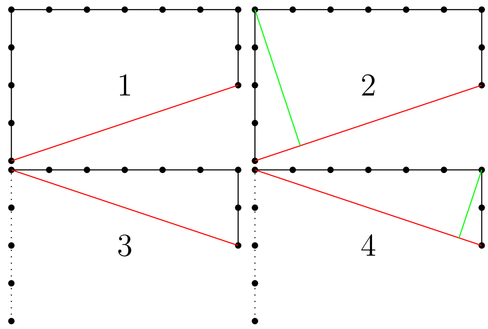


Figure 2.3: Iterative Endpoint Fit process steps

Figure 2.3 depicts this process. The process starts with one continuous wall segment, indicated in black. Step 1 creates the red line between the first and last points. Step 2 shows the max distance with the green line. The corner point is where the process splits the two Walls. This point becomes the start point for the dotted Wall in Step 3. The reason for it to be dotted is, that the process recognized, that no point here exceeded the minimum distance to be a Corner, thus the segment is one Wall segment. The new red line uses the same Corner point, only now as the end point. Step 4 shows the max distance with the line in green and splits at the Corner. Both ends of this split do not have a point exceeding the minimum distance and thus the process finishes and returns all three walls.

3 Feature Extraction

Chapter 2 has been about the work this thesis builds upon. It described the method for extracting Walls from a set of laser scan points. Chapter 3 focuses on how these Walls can be used to extract Corners, Doors and Corridors by applying geometric comparisons. Difficulties are presented by the relative location of the Robot to each feature. The extraction of these Features are contributions by the author of this thesis.

3.1 Definitions

Before the extraction process is explained, some terms need to be defined first.

- A *Wall*, shown in Figure 3.1, consists of a tuple of two Points. With $W = (P_s, P_e)$. A thing to note here, the Wall (A, B) is not the same as the Wall (B, A). The order in which each Point is added determines the direction of the Wall. The direction of the wall indicates the side of the wall the laser scanner is facing. This side is always to the left of the wall.

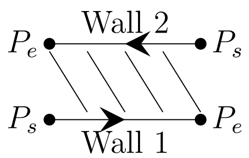


Figure 3.1: Two walls with their direction indicated by an arrow. The shaded area is navigable

- While under the hood a Door may share the structure of a Wall, that being $D = (P_s, P_e)$, the way it is detected is by finding a gap between two walls. This gap will have at least one rupture point associated with it. Here the assumption is made, that a doorway exists only when the door is open. Because of this assumption and the check for a gap we only need one rupture point, as the door might still be attached to one side. The gap between the two points is between 0.8 and 1.2 meters.
- A *Corner* is made up of a tuple containing two Walls, which share a Point, and one integer $C = (W_1, W_2, i)$ as shown in Figure 3.3. The Point both Walls share is the corner in question. It is always the end Point of the first Wall and the start

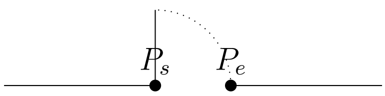


Figure 3.2: Here we have two Walls separated by one open Door

Point of the second Wall. The integer keeps track of the Corner type. Possible Corner types are inner Corner, outer Corner and potential Corner, examples of each show up in Figure 3.4. The corner type impacts how the Robot can approach the Corner.

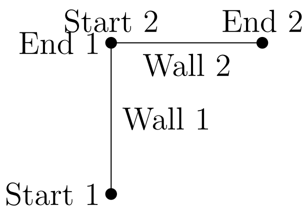


Figure 3.3: A display of what a Corner looks like with its Walls

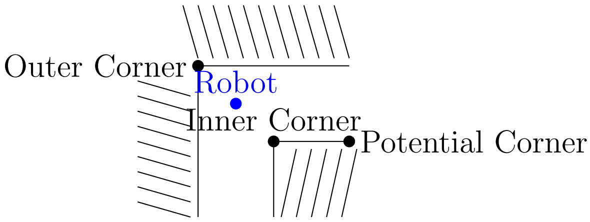


Figure 3.4: Corner Type Examples

- Finally a *Corridor* is represented by a single Point P_c. This point is located between a corner and a wall, which indicates the entrance or exit into a given corridor.

