Apriltag Docking

Autonomous Docking with Apriltags

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Technical Aspects of Multimodal Systems

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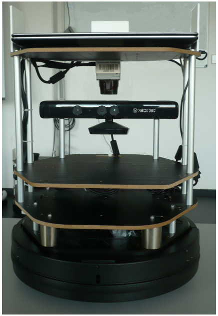
Content

The Kobuki TurtleBot

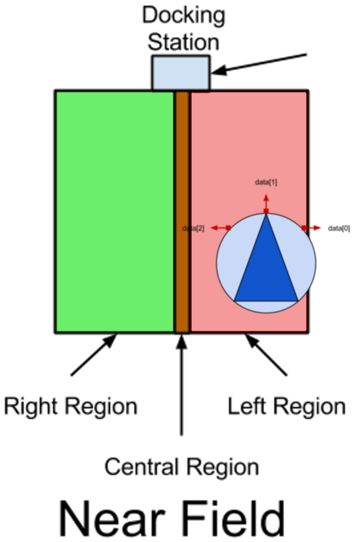


Kobuki TurtleBot

Kobuki TurtleBot Base with

- Laser Sensor
- Kinect
  Camera with a resolution of 640x480Pixel
  Field of View: 43° vertical and 57° horizontal
- Notebook
- Three IR-Sensors on the Base (Left,Right,Center)

Kobuki's Docking Algorithm



Docking Algorithm

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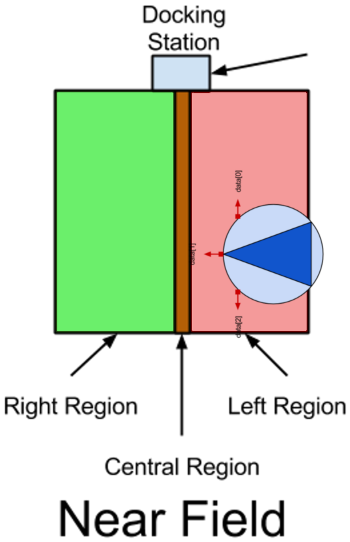
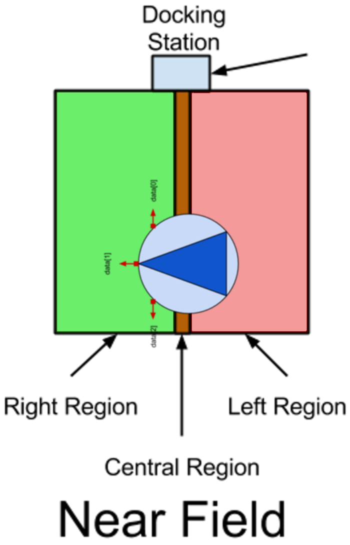


Docking Algorithm

- Turn LEFT until right IR-Sensor detects Left Regions signal.

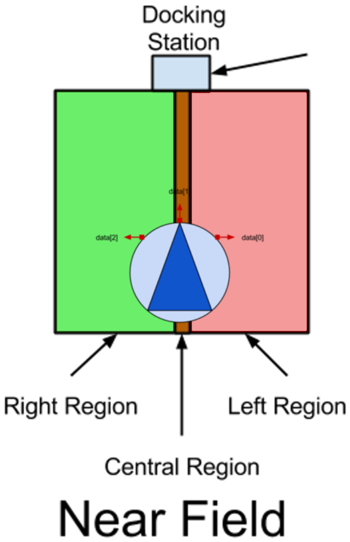
Kobuki's Docking Algorithm



Docking Algorithm

- Turn LEFT until right IR-Sensor detects Left Regions signal.
- Drive Forward until right IR-Sensor detects central regions signal

