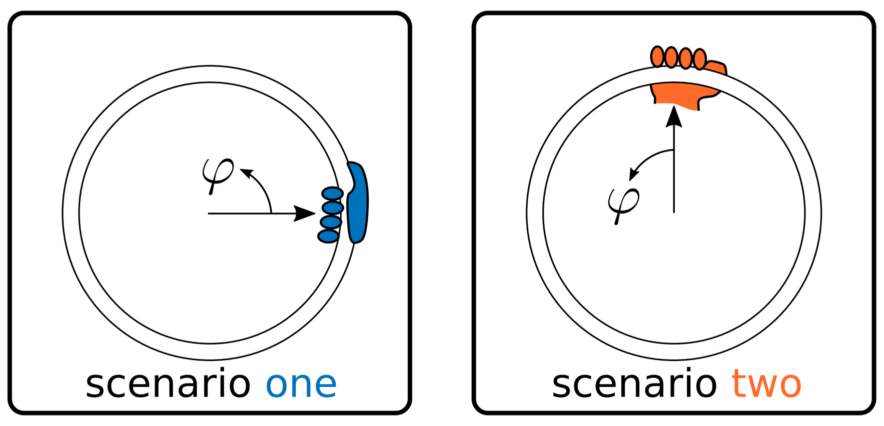
Kinematics of a Human Steering a Car

Schwegel Michael, Maderthaner Jakob

FAKULTÄT FÜR ELEKTROTECHNIK UND INFORMATIONSTECHNIK
Faculty of Electrical Engineering and Information Technology
AUTOMATION & CONTROL INSTITUTE
INSTITUT FÜR AUTOMATISIERUNGS- & REGELUNGSTECHNIK

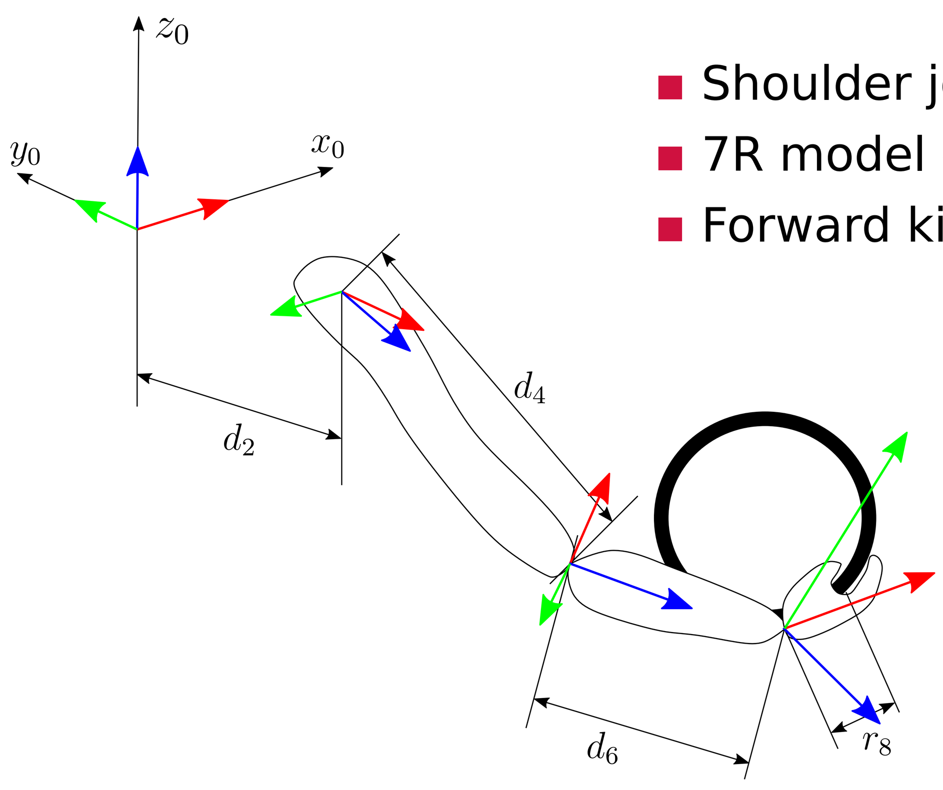
Introduction

There are various approaches for steering a car, including different grips and angles at which the hand is in contact with the steering wheel. Two such grips are analyzed for their kinematic optimality by turning the steering wheel about +90deg, where the starting configuration is given in the drawings below. Therefore, different optimality measures and a model of the human arm are used.