  Due to how the midpoints are detected, the same object humans would describe as a corridor will contain multiple different corridor entrances. This is due to the fact that a corridor can have open doors or objects in its way that create more corners. However by having more of these points in the same corridor, a path finding system can have an easier time navigating past objects, such as pillars. Figure 3.5 shows in what instances the probing walls get used and when they yield a corridor midpoint. The 6 red lines indicate probing walls that do not yield a corridor midpoint. The line marked with 1 does not provide a corridor midpoint as it is too close to the laser scanner. Lines 2, 3 and 6 do not intersect with a wall. The wall in Line 4 is too close to the corner from where the probing wall originates. 5 is too far from the laser scanner and 6 both does not intersect with a wall and is too far from the laser scanner. All other probing walls yield a midpoint, even the door.

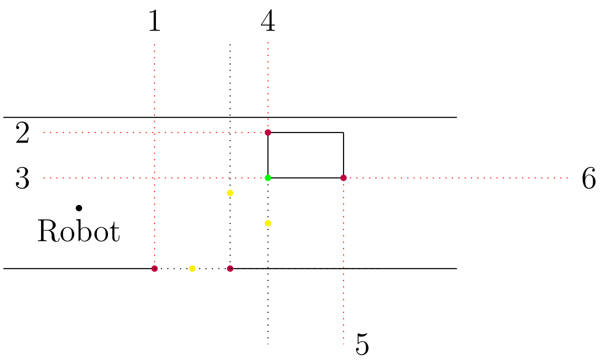


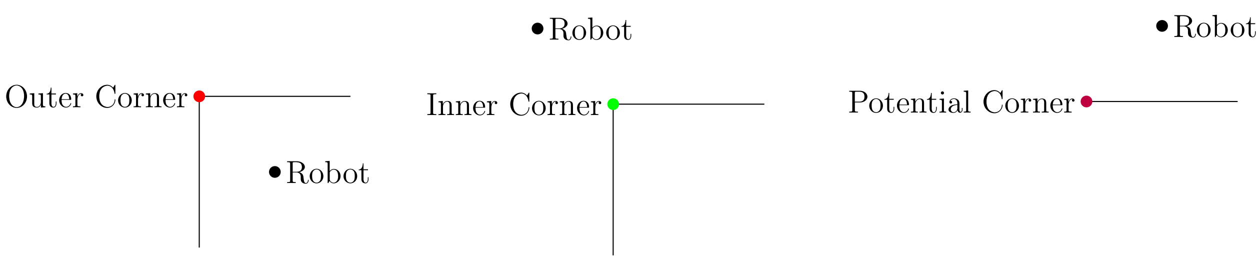
Figure 3.5: The red dotted lines indicate that the search for another wall yielded for one reason or another no match

3.2 Corner Detection

Now that a corner has been defined, the next step is detecting them. Currently this is done by comparing the two Walls. Should there be a pair $P_{nstart} == P_{mend}$ the Walls m and n are combined and the corner point is set as P_{mend}. Now that the corner has been identified we need to determine on which side of the corner the laser scanner can traverse. This information is not directly obvious just based on having two walls, as the corner in question could either be facing to the laser scanner and be an inner corner or be facing away from the laser scanner and be an outer corner. To distinguish between the two the Corner Type Detection has been implemented.

3.2.1 Corner Types

- Outer Corner is assigned 0. This Corner type points away from the laser scanner as shown in Figure 3.6a.



(a) Outer Corner

(b) Inner Corner

(c) Potential Corner

Figure 3.6: The Corner Types

- Inner Corner is assigned 1. This corner type points to the laser scanner as shown in Figure 3.6b

- Potential Corner is assigned 2. A potential Corner occurs when a Wall has either a rupture or breakpoint at its start or end point. This rupture or breakpoint is then assigned the potential Corner. This works by creating a dummy Wall, where both start and end point are equal to the rupture or break point in question. This is best done by example. Figure 3.7 shows a Wall going from point A to point B. In the event that A is to be the potential Corner a dummy Wall is created where $P_{start} = P_{end} = A$. The Corner then is made up of (dummy Wall, original Wall, 2). Similarly when B is to be the potential corner a dummy Wall is created, only now $P_{start} = P_{end} = B$. This Corner is then made up of (original Wall, dummy Wall, 2). By defining the potential Corner this way the information of it being the start or end point of the Wall is preserved. The reason potential corners are relevant is that there are many situations where a laser scanner will not be able to accurately determine if a wall continues or if the hallway turns off. Thus the assumption is made, that any break or rupture leads to a chance of there being a corner, a potential corner.