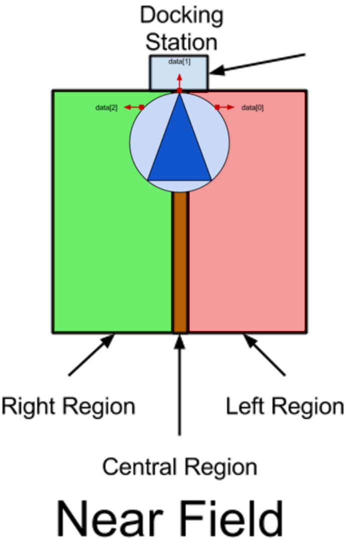
Kobuki's Docking Algorithm



Docking Algorithm

- Turn LEFT until right IR-Sensor detects Left Regions signal.
- Drive Forward until right IR-Sensor detects central regions signal
- Turn RIGHT until frontal IR-Sensor detects central regions signal

Kobuki's Docking Algorithm



Docking Algorithm

- Turn LEFT until right IR-Sensor detects Left Regions signal.
- Drive Forward until right IR-Sensor detects central regions signal
- Turn RIGHT until frontal IR-Sensor detects central regions signal
- Drive Forward until docking station is reached

Disadvantages of the infrared based docking algorithm from Kobuki

1) Distorted by daylight
2) Not able to distinguish between different docking stations
3) Sometimes sensors are badly manufactured.
4) No retry after a failed docking attempted

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⇒ Replace the old docking approach with a new one.

Motivation

Disadvantages of the infrared based docking algorithm from Kobuki

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Localisation Approaches
with Landmarks

- Infrared Sensors
  Mesures the electromagnetic spectrum in the optical range of 1mm to 78nm
- IEEE 802.11 RADAR
  Uses standard 802.11 network adapters and localizes by measuring the signal strength.
- RFID
  Uses radio-frequency identification. Signal strength is used to calculate the position.
- Optical
  Uses visual fiducial markers like Apriltags or QR-Codes

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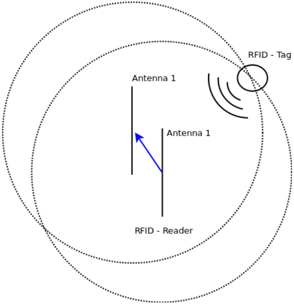
Localisation with RFID(1)

- RFID systems consist of RFID-Reader and RFID-Tags
- RFID- Tags are available in active and passive from.
- The active Tags does have a radio transceiver.
- The passive Tag reflects the signal from the reader and adds information by modulating the reflected signal.
- Both Tags does have an unique hardware IDs.
- Because RFID is not primary designed for localization tasks there is only one antenna used in the RFID-Reader.

Localisation with RFID (2)



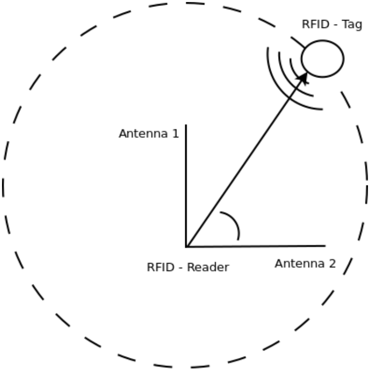
Shows the Localization task with

only one antenna.

When only one Antenna is used only one Voltage can be measured at the RFID-Reader.

- We need two Positions to triangulate the position.
- Voltage variates when antenna is rotated.

Localisation with RFID (3)



Dual antennas as described in [2].

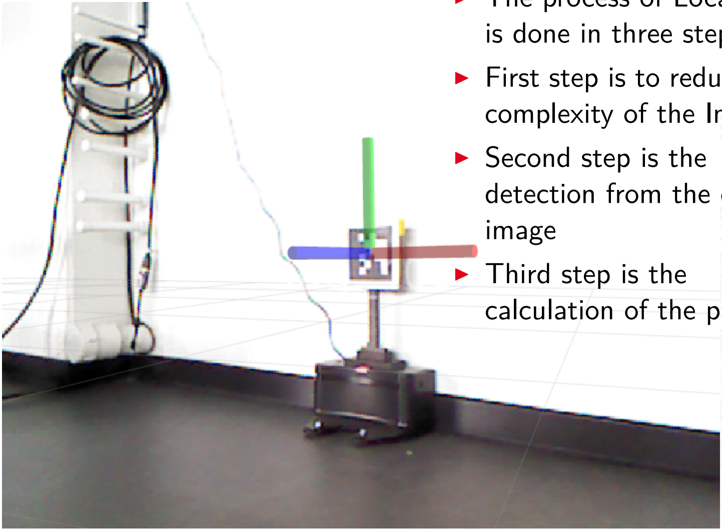
$$V_1 \propto \left|\frac{C \cdot S \cdot B}{r} \cdot sin(\theta - \phi)\right|$$

