Bewegungsplanung und Regelung für autonomes Greifen mit einem Unterwasserroboter

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- D.-A. Dücker, M.Sc.

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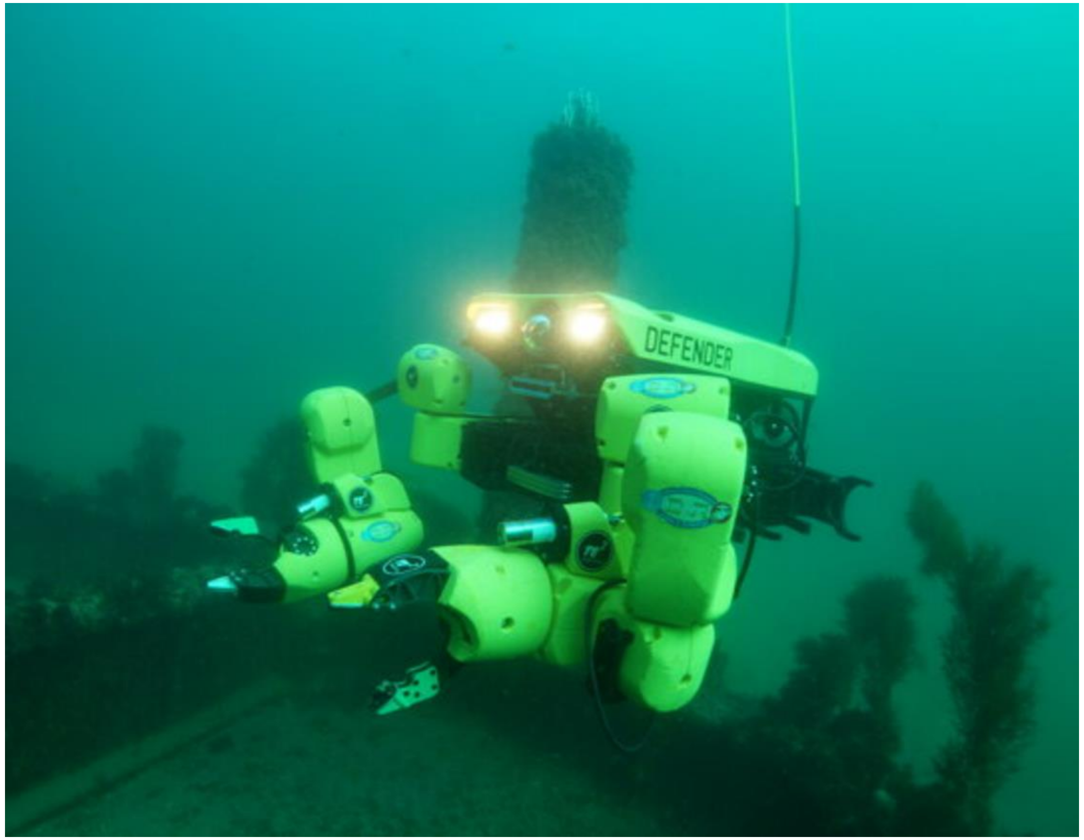
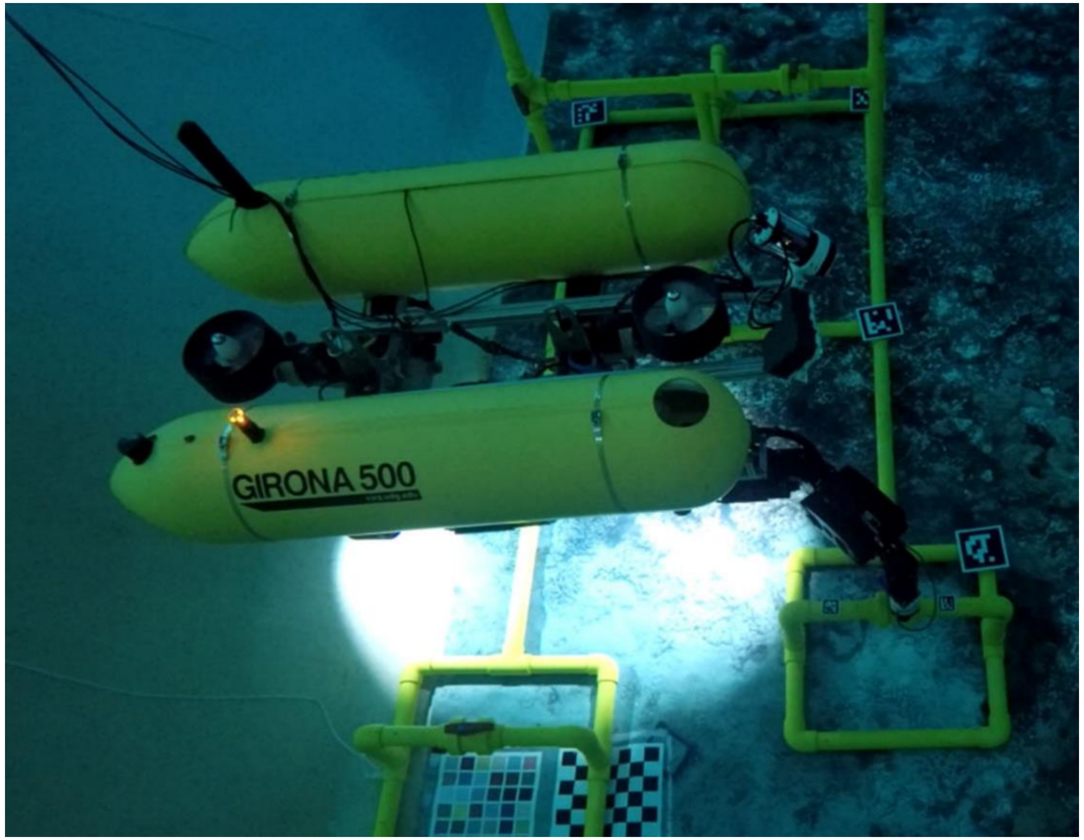
Motivation

RE2 Sapien Sea Class ROV



RE2 Robotics, RE2 Sapien Sea Class, https://www.resquared.com/underwater, 2020.

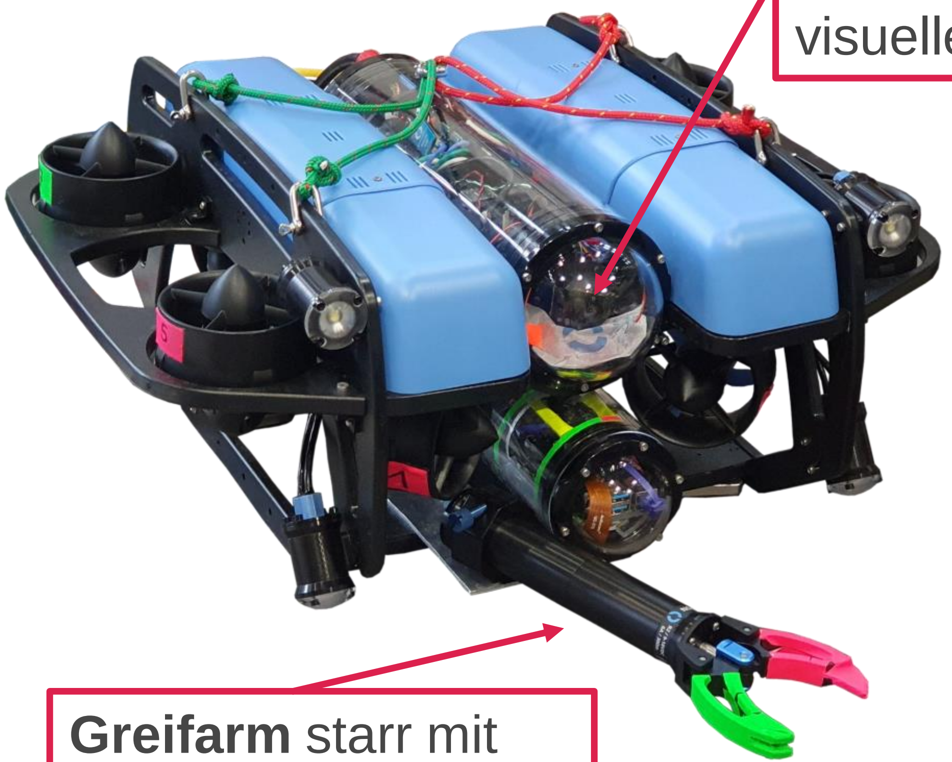
Girona500 I-AUV



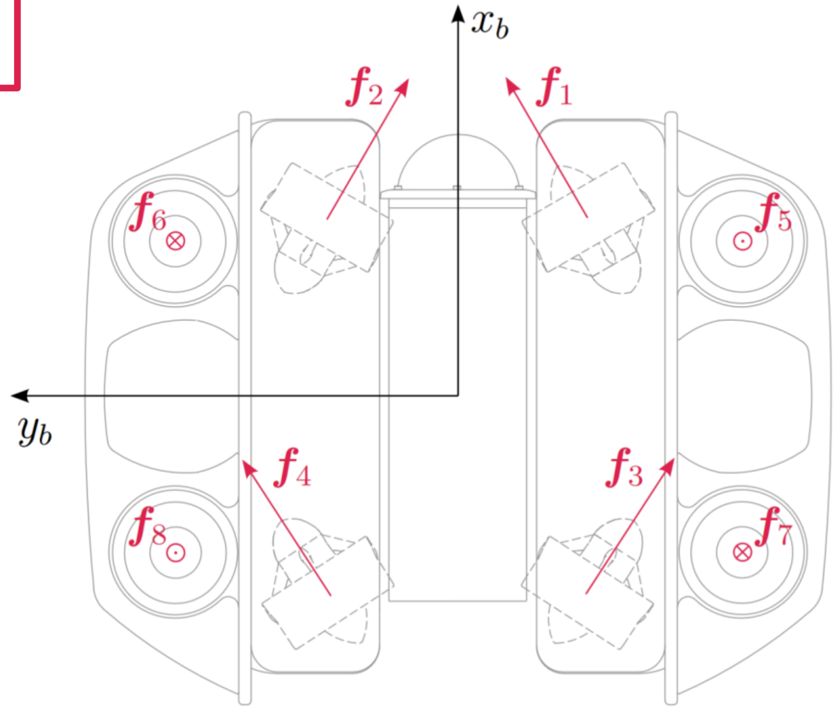
Youakim, D, Cieslak, P, Dornbush, A, Palomer, A, Ridao, P, Likhachev, M. Multirepresentation, Multiheuristic A* search-based motion planning for a free-floating underwater vehicle-manipulator system in unknown environment. *J Field Robotics*. 2020; 37: 925– 950.