- Human arm modeled as 7R robot to analyze movements
- Optimization based inverse kinematics
- Kinematic motion analysis using manipulability measures
- Optimize seat position for manipulability

7R arm model



- Shoulder joint modeled with fixed position
- 7R model of the arm
- Forward kinematics using DH-convention

n	θ_n	d_n	r_n	α_n
1	0	0	0	$\pi/2$
2	$q_1-\pi/2$	0.15m	0	$\pi/2$
3	$q_2+\pi/2$	0	0	$\pi/2$
4	$q_3+\pi/2$	0.31m	0	$\pi/2$
5	q_4	0	0	$-\pi/2$
6	$q_5-\pi/2$	0.19m	0	$-\pi/2$
7	$q_6-\pi/2$	0	0	$-\pi/2$
8	q_7	0	0.05m	0

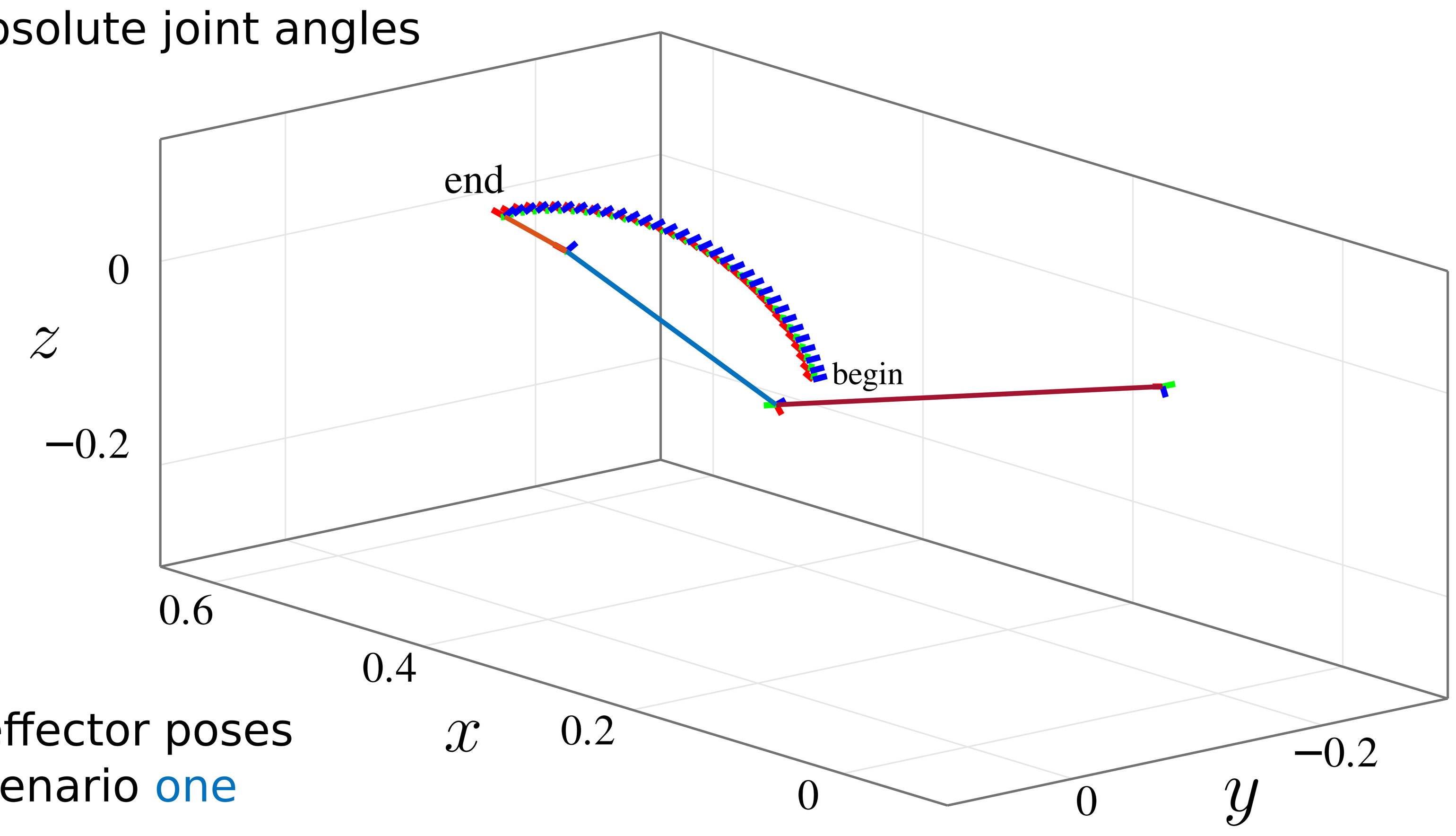
Inverse Kinematics

In order to obtain the joint angles of the model corresponding to a prespecified steering maneuver an optimization was set up. An analytical solution to the inverse kinematics was not used, since the relative weighting of position and orientation allows for a realistic approximation of human behavior.