$$V_2 \propto \left|\frac{C \cdot S \cdot B}{r} \cdot sin(\theta - \phi + 90^\circ)\right|$$

$$\upsilon_{12} = \frac{V_1}{V_2} = |tan(\theta - \phi)|$$

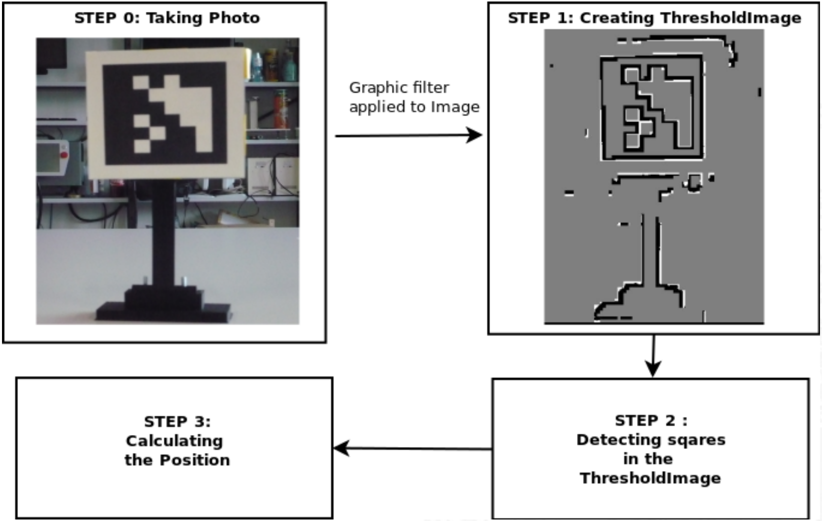
S : surface area of the antenna
B : average magnetic flux density of the wave passing through the antenna
C : accounts for the environmental conditions
r : distance from the transponder

Apriltag Localisation

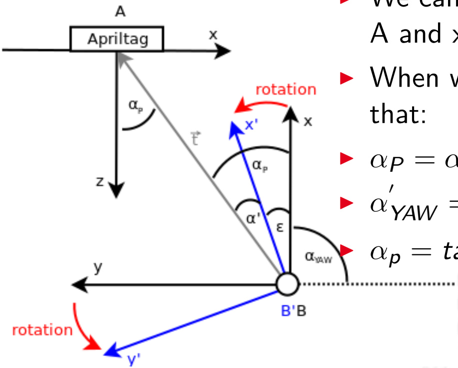


- The process of Localization is done in three steps
- First step is to reducing the complexity of the Image
- Second step is the detection from the camera image
- Third step is the calculation of the position

Apriltag Localisation



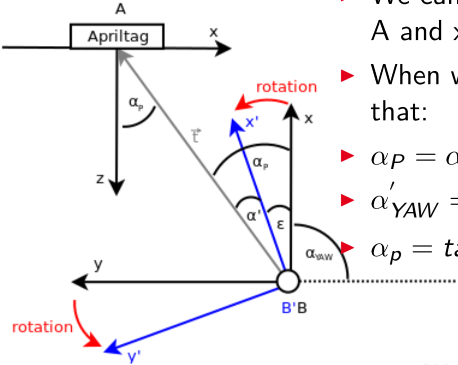
Important Angles



- We can find α_P in B, when z-axis of A and x-axis of B are parallel.
- When we rotate B about $-\epsilon$ we see that:
- $\alpha_P = \alpha^{'} + \epsilon$ with:
- $\alpha^{'}_{YAW} = -\frac{\pi}{2} - \epsilon \Rightarrow \epsilon = -\frac{\pi}{2} - \alpha^{'}_{YAW}$
- $\alpha_p = tan(\frac{t_y}{t_x}) + (-\frac{\pi}{2} - \alpha^{'}_{YAW})$