Systembeschreibung: BlueROV2

Frontkamera zur visuellen Lokalisierung



Greifarm starr mit Fahrzeug verbunden

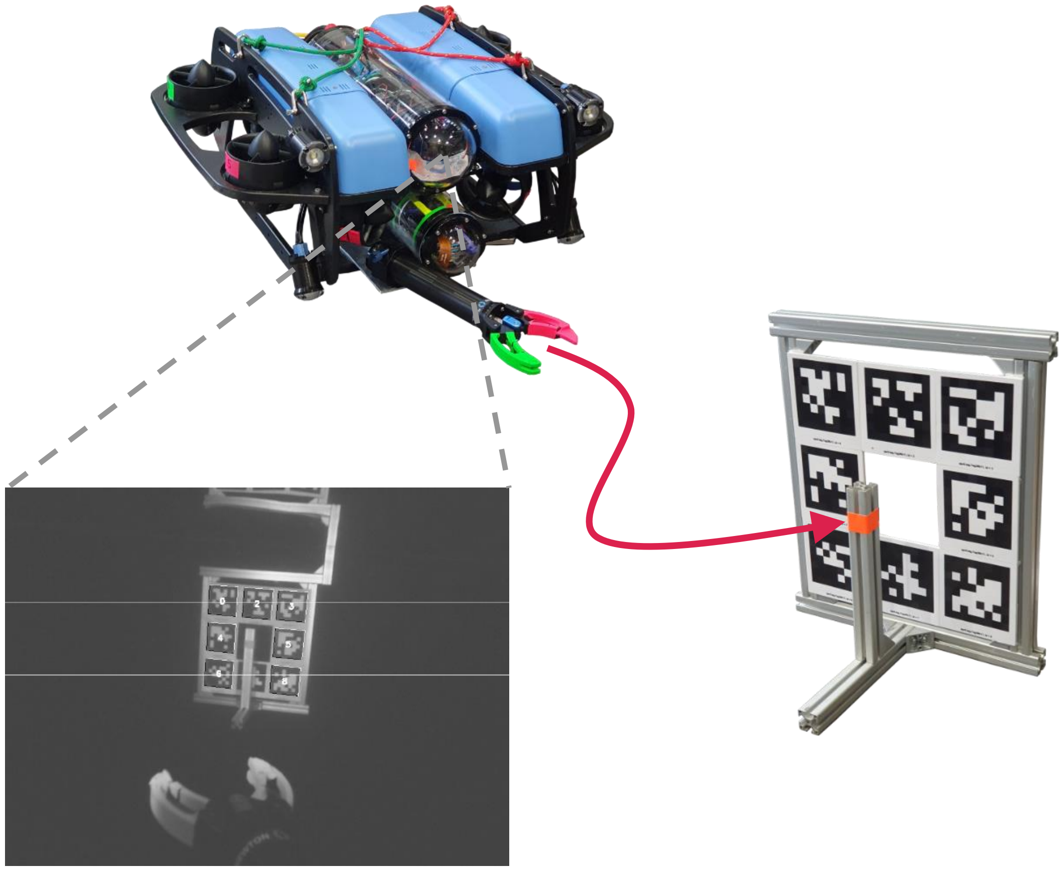


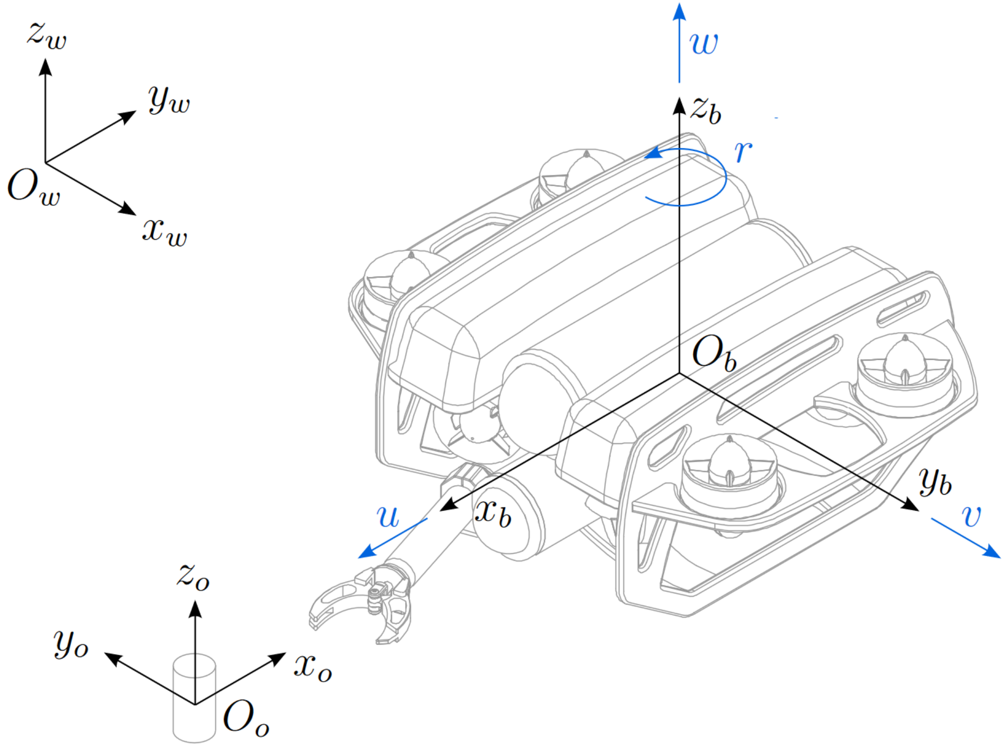
vollaktuiert über acht Propeller

Implementierung im Robot Operating System (ROS)

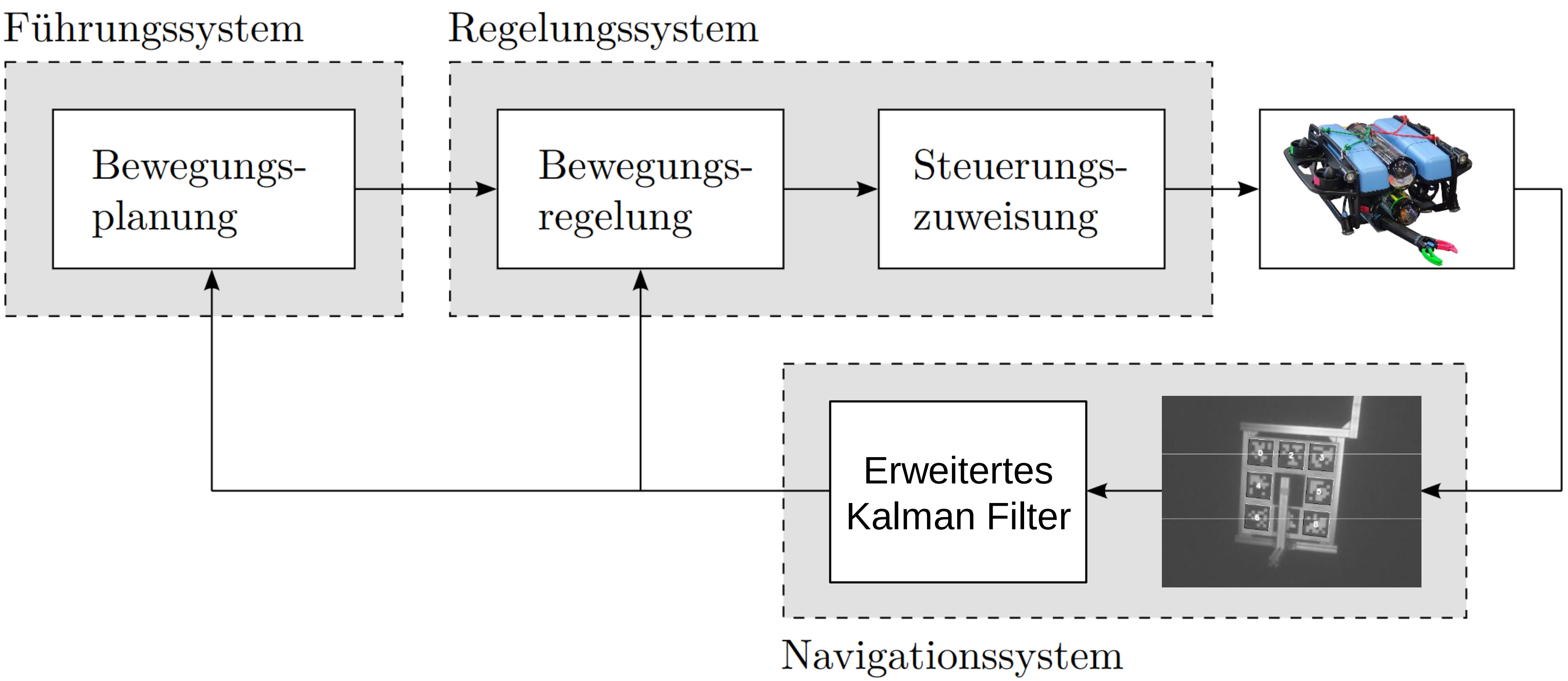
Problemformulierung

Aufgabe: Greifbacken des Endeffektors um das Objekt platzieren, damit ein Griff möglich ist.



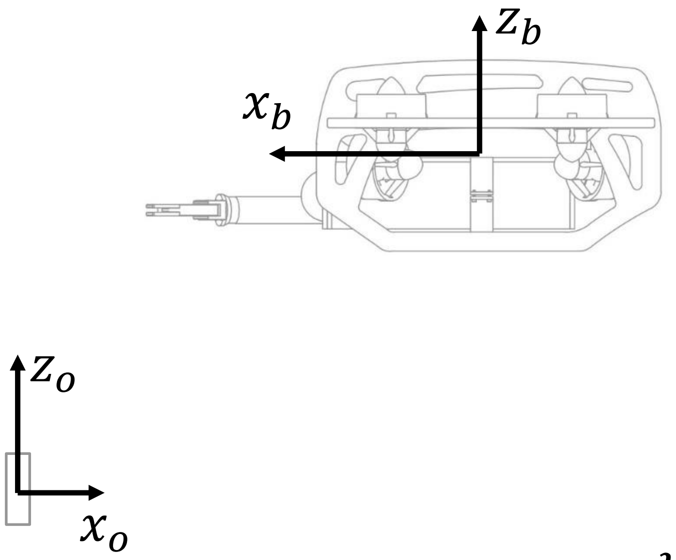


Wie wird ein autonomes Fahrzeug gesteuert?

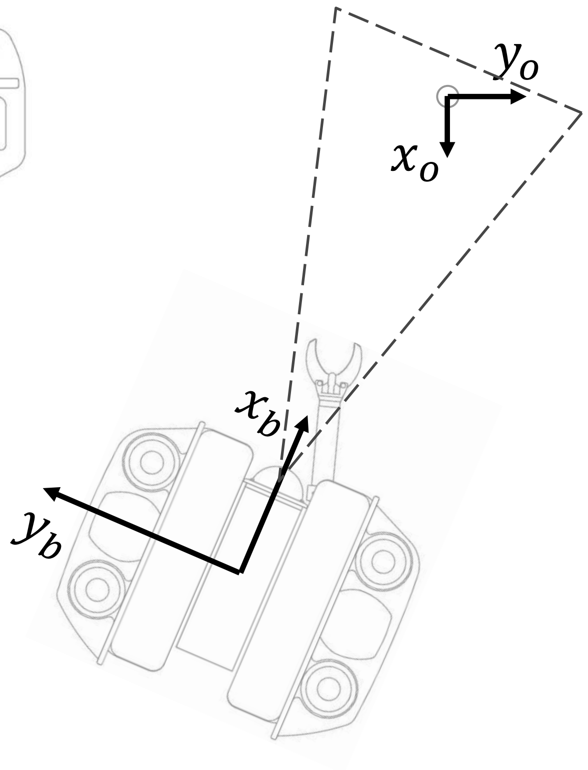


Bewegungsplanung (1): Grundidee

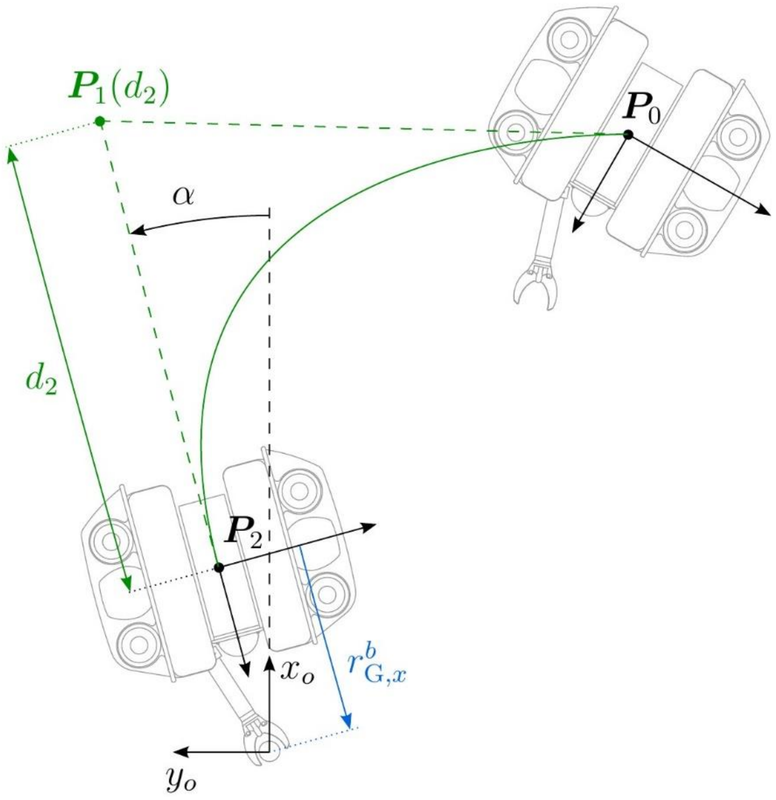
Tiefenregelung:

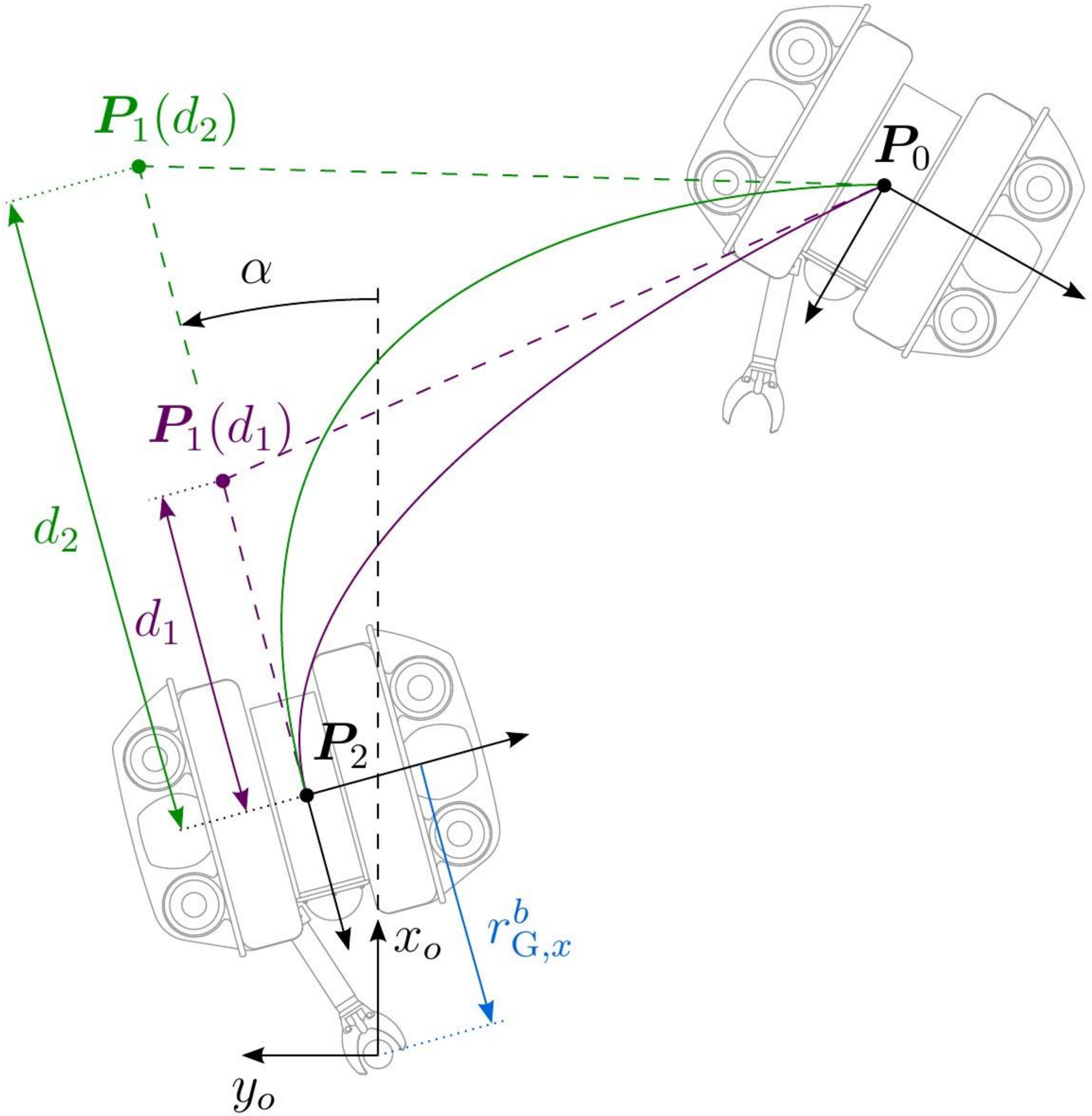


Gierwinkel-Regelung:



Pfadplanung:

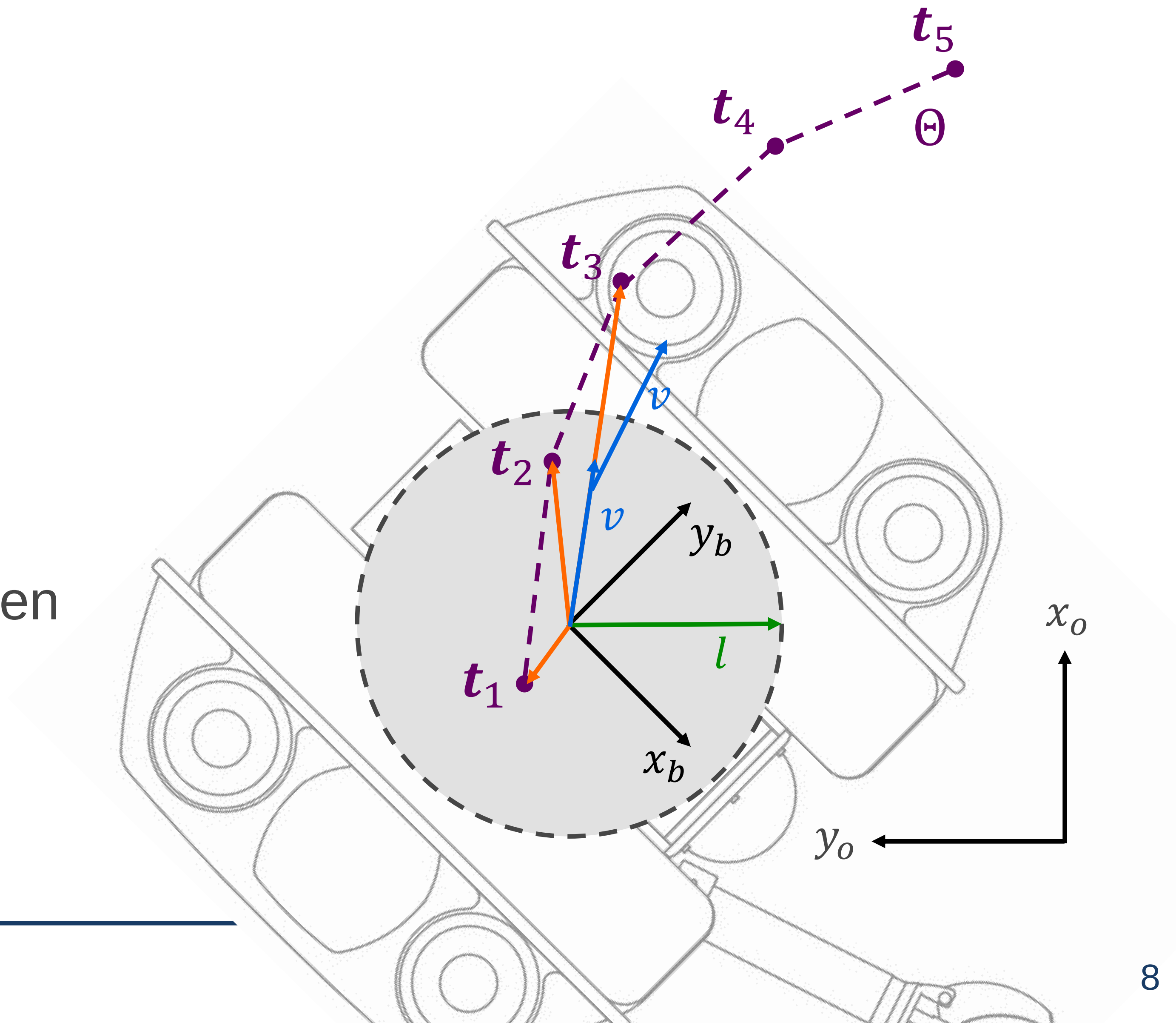




$P_1(d_2)$
P_0
α
$P_1(d_1)$
d_2
d_1
P_2
x_o
$r^b_{G,x}$
y_o

Orientierung an *Pure Pursuit:*

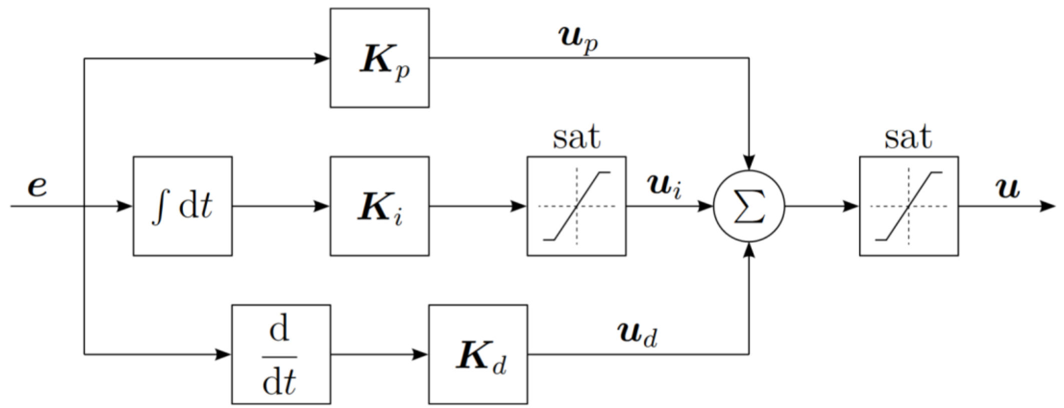
- wenn $\left\| \boldsymbol{t}_i^o - \boldsymbol{p}^o \right\| < l$, dann $i+1$, sonst ist $\boldsymbol{t}_i^o$ nächster Wegpunkt
- Geschwindigkeitsvektor zum nächsten Wegpunkt ausrichten
- Sollposition $\boldsymbol{p}_d^o = \boldsymbol{t}_i^o$
- $\boldsymbol{p}_d^o$ wird an die Regelung übergeben



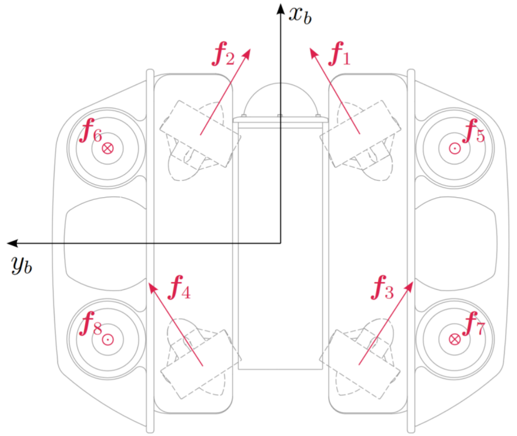
Regelabweichung

$$\boldsymbol{e} = \begin{bmatrix} e_x & e_y & e_z & e_\psi \end{bmatrix}^\top$$

PID-Regler



Mixer-Matrix



$$\begin{bmatrix} u_x \\ u_y \\ u_z \\ u_\psi \end{bmatrix} \begin{bmatrix} 1 & 1 & 0 & 1 \\ 1 & -1 & 0 & -1 \\ 1 & -1 & 0 & 1 \\ 1 & 1 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} \tilde{u}_1 \\ \tilde{u}_2 \\ \tilde{u}_3 \\ \tilde{u}_4 \\ \tilde{u}_5 \\ \tilde{u}_6 \\ \tilde{u}_7 \\ \tilde{u}_8 \end{bmatrix}$$