$$\begin{aligned} q = \arg\min_{q} \sum_{k=1}^{N} & (f(q_k)-p_{k,ref})^{\mathrm{T}}(f(q_k)-p_{k,ref}) + \\ & (o_{v,k}-o_{v,k,ref})^{\mathrm{T}} W_o (o_{v,k}-o_{v,k,ref}) + \\ & (q_{k+1}-q_k)^{\mathrm{T}} W_{\Delta q}(q_{k+1}-q_k) + \\ & q_k^{\mathrm{T}} W_q q_k \end{aligned}$$

The terms of this formula (in order of appearance) corresponding to the

- Position error
- Orientation error
- Change of joint angles between two adjacent configurations
- Absolute joint angles



End-effector poses for scenario one

Manipulability

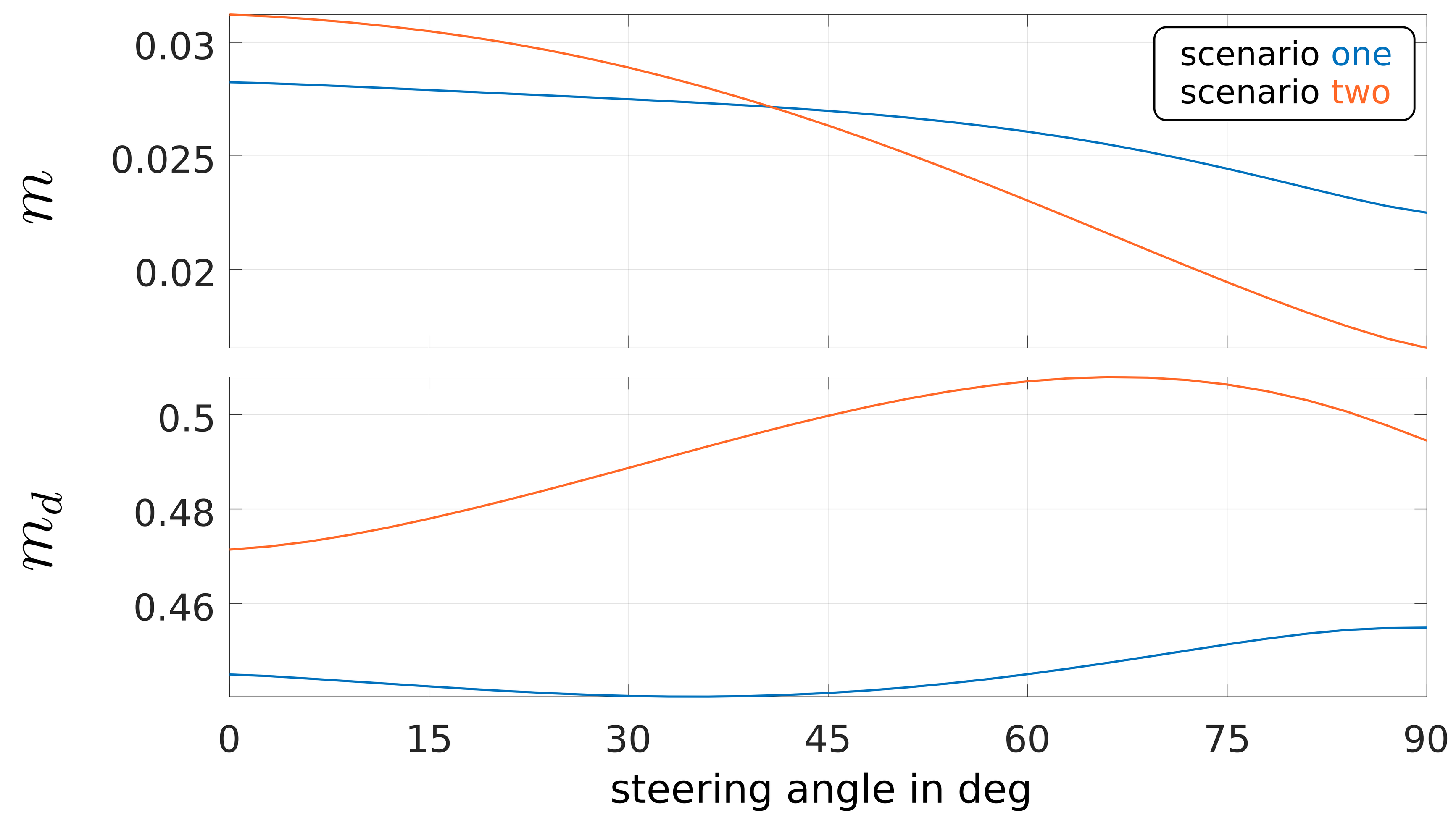
For steering the translation of the end-effector determines the rotation of the steering wheel. Thus only the position part is used in the Jacobian matrix, i.e. $J \in \mathbb{R}^{3\times 7}$, on which the manipulability

$$m = \sqrt{\det(J(q)J^{\mathrm{T}}(q))}$$

is based. Turning the steering wheel is achieved by moving the hand tangent to the steering wheel. This movement can be described by joint movements mapped through the Jacobian matrix. Thus, the directional manipulability is proposed.