- Docking Angle: $\alpha_D = \alpha^{'} = tan(\frac{t_y}{t_x})$
- Positioning Angle: α_P

Important Angles



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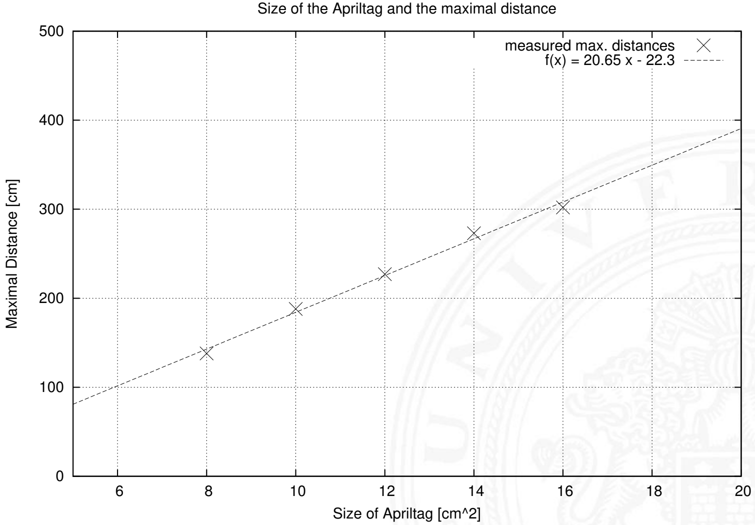
- Docking Angle: $\alpha_D = \alpha^{'} = tan(\frac{t_y}{t_x})$
- Positioning Angle: α_P

Apriltag Range



Shows the relagtionship between the size of an Apriltag and the maximal distance. $f(x) = 20.63x - 22.3$

Fundamental Functions

- Turn by Angle
  The Internal Measurement Unit (IMU) with an build in Gyroscope is used to measure the Angle while turning the robot.
- Driving Forward
  We calculate the time the robot has to drive with:

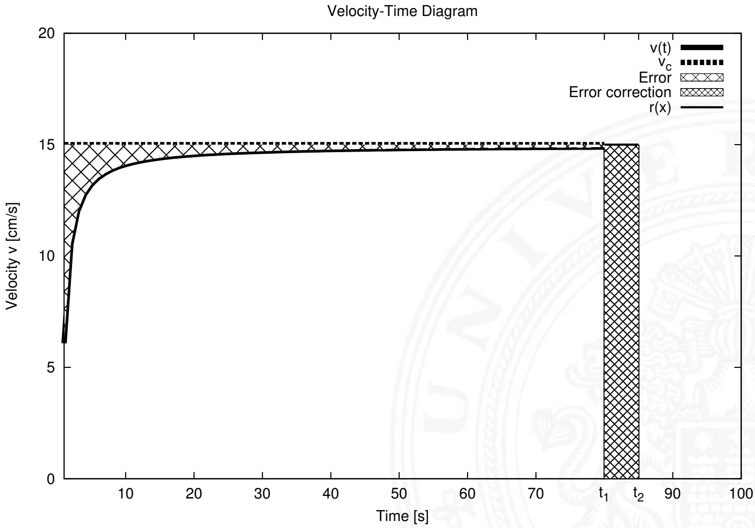
$$t_{drive} = \frac{S}{v_c}$$

Example:

$$t_{drive} = \frac{60cm}{15\frac{cm}{s}} = 4s$$

We assume the velocity V_c to be constant, but this is not the case.