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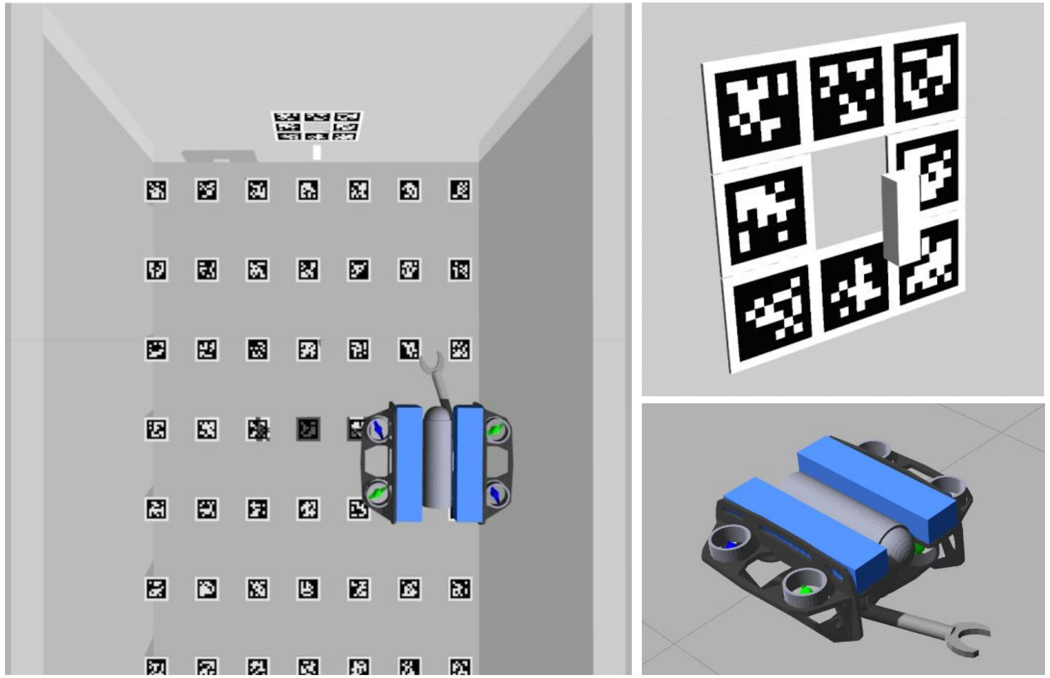
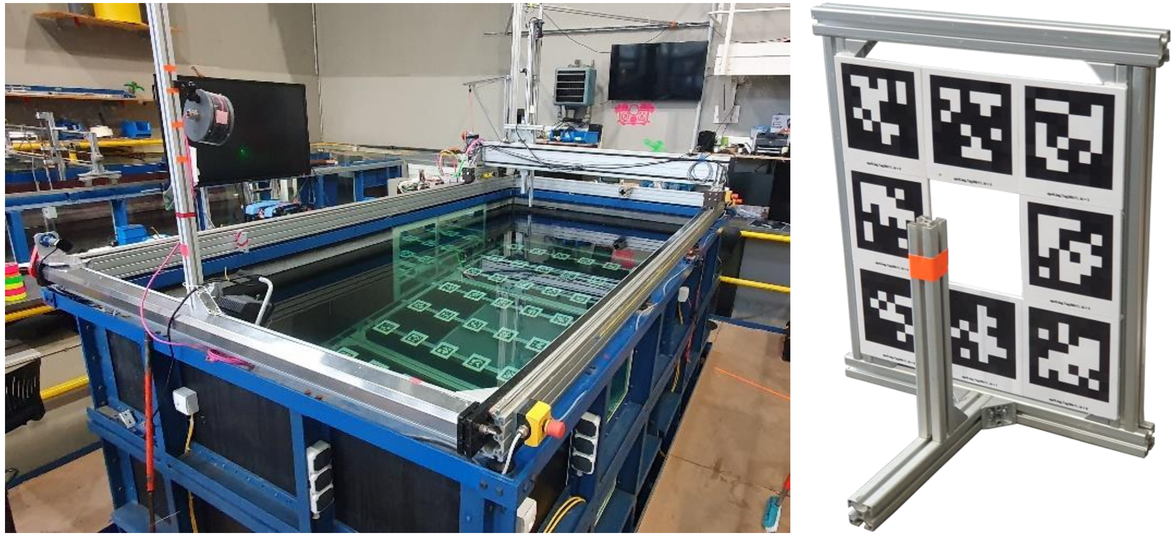
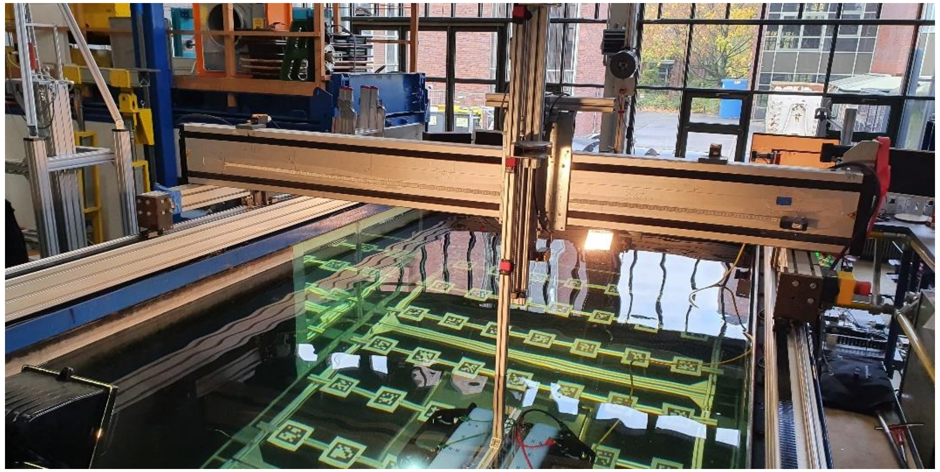
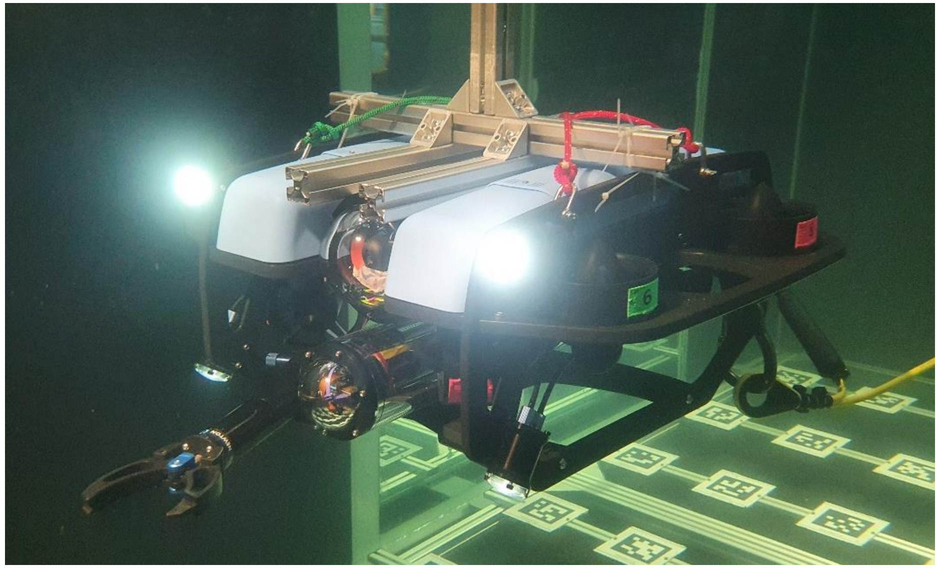
Gazebo-Simulation



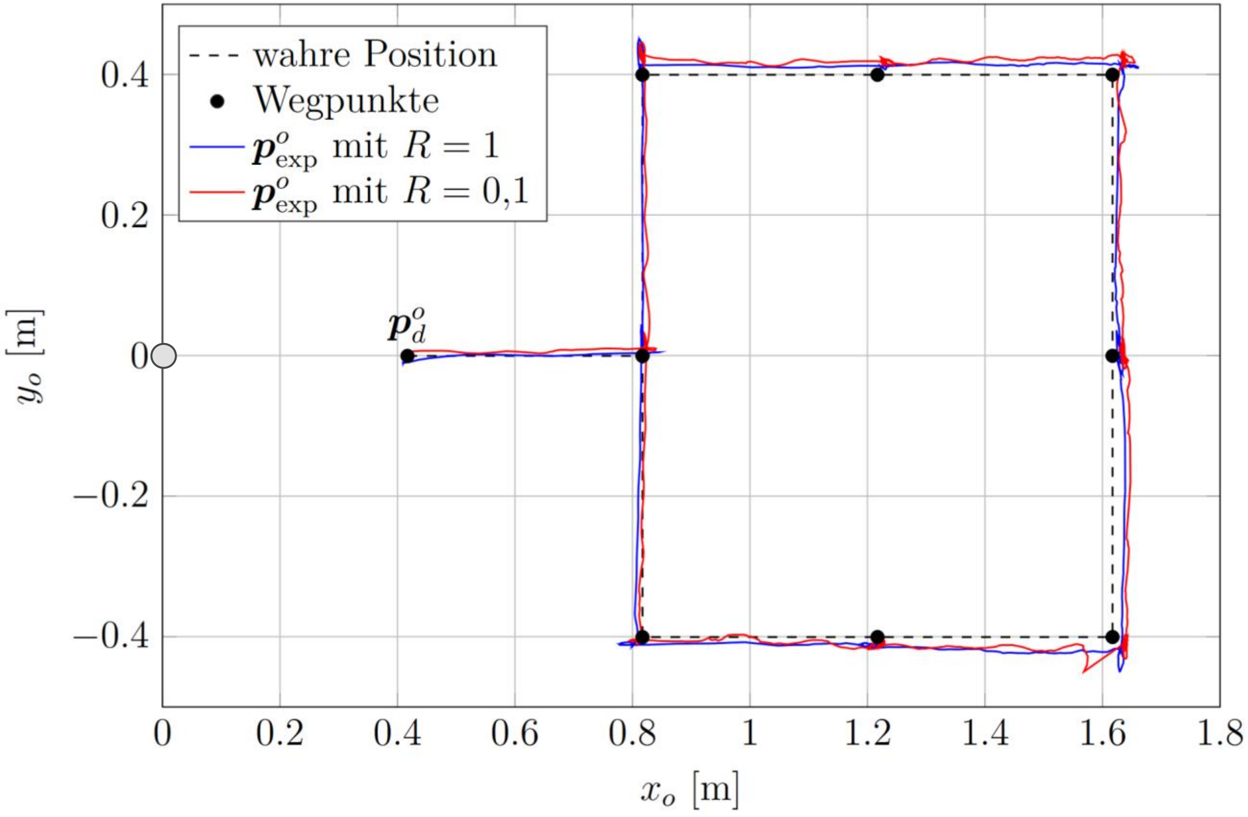
Hardware-Experiment







Wie genau ist die visuelle Lokalisierung?



→ erscheint ausreichend genau (wenige cm Unsicherheit)

Ergebnisse in der Simulation (1)