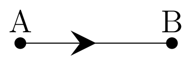


Figure 3.7: Caption

3.2.2 Corner Type Detection

When we look at a Corner there are two possibilities for the orientation, an inner Corner and an outer Corner.

As humans we can identify the type by standing in front of the Corner and looking at it. But when we are dealing with machines it is not always that simple. As mentioned above a Corner is defined by the two connecting Walls and an integer, representing the corner type. When looking at a Corner one can make the observation, that the construct is simply a triangle with the hypotenuse missing. With this in mind we can examine the relative position of the robot to this triangle. When considering that the robot needs to see both Walls to properly determine that it is looking at a Corner we end up with 3 distinct possibilities:

1. We have an inner corner
2. We have an outer corner where the robot is within the triangle
3. We have an outer corner where the robot is outside of the triangle

With this in mind we now need to figure out how to convey this to the robot. One way we can do this is by measuring distances. To fully determine if we are dealing with an inner or outer Corner we will need three distances.

- the distance from the robot to the corner (rc)
- the shortest distance from the robot to the missing hypotenuse of the triangle (rh)

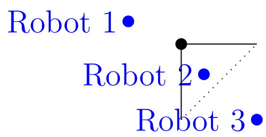


Figure 3.8: Possible Robot Relative Locations

- the shortest distance from the corner to the missing hypotenuse of the triangle (ch)

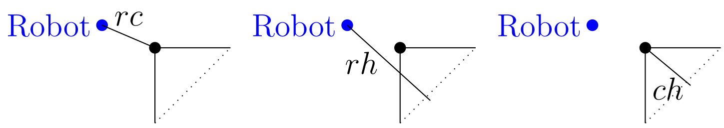


Figure 3.9: All relevant distances

Once we have these three distances we can start comparing these against each other to determine, whether or not the corner is an inner or an outer. With three variables there are three comparisons to be made:

- the distance from robot to corner is less than the distance from robot to the missing hypotenuse ($rc < rh$)
- the distance from robot to corner is less than the distance from corner to the missing hypotenuse ($rc < ch$)
- the distance from the robot to the missing hypotenuse is less than the distance from the corner to the missing hypotenuse ($rh < ch$)

By going through each possible combination and creating a visualization one is left with the results of Figure 3.10.

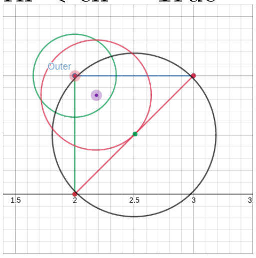
As you may have noticed, the cases (True, False, True) and (False, True, False) did not appear. This is because we are dealing with a 2D plane. If we were on a cylinder or other non flat plane there might be three Points where $rc < rh < ch > rc$ or $rc > rh > ch < rc$, however the space we live in does not have Points which could satisfy these conditions.

Having determined under which conditions we have an inner corner or not we can translate this into a Karnaugh map. The result of which is shown in Table 3.1 where a refers to ($rc < rh$), b refers to ($rc < ch$) and finally c refers to ($rh < ch$).

Extracting the information provided by the Karnaugh map the Formula (3.1) is left. We can now use this Formula to determine the corner type. The result of Formula (3.1) is a Boolean. In 3.2.1 an Outer Corner was said to hold the integer value of 0 and an Inner Corner to hold the value of 1. So the Boolean is directly transferable to the corner type.