Fundamental Functions
Driving Forward



Fundamental Functions
Driving Forward

To approximate the Velocity-Time-Law we use:

$$v(t) = -\frac{A}{t} + v_c \text{ with A as acceleration}$$

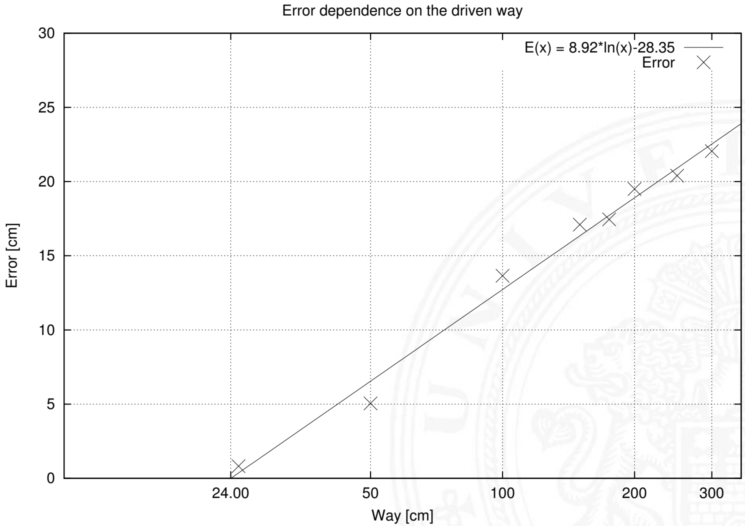
$$E(t) = W_e(t) - W_d(t) = v_c \cdot t_1 - \int_0^{t_1} (v(t))dt = v_c \cdot t_1 - [-A \cdot ln(t) + v_c \cdot t_1]$$

$= A \cdot ln(t)$ with $t = \frac{W_e}{v_c}$ gives:

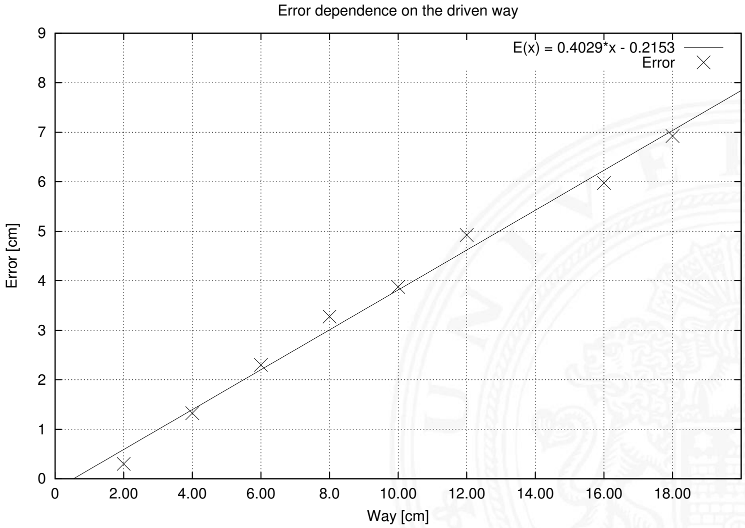
$$E(\frac{W_e}{v_c}) = A \cdot ln(\frac{W_e}{v_c}) = A \cdot ln(W_e) - A \cdot ln(v_c)$$