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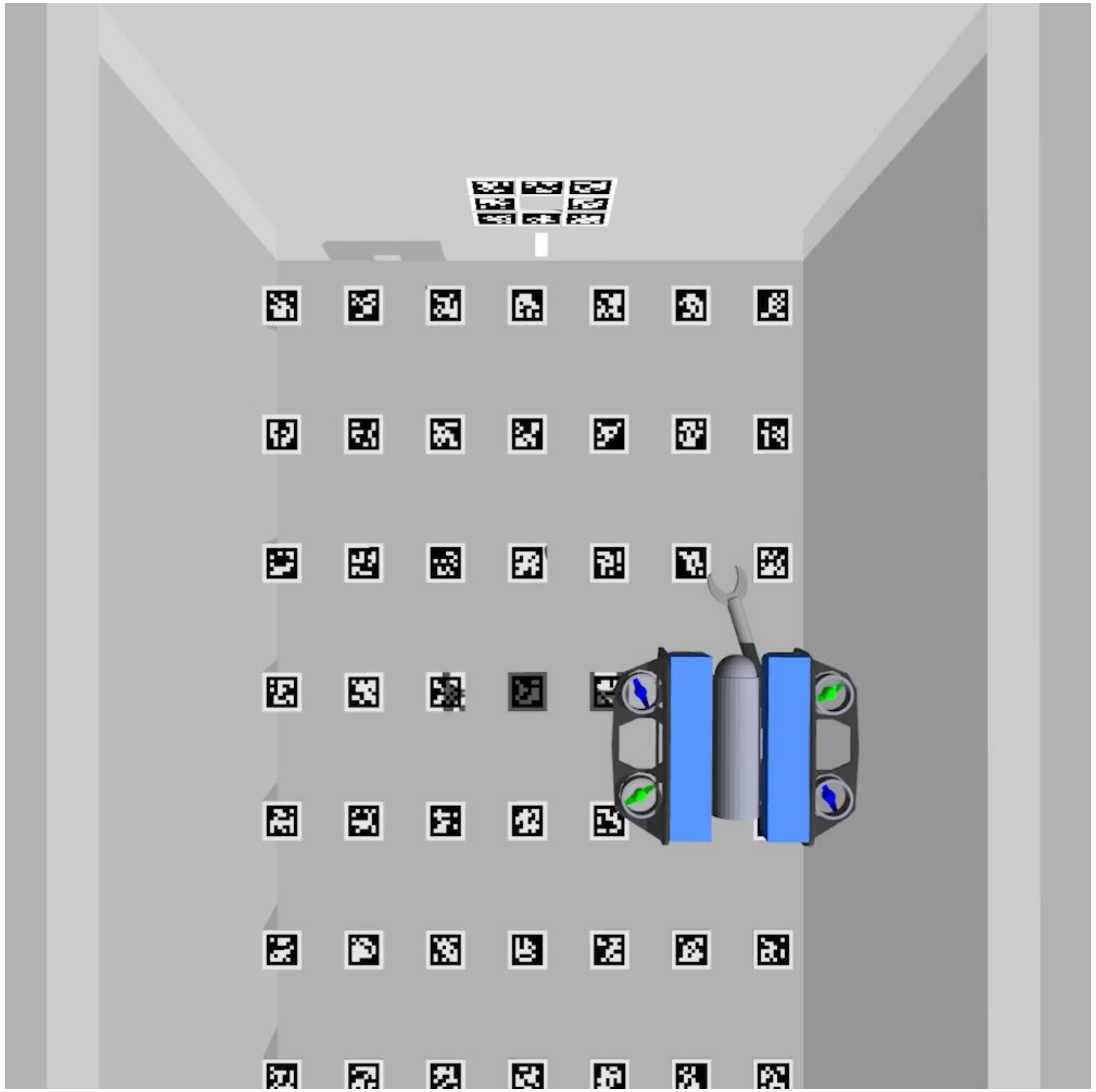
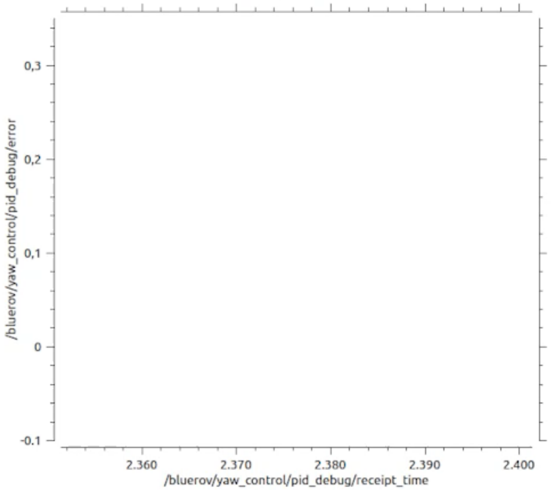
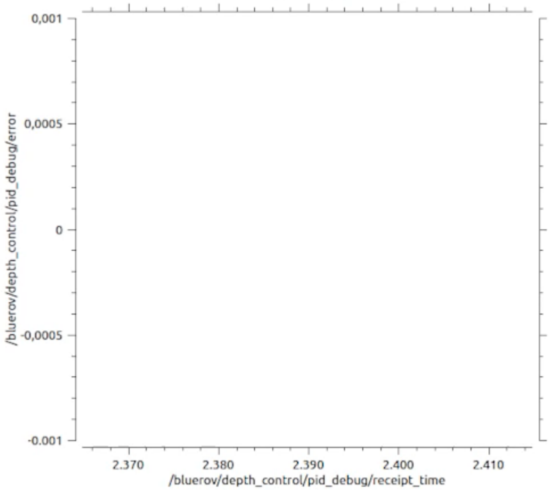


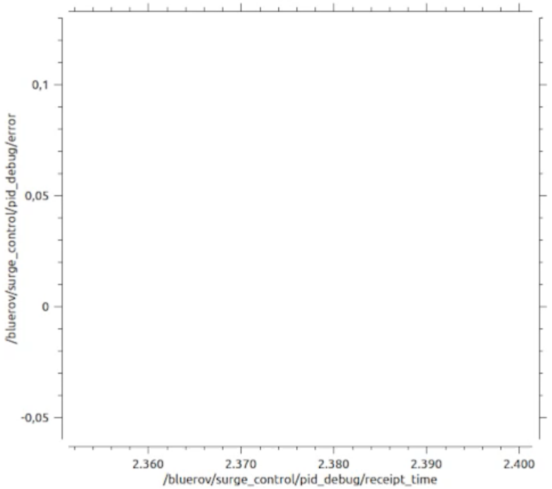
Gierwinkel-Fehler



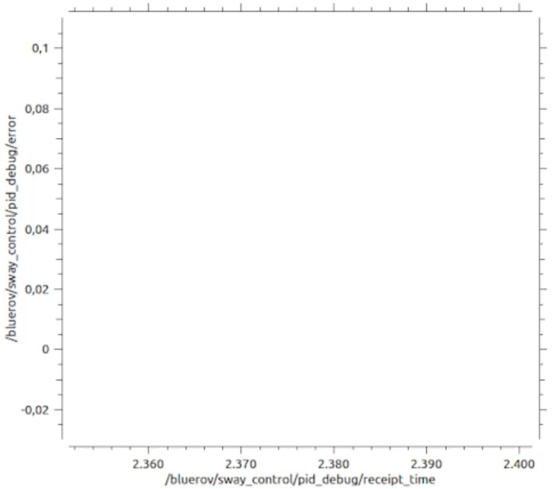
Tiefen-Fehler



x_b-Fehler



y_b-Fehler



Ergebnisse in der Simulation (2)

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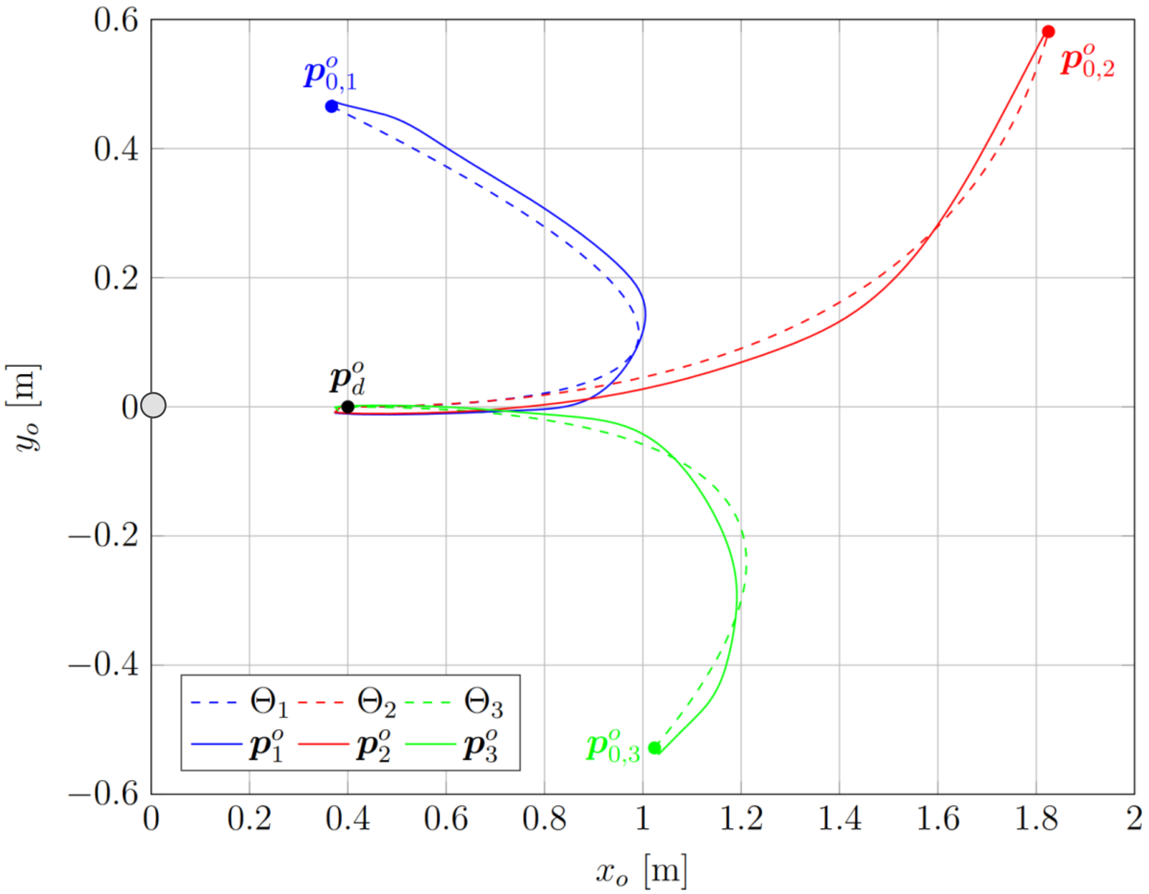
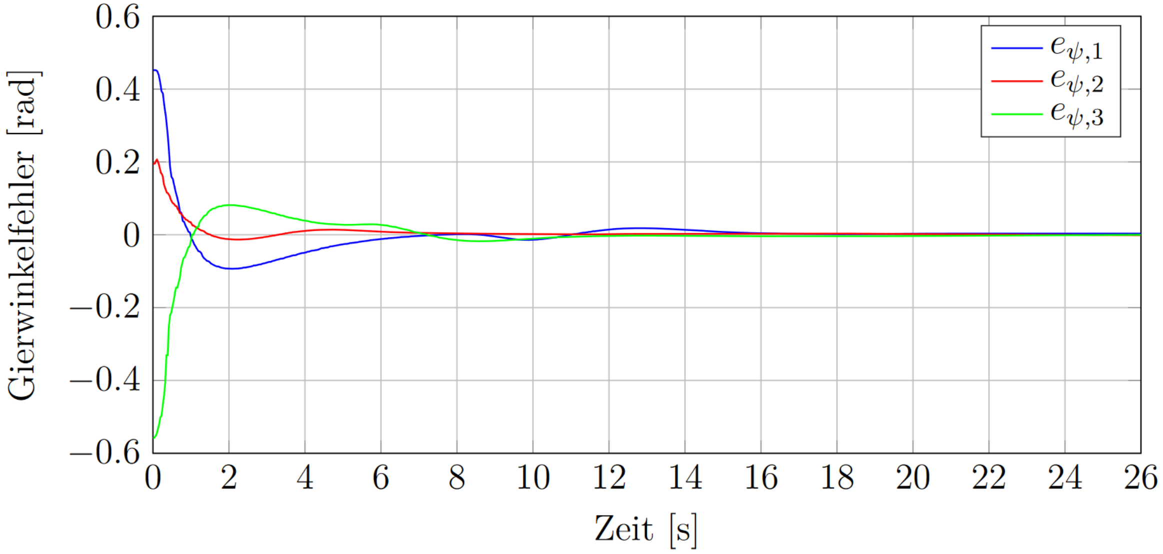
Wie gut wird der Pfad verfolgt?



Wie gut wird die Ausrichtung zum Objekt gehalten?



Ergebnisse im Experiment (1)