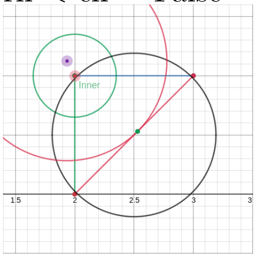
$$corner\_type = ((rc < rh)\ \ \&\ !(rh < ch)) \tag{3.1}$$

$rc < rh$ = True
$rc < ch$ = True
$rh < ch$ = True



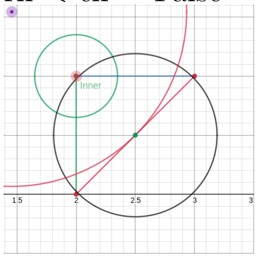
(a) Outer Corner

$rc < rh$ = True
$rc < ch$ = True
$rh < ch$ = False



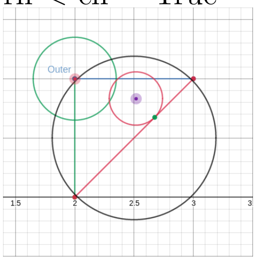
(b) Inner Corner

$rc < rh$ = True
$rc < ch$ = False
$rh < ch$ = False



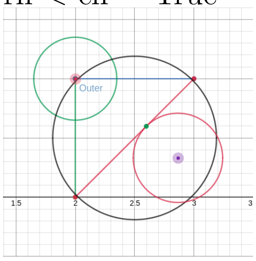
(c) Inner Corner

$rc < rh$ = False
$rc < ch$ = True
$rh < ch$ = True



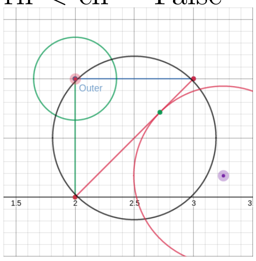
(d) Outer Corner

$rc < rh$ = False
$rc < ch$ = False
$rh < ch$ = True



(e) Outer Corner

$rc < rh$ = False
$rc < ch$ = False
$rh < ch$ = False



(f) Outer Corner

Figure 3.10: Corner Labels

	b		$\overline{b}$	
	$\overline{c}$	c	c	$\overline{c}$
a	1	0	0	1
$\overline{a}$	0	0	0	0

Table 3.1: Karnaugh map

3.3 Corridor Detection

To detect the corridor midpoint the corner types will be made use of. Starting from every inner and potential corner two probing walls are created at a 90 and 180 degree offset to the corners walls. These probing walls have a length of 2.5m and search for any intersection with another wall. Should such an intersection exist we can assume that the midpoint of the corner and intersection point is a location the laser scanner can traverse to.

Looking again at Figure 3.5 the inner and potential corners have probing walls exiting at 90 and 180 degree angles to the walls searching for a wall.

Meta Wall

An early version of the corridor detection attempted to create a so called *Meta Wall* as shown in Figure 3.11. One reason the definition ultimately moved away from this sort of a Meta Wall idea, was that comparing each Wall with each other proved more complex than initially assumed.

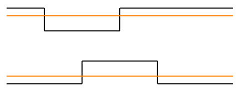


Figure 3.11: Meta Wall

3.4 Implementation Overview

Having explained the theory behind this Thesis, the interesting question becomes how to implement it in a practical manner.

3.4.1 Pseudo Code

```
forall scan from laserscan measurements do
    rupture_points = Detect_Rupture_Points(scan);
    break_points = Detect_Break_Points(rupture_points);
    walls = Extract_Lines(break_points);
    corners = Detect_Corners(walls);
    corridors = Detect_Corridor(corners)
end
```

Algorithm 1: Overview

Rupture Point Detection Implementation

The way the Rupture Point Detection was implemented was that it started by taking the polar coordinates returned from the laser scan measurements and checking, each individual point if it has a valid length. If this is the case it converts this to Cartesian coordinates using Formula (1.1) and adds a Flag to indicate that this point was not a rupture point. After having converted all points to Cartesian each point is analyzed for a positive rupture flag. Any point that has one of these does not get added for further analysis and the two points before and after it receive the final rupture flag. The final list is then made up of the Point in the Cartesian system, the point in the polar system and the Rupture Flag, which indicates if next to it a rupture occurred.

Breakpoint Detection Implementation

The Breakpoint Detection receives the List of Points and Rupture Flags created in the Rupture Detection. As described in the breakpoint detection the distances between consecutive points is measured and checked against the d_{break_max}. If two Points exceed this distance the breakpoint flag for both is set to true. After having compared all distances this new List is passed on.