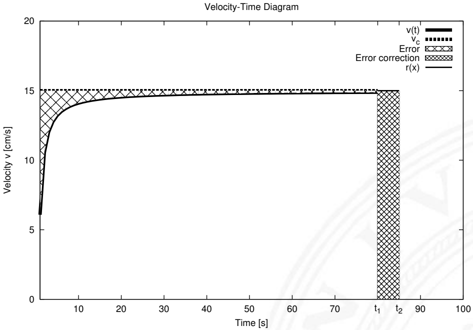
$$E(W_e) = A \cdot ln(W_e) - B$$

Fundamental Functions
Driving Forward



Fundamental Functions
Driving Forward

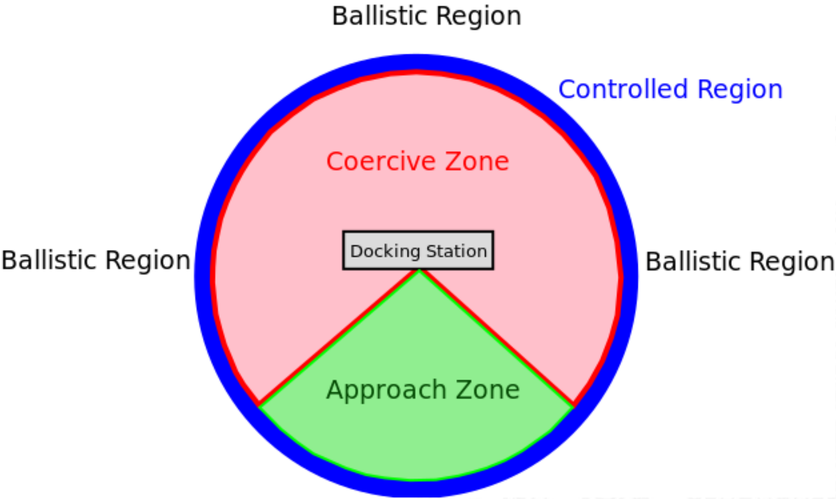




$$E(way) = \begin{cases} 0.4029 \cdot way - 0.2153 & \text{for } way < 24\text{cm} \\ 8.92 \cdot ln(way) - 28.35 & \text{for } way \geq 24\text{cm} \end{cases} \qquad (1)$$

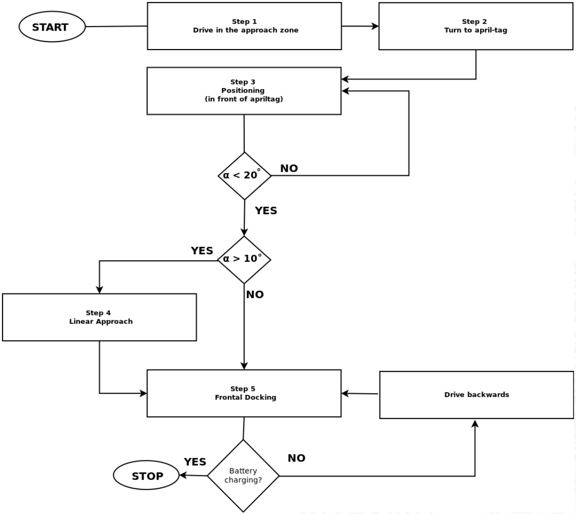
$$t_{drive} = t_1 + (t_2 - t_1) = \frac{way}{v_c} + \frac{E(way)}{v_c} \qquad (2)$$

Docking Regions



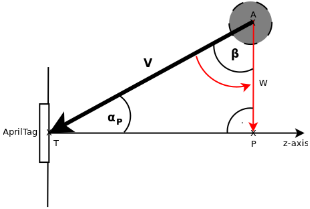
As described in [4]

New Docking Approach
with Apriltags for Localization



New Docking Approach

Spep3 :Positioning

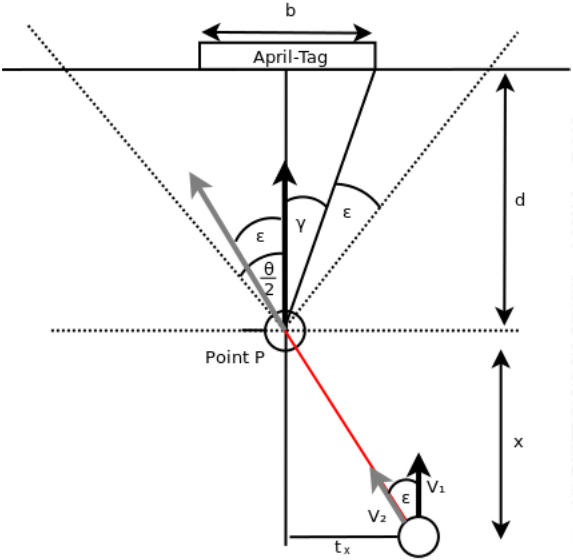


This figure shows the situation where the robot is after he arrived near the Apriltag by using the approach described in Phase 1. At Point A the robot still have to do the positioning in order to reduce the angle α_P.