$$m_d = \max_{\dot{q}^{\mathrm{T}}\dot{q}\leq 1} t^{\mathrm{T}} J \dot{q}$$

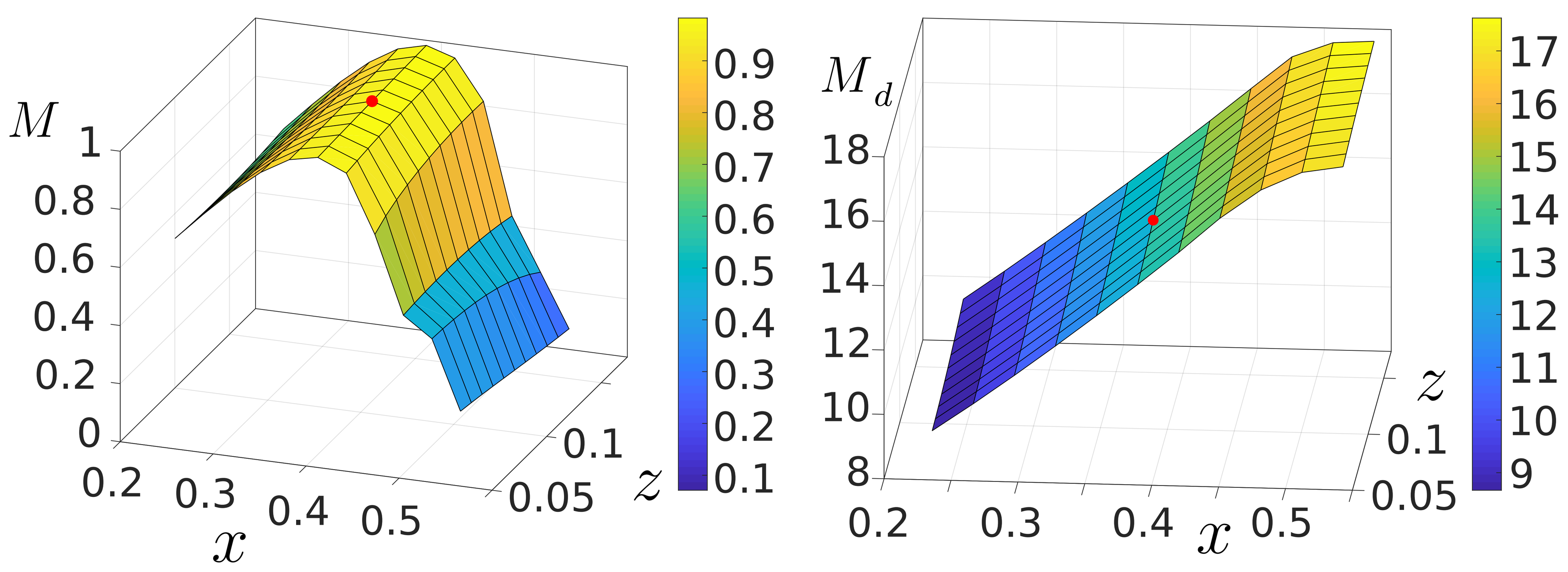
$$m_d = ||t^{\mathrm{T}} J(q)||_2 = \sqrt{(t^{\mathrm{T}} J(q))(t^{\mathrm{T}} J(q))^{\mathrm{T}}}$$



Optimal seat position

In order to calculate the optimal position of the driver seat the optimization problem is solved for different shoulder joint positions. The integrated manipulability is used as cost function to determine the optimal shoulder position.

$$M = \int_0^{90^\circ} m(\varphi)\mathrm{d}\varphi \qquad M_d = \int_0^{90^\circ} m_d(\varphi)\mathrm{d}\varphi$$



Note: The red dots in the figures above show the manipulability M and the directional manipulability M_d for the nominal shoulder position.

Results

- Directional manipulability suggest the shoulder to be far away from the steering wheel (Note that this conflicts with force-manipulability)
- Manipulability gives a distinct optimal distance to the steering wheel (different measures are possible)
- Seat height has little influence on the manipulability

TU Wien, Automation and Control Institute, Group for Complex Dynamical Systems
Supervisor: Georg Nawratil
Institute of Discrete Mathematics and Geometry
Differential Geometry and Geometric Structures

Contact: {schwegel,maderthaner}@acin.tuwien.ac.at