Line Extraction Implementation

The Line Extraction now takes the List provided by the Breakpoint Detection

Iterative Endpoint Fit Implementation

The Iterative Endpoint Fit receives a List "list_of_walls" wherein the separated Walls will be placed, a List of all the Points that were returned in Breakpoint Detection "breakpoints", a start index "start", and an end index "end". From here the distance to the line that is spanned by breakpoints[start], breakpoints[end] to each point between start and end is measured with 1.3. Should the maximum distance of all of these points exceed 6cm this point is likely a corner. This means that the Iterative Endpoint Fit gets called two more times, once where the start remains the same and the end is the corner point and once where the end remains the same and the start is the corner point. Should there be no such point a Wall is created with breakpoints[start] and breakpoints[end] and placed within list_of_walls.

Door Detection Implementation

The Door Extraction takes the list returned by the Line Extraction Process as its argument. The distance and angle between each pair of walls is then determined. The distance is determined with Formula (1.4) and the angle with Formula (1.6). Should the angle be less than 2 degrees or greater than 358 degrees and the distance is between 0.8m and 1.2m the angle of the potential door is compared to the angles of the two walls. The angle of the potential door is calculated using Formula (1.5) where P_1 is equal to the end point of the first wall and P_2 is equal to the start point of the second wall. The angle of the two walls is also determined using Formula (1.5), only as expected with first their start points then their end points. If the potential doors angle is within two degrees the potential door is added to the list of doors.

Corner Detection Implementation

The Corner Detection takes the list returned by the Line Extraction Process as its argument. Each combination of walls is checked to see if $P_{Wall1-end} == P_{Wall2-start}$. Every such pair is then checked, if the angle between the two is within the range of 50 degrees and 310 degrees. Should this be the case a corner is set with the two walls. In the event that a Wall has a rupture or break point that point is set as a potential corner.

Corridor Detection Implementation

The Corridor Detection takes both the list returned by the Line Extraction Process and the list returned by the Corner Detection Process. The first step is to have two perpendicular lines extrude out of each corner and these lines added to a list. From here each line is compared with every wall for an intersection. Should an intersection exist and the distance of this intersection be less than 3m to the origin the algorithm assumes that the line used could be an entrance to a corridor, so the center point of the corner and the intersection point is determined. Should this point be more than 0.3m from the Wall and 0.5m to the origin this center point is added as a corridor point.

4 Experimental Results

4.1 Measurements

Now that the processes have been described they need to be analyzed.

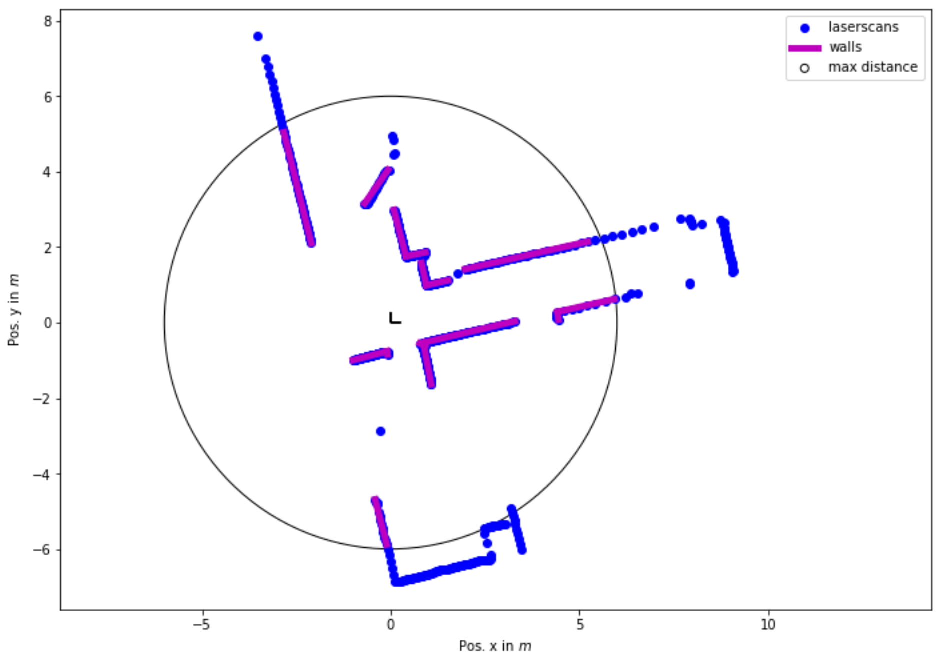


Figure 4.1: Wall Detection 1

Figure 4.1 shows the Wall detection process in action as presented by ¡Paper¿ in Chapter 2.1. The Walls that are within range are detected with little to no problem.