POSITIONING:

- $\beta = \frac{\pi}{2} - \alpha_P$
- $w = sin(\alpha_P) \cdot \sqrt{(v.x)^2 + (v.z)^2}$
- Turn the robot about β to the LEFT
- Drive the distance w forward.
- Turn $\frac{\pi}{2}$ to the RIGHT.
- IF $\alpha_P > 20^\circ$ THEN
  Repeat the POSITIONING
- IF $\alpha_P > 10^\circ$ THEN
  Start Step 4: LINEAR APPROACH
- IF $\alpha_P < 10^\circ$ THEN
  Start Step 5: FRONTAL DOCKING

New Docking Approach
Step 4: LINEAR APPROACH



Finally, we get the following equations:

$$p = \frac{x}{x+d} = 0.25, a = tan(\frac{\pi}{2}), b = tan(\frac{\theta}{2})$$

$$A(p, t_x) = \frac{-b \cdot p}{2 \cdot (p-1) \cdot t_x}$$

$$Q(p, t_x) = \frac{-(ab + A(p,t_x))}{(1 + ab \cdot A(p,t_x))}$$

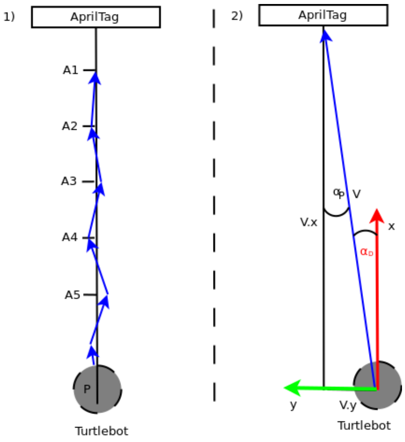
$$P(p, t_x) = \frac{(b + a + A(p,t_x) \cdot a - b \cdot A(p,t_x))}{(1 + ab \cdot A(p,t_x))}$$

$$\epsilon_{1,2}(p, t_x) = atan\left(\left(\frac{-P(p,t_x)}{2}\right) \pm \sqrt{\left(\frac{-P(p,t_x)}{2}\right)^2 - Q(p, t_x)}\right)$$

LINEAR APPROACH:

- Compute ϵ
- Turn ϵ to the left/right
- Drive forward until α_P is zero
- Turn about $-\epsilon$ to the right/left
- Start: FRONTAL DOCKING

New Docking Approach
Step 5: FRONTAL DOCKING

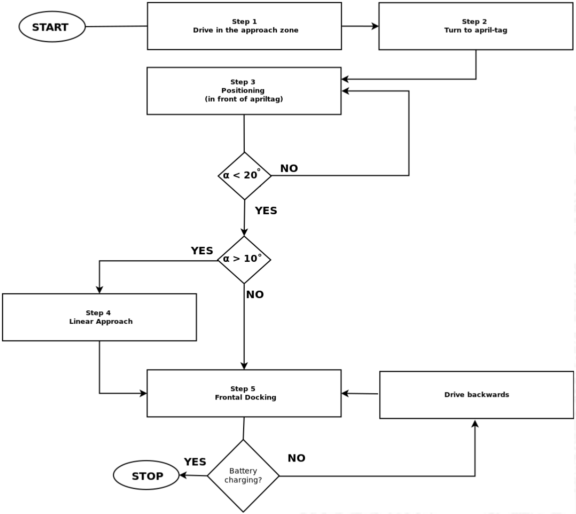


Kobuki TurtleBot

FRONTAL_DOCKING()

$\alpha_D = tan(\frac{V_y}{V_x})$
IF $-2^\circ < \alpha_D < 2^\circ$ **THEN**
// DRIVE FORWARD
$\omega = 0^\circ$;
velocity $= 0.35$;
ELSE
// TURN UNTIL $\alpha_D = 0$
$\omega = -\frac{\alpha_D}{|\alpha_D|} \cdot 2^\circ \cdot \frac{\pi}{180^\circ}$;
velocity $= 0.0$;
DRIVE(ω,velocity);
IF $V_x >$ STOP_DIST **THEN**
FRONTAL_DOCKING();
ELSE
sleep(3s)
IF !isRecharging() **THEN**
DIRVE_BACKWARD(0.65);
FRONTAL_DOCKING();