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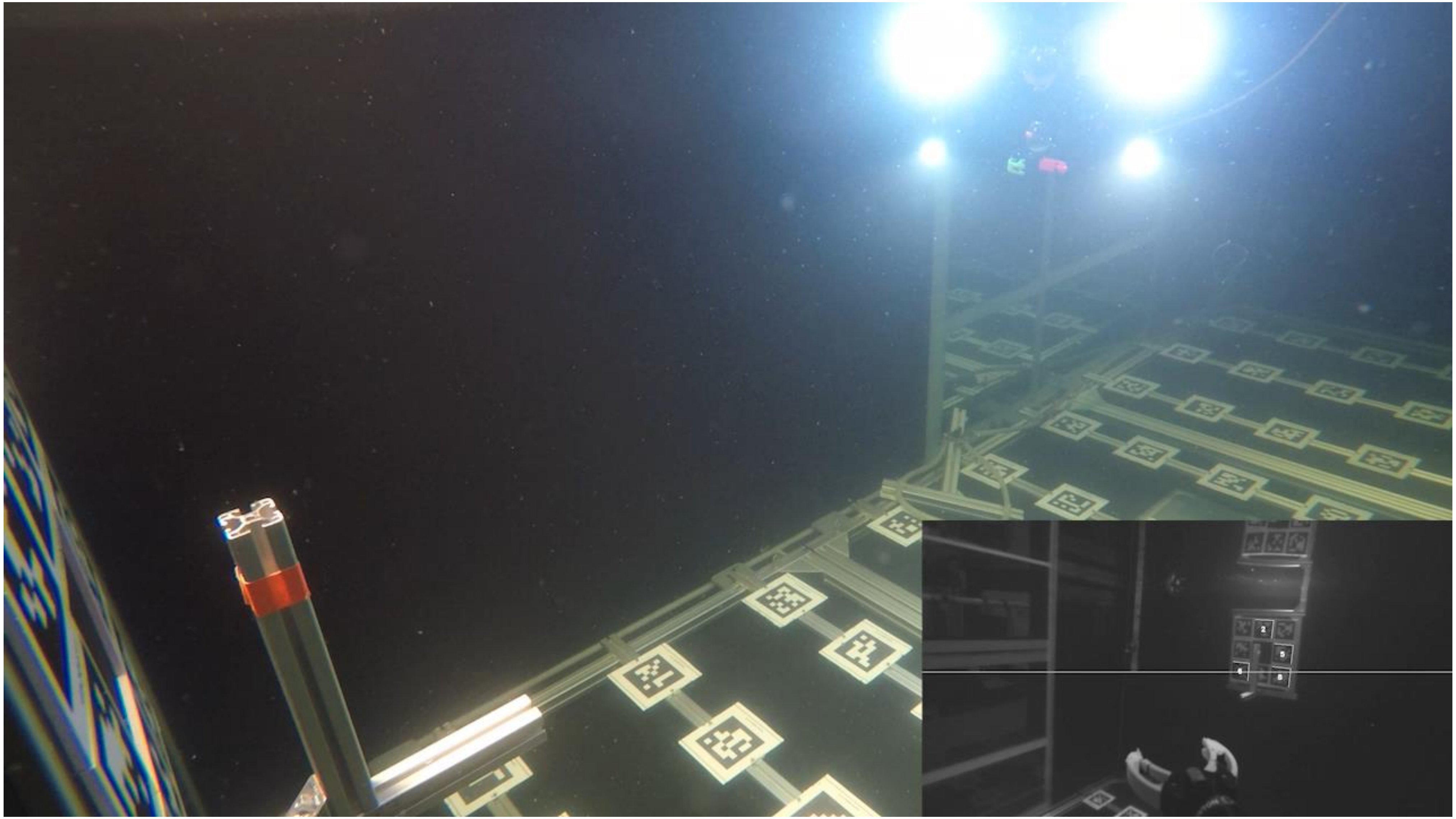
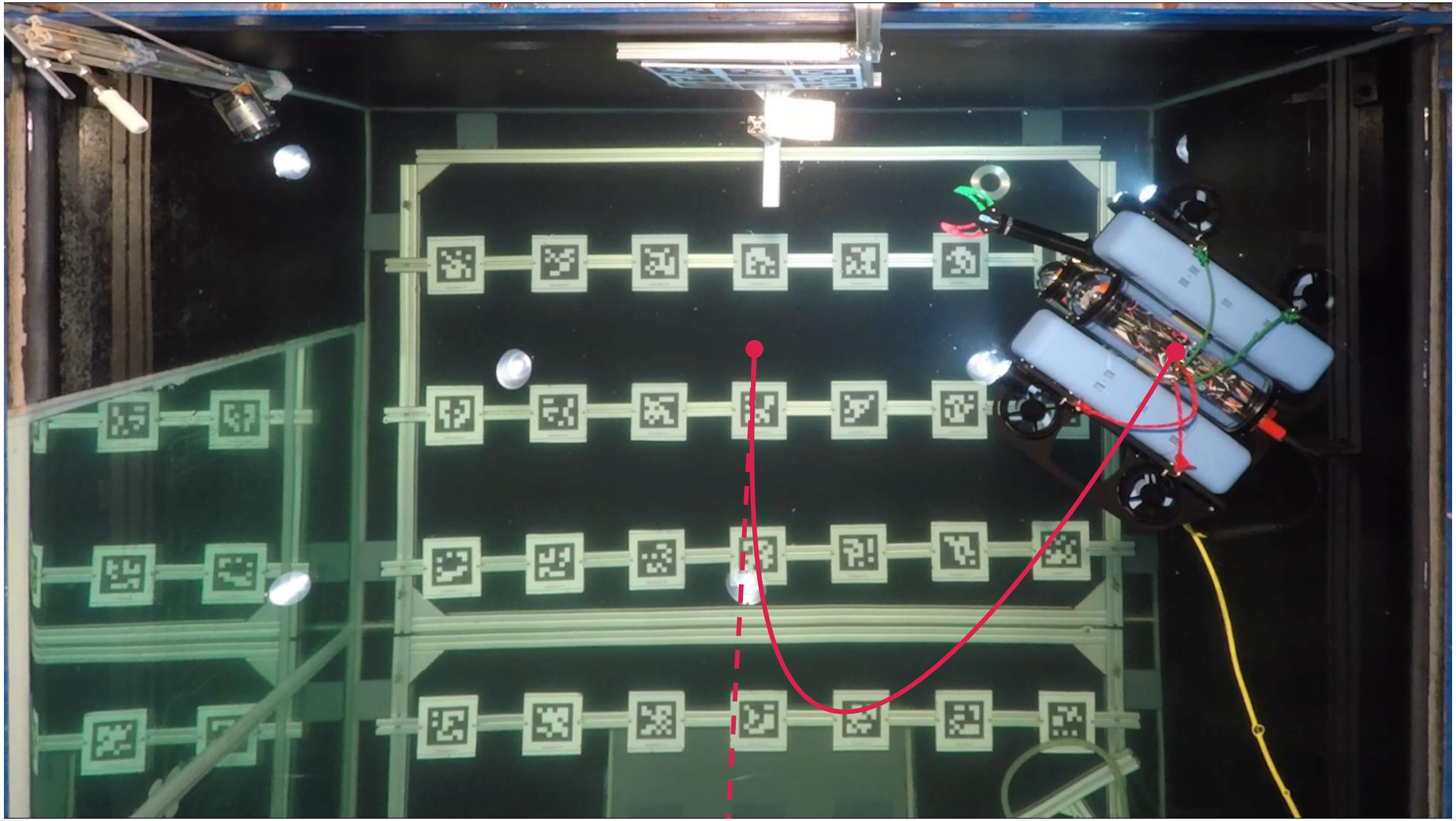
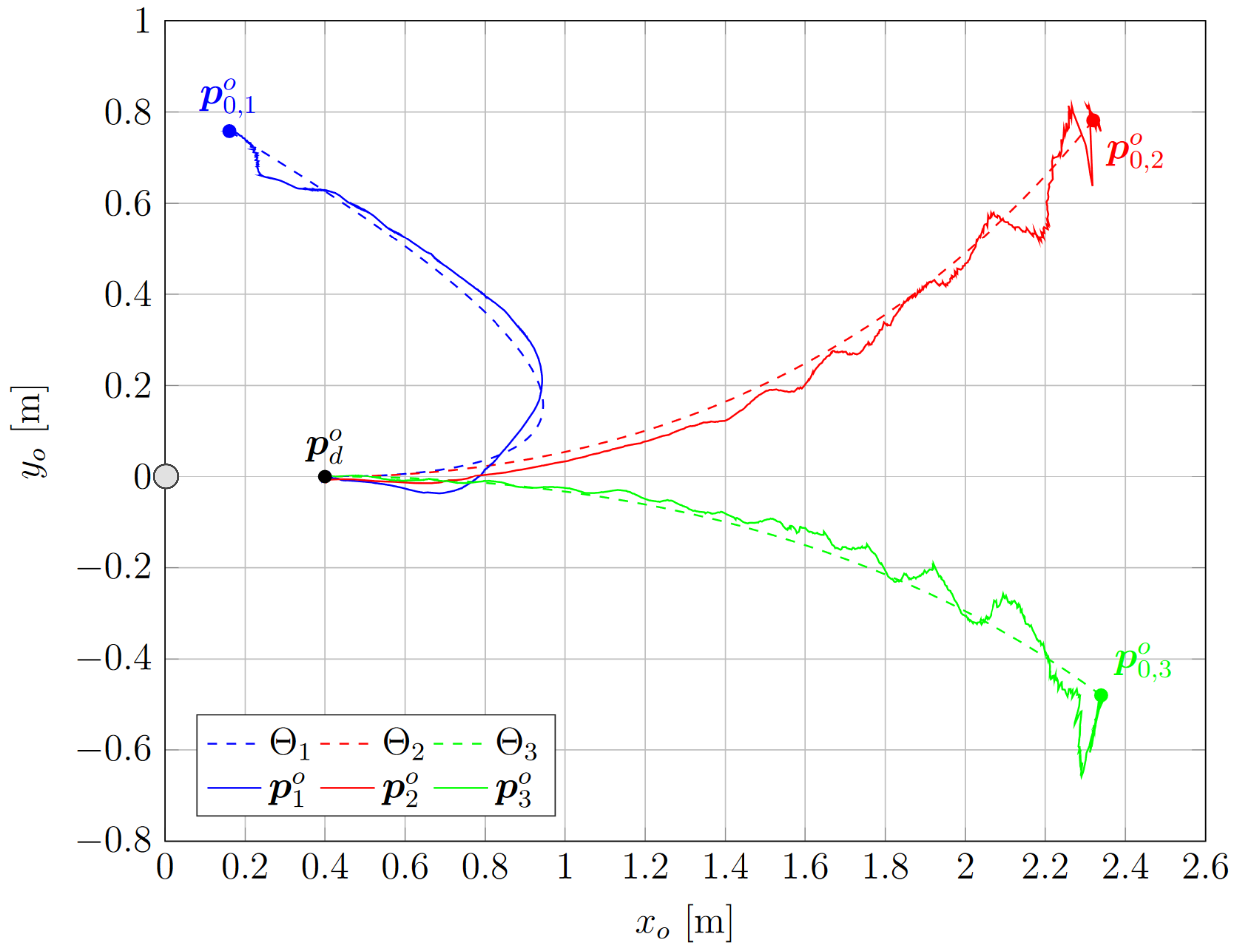


Ergebnisse im Experiment (2)



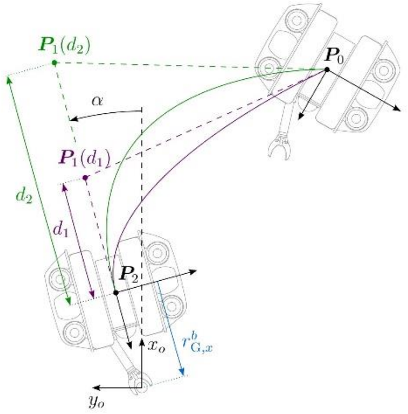
Wie gut wird der Pfad verfolgt?



Zusammenfassung und Ausblick

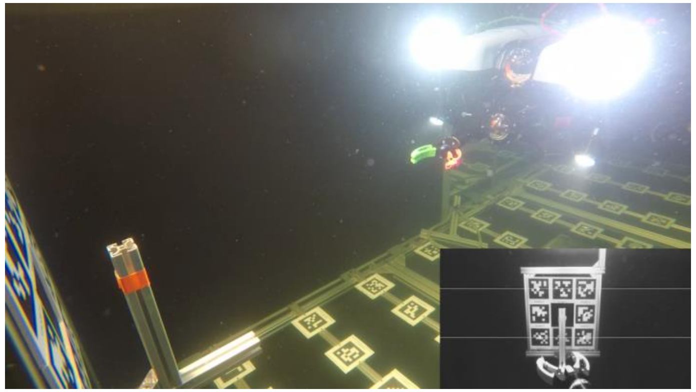
Zusammenfassung:

- Anpassung eines vorhandenen Lokalisierungssystems
- Bahnplanungsalgorithmus basierend auf Bézier-Kurven
- Regelungsarchitektur zur Steuerung des BlueROV2
- Untersuchung der Leistungsfähigkeit in Simulation und Experiment