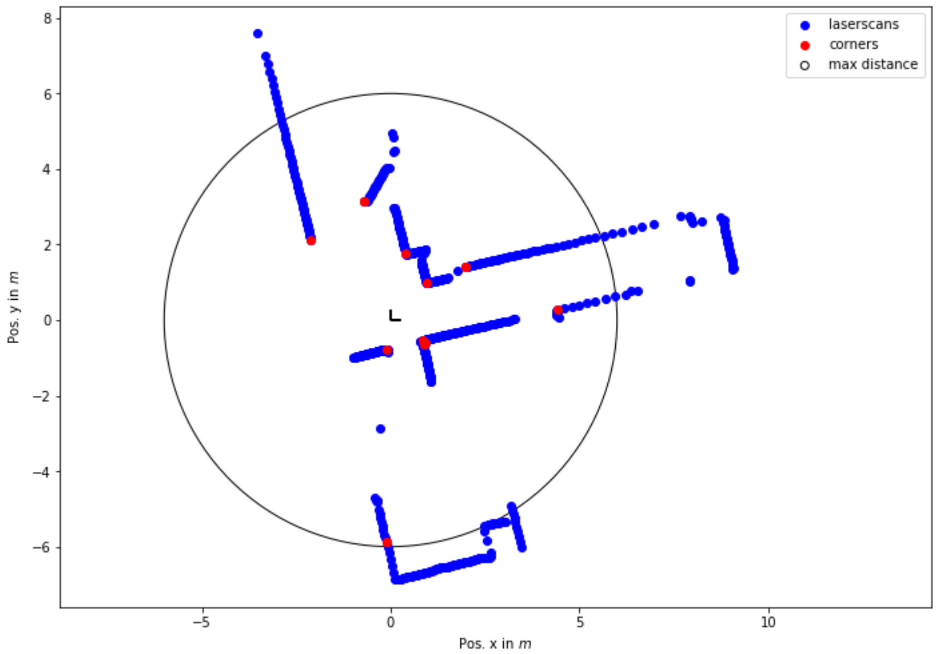


Figure 4.2: Corner Detection 1

Figure 4.2 on the other hand demonstrates some minor inconsistencies. Around (2,-0.5) the detection process has found several corners, despite there only being one. This is likely due to the fact, that the here open door contains gaps around the corner area and thus confuses the detection. Another Corner that has been falsely detected is at (0,-6). Here the wall is a single straight line.