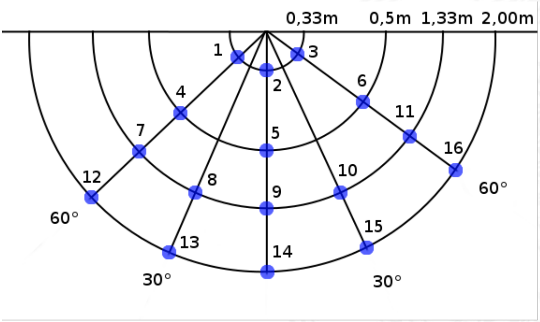
New Docking Approach
with Apriltags for Localization



Evaluation

Results of the measurements

- In order to compare the old approach with the new one, a test field is required.
- The test field consists of 16 point, that are in the approach zone.
- For each of that points multiple docking attempts are made.
- The results(failure/success) are notated in a table.

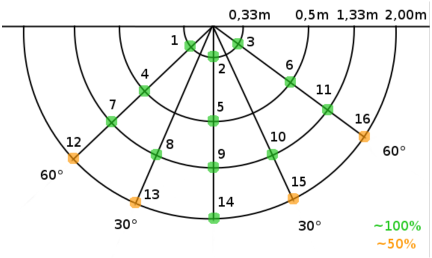


Evaluation
Results of the measurements

degree	Points	New Docking			Kobuki's Docking		
		sucess	missed	%	sucess	missed	%
0	2	6	0	100	6	0	100
0	5	6	0	100	6	0	100
0	9	6	0	100	6	0	100
0	14	6	0	100	6	0	100
30	8,10	7	0	100	0	6	0
30	13,15	8	7	50	0	6	0
60	1,3	8	1	87,5	0	6	0
60	4,6	6	0	100	0	6	0
60	7,11	6	0	100	0	6	0
60	12,16	8	10	44	0	6	0
all	2,3,5,6,9,10,11	45	1	97.8	18	24	42.8
all	all	67	18	78.8	24	36	40.0

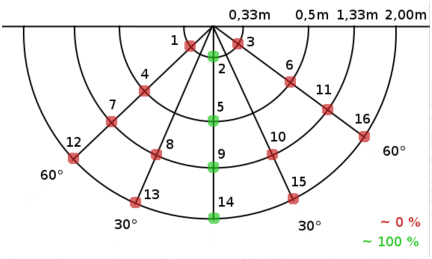
This Table shows the measurements that are taken to evaluate the new docking algorithm and compare it to the Kobuki's docking algorithm

New Docking Approach:



Docking success of the new Docking approach

Kobuki's Docking Approach:



Docking success of Kobuki's Docking

New Docking Approach:

- Bumper is activated during docking
- The range(2m) of the Apriltag was slightly to short

Kobuki's Docking Approach:

- Robot drives to a wrong docking station, because the IR-signals are overlapping
- The Robot does not do a retry after the docking failed
- IR-Sensors work not perceive enough.

Video

Questions

Questions ?

References

[1] "Testing Automatic Docking." http://wiki.ros.org/kobuki/Tutorials/TestingAutomaticDocking. Accessed: 2017-03-19.

[2] M. Kim, H. W. Kim, and N. Y. Chong, "Automated Robot Docking Using Direction Sensing RFID," in *Proceedings 2007 IEEE International Conference on Robotics and Automation*, pp. 4588–4593, April 2007.

[3] E. Olson, "AprilTag: A robust and flexible visual fiducial system," in *2011 IEEE International Conference on Robotics and Automation*, pp. 3400–3407, May 2011.

[4] B. W. Minten, R. R. Murphy, J. Hyams, and M. Micire, "Low-Order-Complexity Vision-based Docking," *IEEE Transactions on Robotics and Automation*, vol. 17, pp. 922–930, Dec 2001.