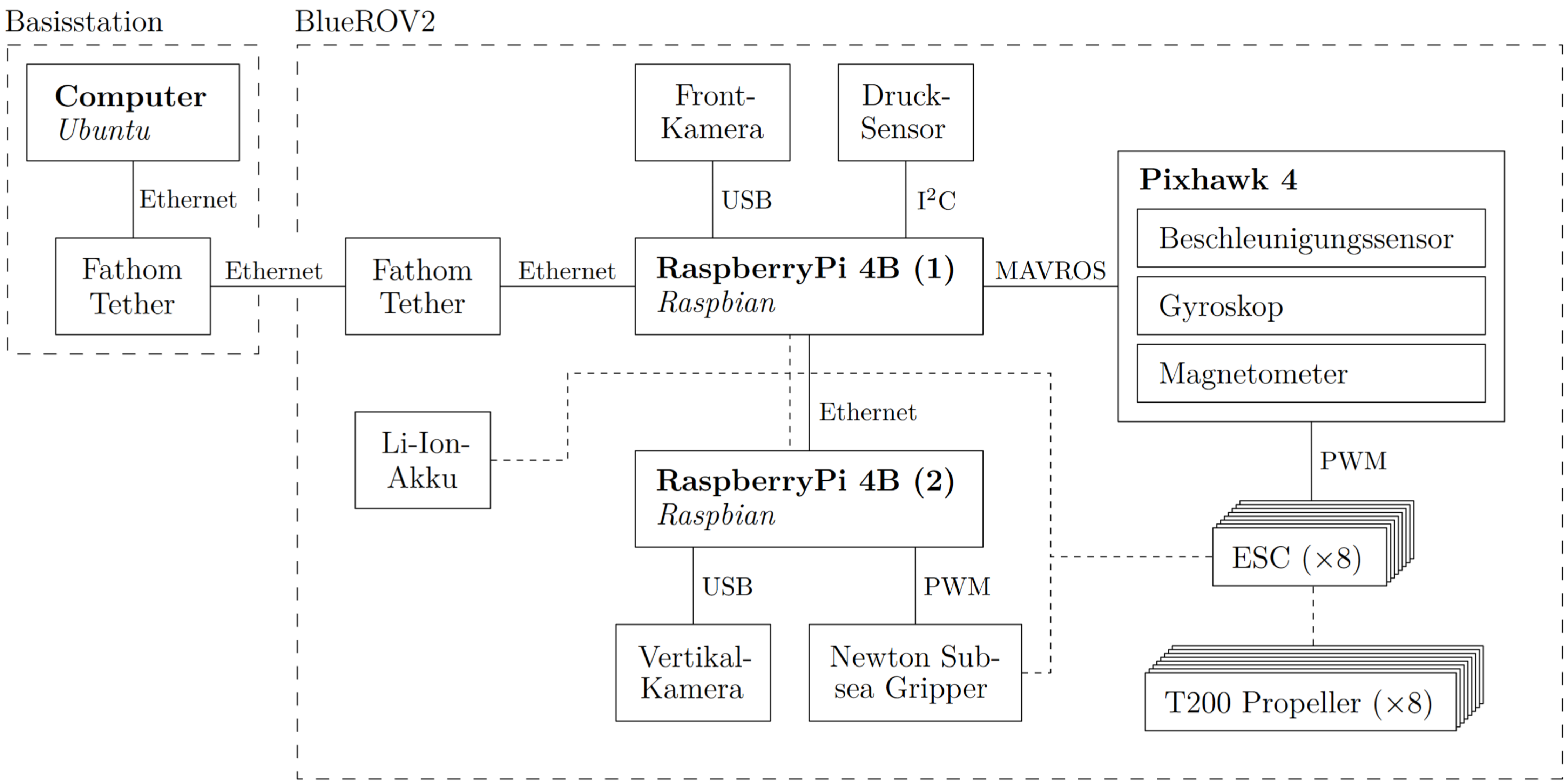


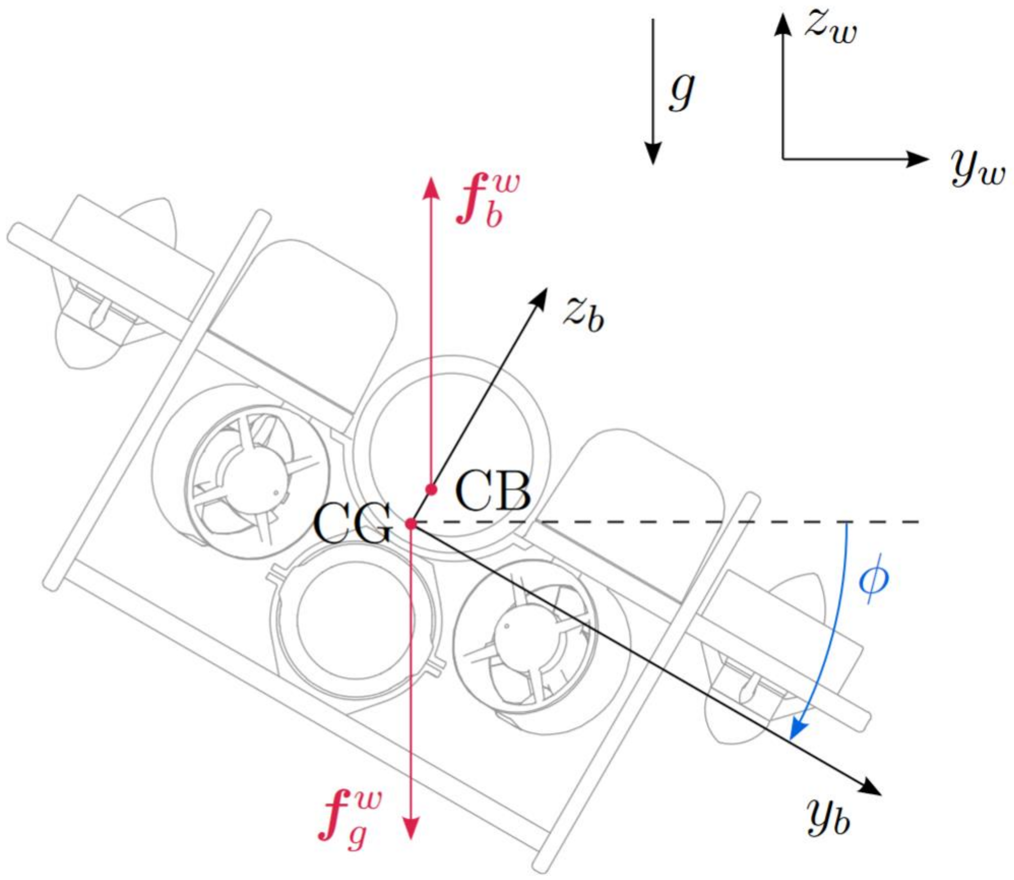
Ausblick:

- umfangreiche Untersuchung des Systems
- andere/dynamische Pfadplanungsmethoden
- Transport, Positionierung

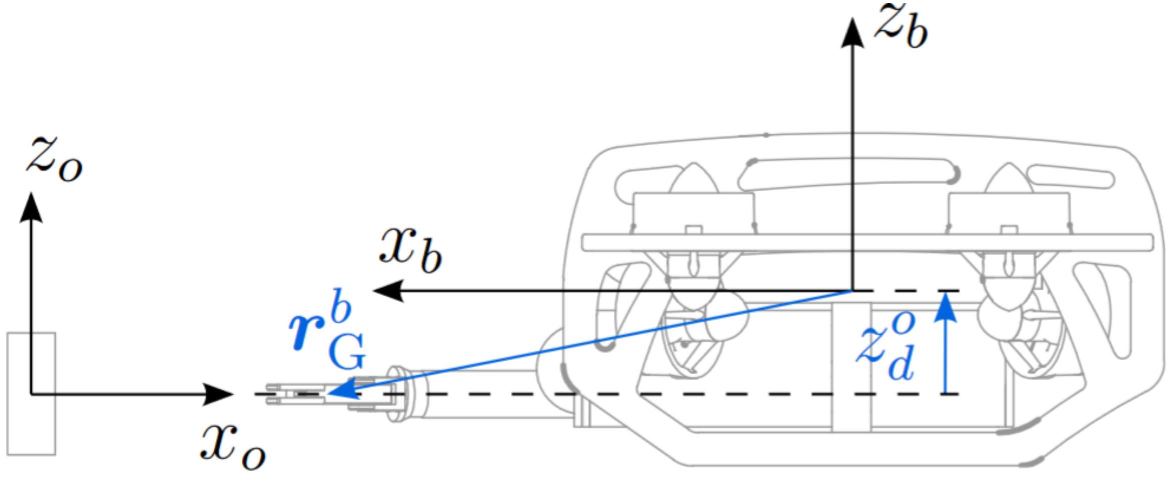


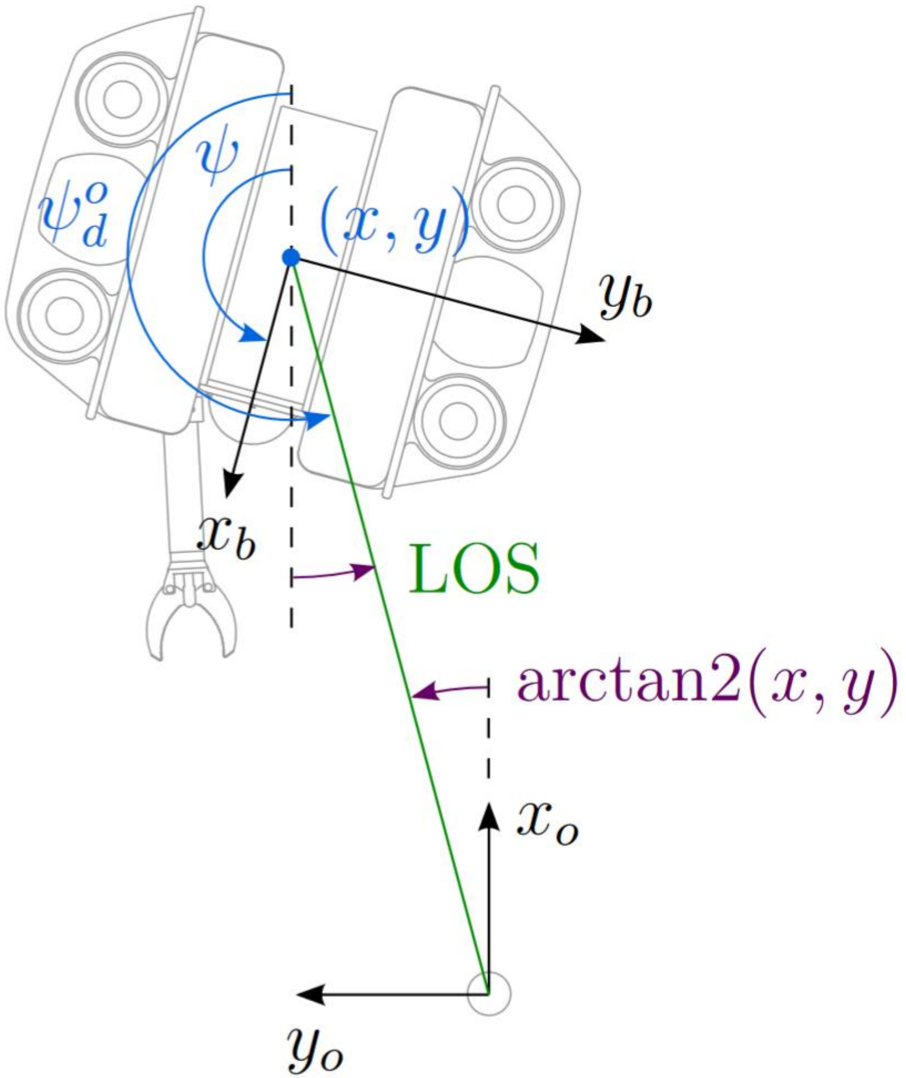
Systembeschreibung (2)




z_w
g
y_w
f_b^w
z_b
CB
CG
ϕ
f_g^w
y_b

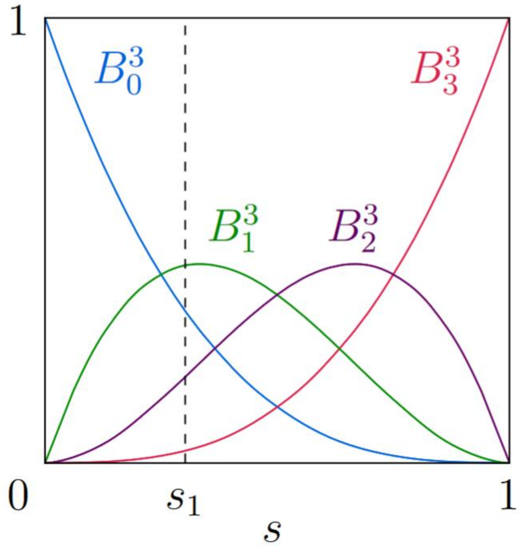
Bewegungsplanung (3)