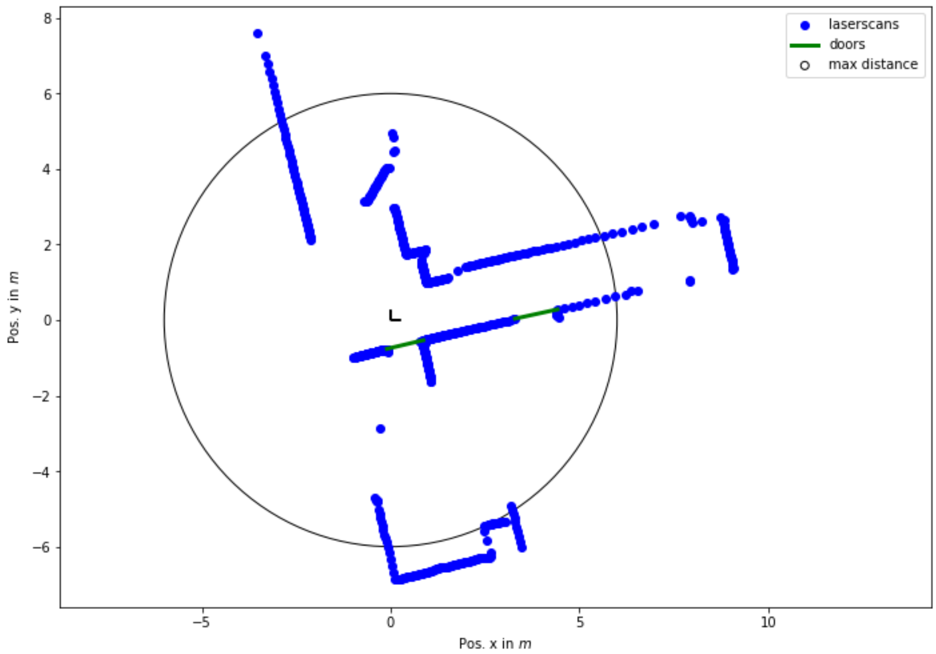


Figure 4.3: Door Detection 1

Figure 4.3 correctly identifies two of the three presently open doors. The door that is not detected is at (1,3). The reason for this door not being detected in this frame is, that the wall behind the open door is obscured, thus the system can not find a wall with a similar angle as the wall on the other side of the door.

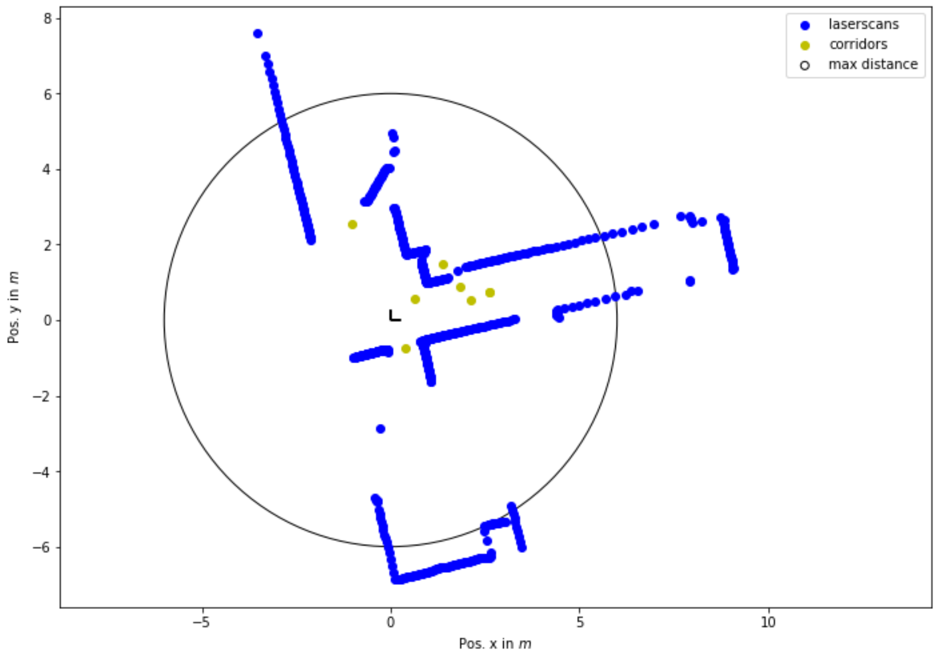


Figure 4.4: Corridor Detection 1

Figure 4.4 shows that the corridor detection can both provide useful points, such as the door and impossible to reach points such as the point behind the pillar.

4.2 Office Hallway

TODO describe the office hallway in which the scans were taken. Maybe add some pictures

5 Conclusion

5.1 Outlook

How well did it work? What were some problems I faced? How can this be used in the future?

5.2 Future Work

What parts can be improved in the future using what things?

5.2.1 Corner Deteciton

An improvement on this system could involve analyzing the distances between start and endpoints. If the two are within a certain distance the corner point can be set in an area that makes sense between the two walls. This could be useful in the event that the laser scanner did not perfectly capture the corner and the two resulting points are too far from each other to be grouped by the program.

5.2.2 Procrustes

The Procrustes algorithm could be a start for looking into recognizing corners. This could be useful to determine relative position at each time step. This in theory can be more precise than just using the odometry information, as we base the position on features in the environment.

References

Appendix