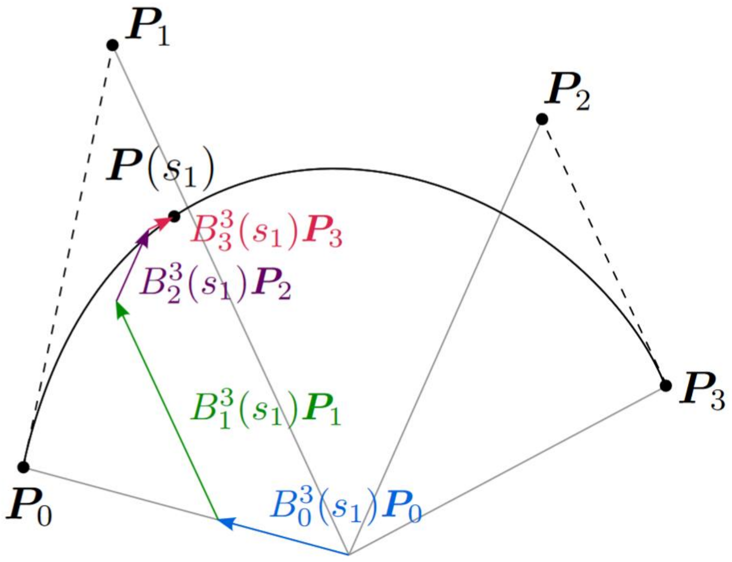


$$\boldsymbol{P}(s) = \sum_{i=0}^{n} B_i^n(s)\boldsymbol{P}_i \quad \text{mit } 0 \leq s \leq 1$$

$$B_i^n(s) := \binom{n}{i} s^i (1-s)^{n-i} \quad \text{mit } 0 \leq i \leq n$$

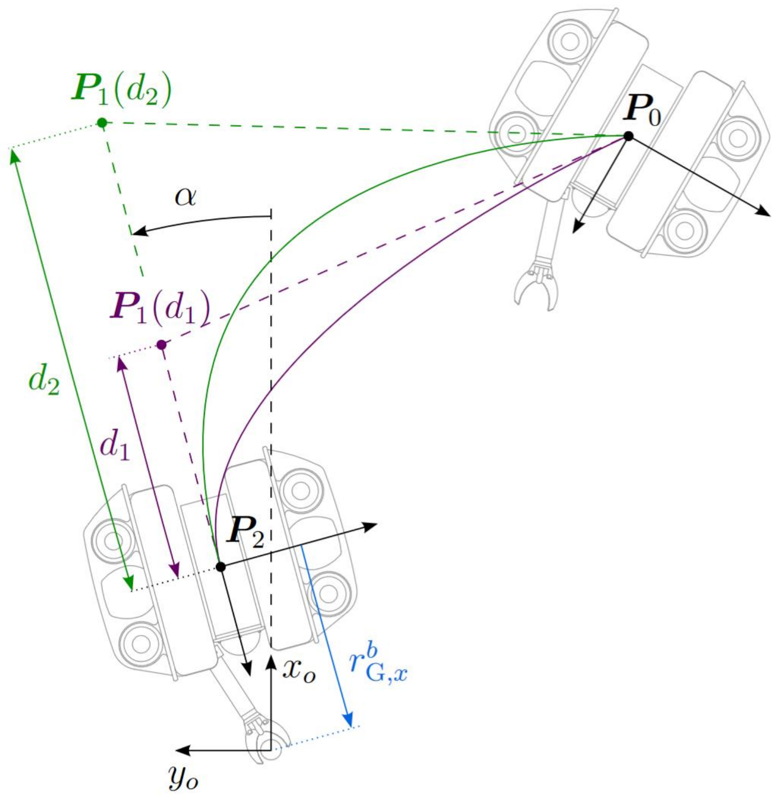


(a) Bernsteinpolynome.



(b) Kontrollpolygon und Bézierkurve.

$$\boldsymbol{P}_0 = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix}, \quad \boldsymbol{P}_1(\alpha, d) = \begin{bmatrix} \cos(\alpha)(r^b_{\mathrm{G},x} + d) \\ \sin(\alpha)(r^b_{\mathrm{G},x} + d) \end{bmatrix}, \quad \boldsymbol{P}_2(\alpha) = \begin{bmatrix} \cos(\alpha) r^b_{\mathrm{G},x} \\ \sin(\alpha) r^b_{\mathrm{G},x} \end{bmatrix}$$

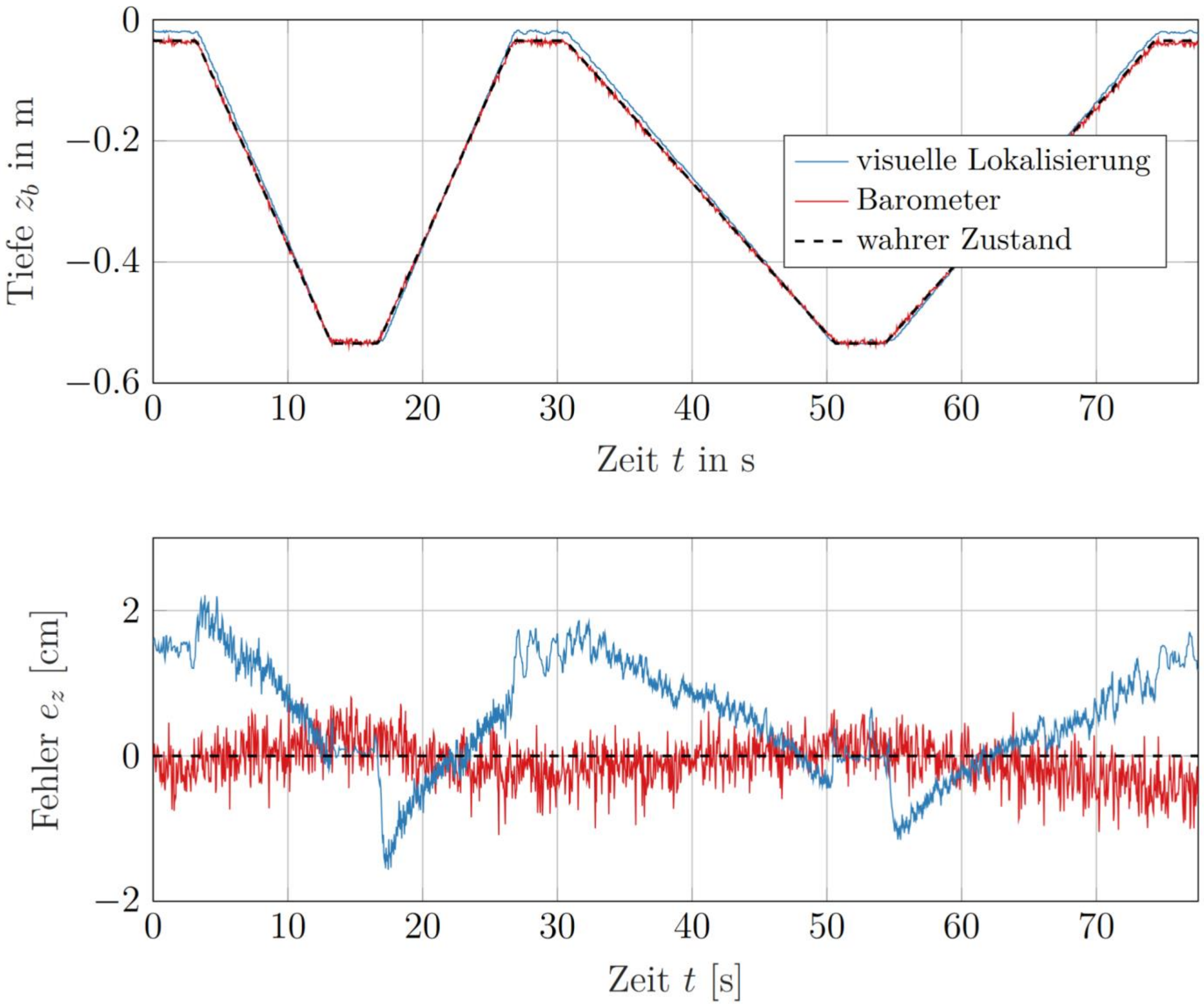


Regelung (2)

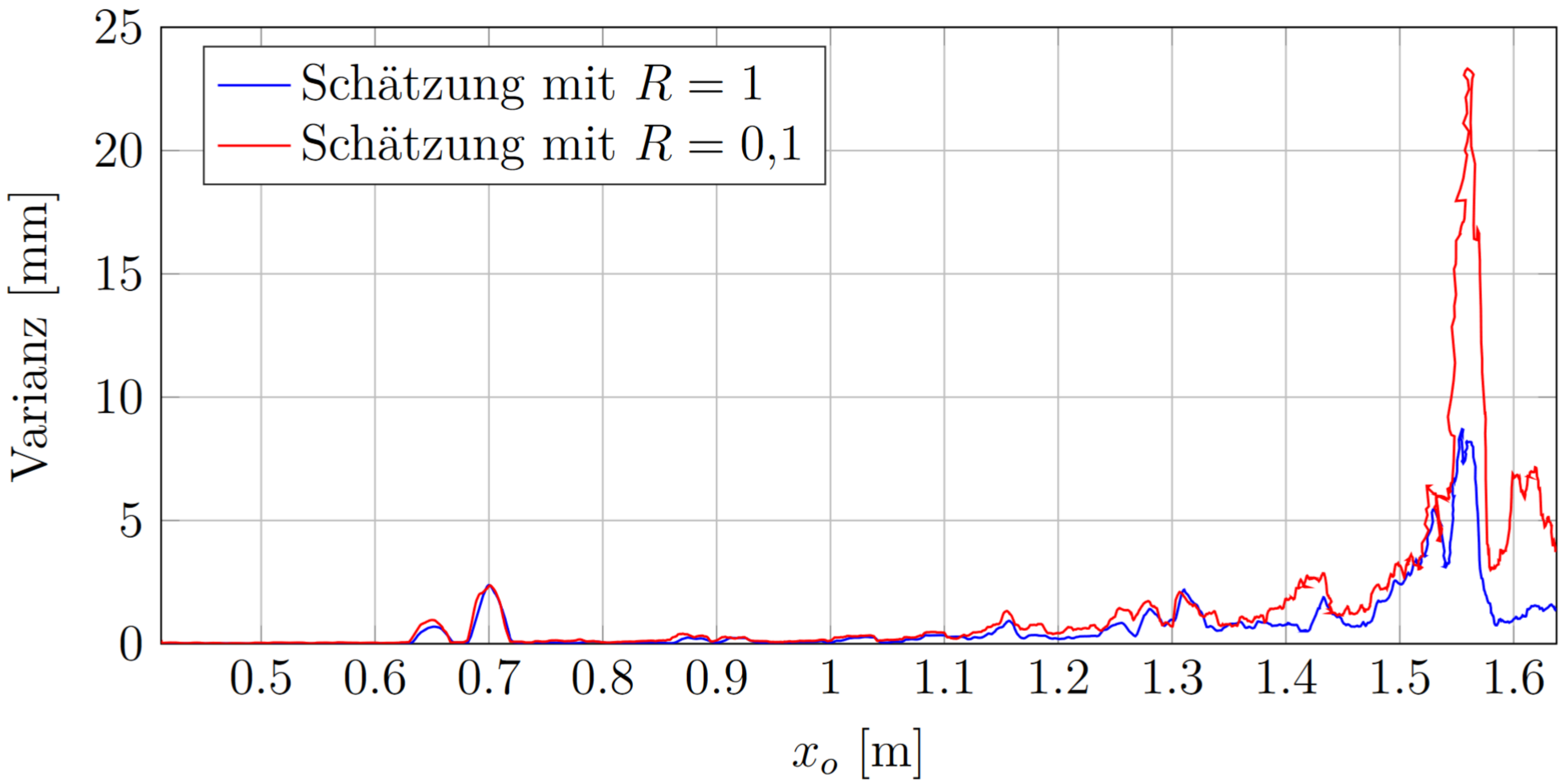
$$e_z = z_d^o - z \quad \text{und} \quad e_\psi = \psi_d^o - \psi$$

$$\boldsymbol{e}_p^b = \begin{bmatrix} e_x \\ e_y \end{bmatrix} = \boldsymbol{S}_{bo}(\boldsymbol{p}_d^o - \boldsymbol{p}^o) = \begin{bmatrix} \cos(\psi) & \sin(\psi) \\ -\sin(\psi) & \cos(\psi) \end{bmatrix} \begin{bmatrix} p_{d,x}^o - x \\ p_{d,y}^o - y \end{bmatrix}$$

Untersuchung im Experiment: Tiefenmessung



Untersuchung der Lokalisierung (2)



Untersuchung im Experiment (4)

Wie gut wird die Tiefe und die
Ausrichtung zum Objekt gehalten?