Robust Control of a Radio Controlled Car Driving on Two Wheels

Daniel Robert Meier
danielme@student.ethz.ch
D-MAVT, ETH Zurich

***Abstract*— This project presents a robust control approach in order to stabilize a radio controlled car on two wheels. Figure 11 shows this driving mode with a real car. A car on two wheels is an unstable system comparable to an inverted pendulum and therefore needs to be actively controlled. Due to many sources of uncertainty a robust controller is desirable.**

Fig. 1. Two-wheeled driving in a real car

I. Declaration of originality

Declaration of originality.

II. Introduction

The R/C car which will be modelled is a HPI Sprint, as depicted in Figure 2. Its length is about 430mm with a weight of about 1.2kg. The resulting nonlinear system is unstable. There is one equilibrium point which is dependant on the weight distribution of the car (center of gravity).

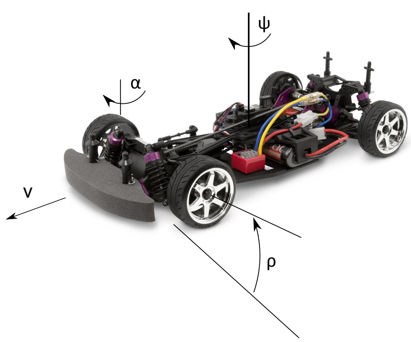

Fig. 2. HPI Sprint

The controller has in- & outputs as depicted in figure II. As shown in [1], a similar system can be controlled in a SISO matter. However, since there are cross-couplings, a MIMO approach would promise better performance.

	Input	Output
SISO	Turning rate $\dot{\psi}$	Steering angle α

TABLE I

In- and outputs of the control systems

III. Prior Work

Arndt [1] presented an approach to control a car on two wheels however not with an optimal controller. Moreover, their car has significantly bigger tires, more inertia and a higher center of gravity which facilitates control. Liu [2] developed a PID approach to control a car driving on two wheels.

IV. Dynamic System Model

The system model is set up as depicted in Figure 3. It consists of the steering mechanism, the roll angle dependant mapping of the steering angle and the vehicle body dynamics.

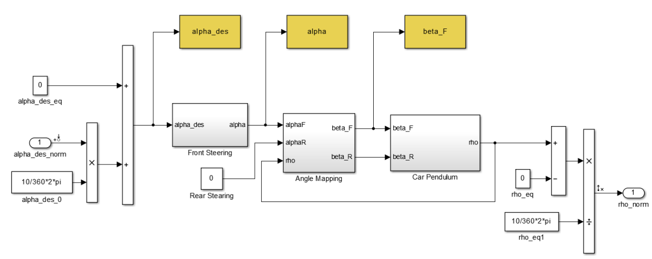

Fig. 3. Normalized plant

As normalization factors, a steering angle $\alpha_0 = 10$ and a roll angle $\rho_0 = 10$ is chosen.

A. Modelling Assumptions

- Constant velocity. Dynamics of motor are slower.
- Coriolis force is neglected, since it small for small steering angles.
- Tires have infinite grip and follow exactly the steering direction.

B. Steering

The FRONT STEERING is modelled as a second order system as described by equation 1. $\alpha_{desired}$ is the systems control input, ω and ζ are chosen to match the dynamics as realistic as possible.

$$\frac{d^2}{dt^2}\alpha = -2\zeta\omega\dot{\alpha} - \omega^2\left(\alpha - \alpha_{desired}\right) \tag{1}$$

To get the effective steering angle β, a nonlinear mapping is required. It is depicted by Figure 4 and implemented in the block ANGLE MAPPING. It can be seen, that steering inputs lead to high effective angles when operating at a high roll angle.

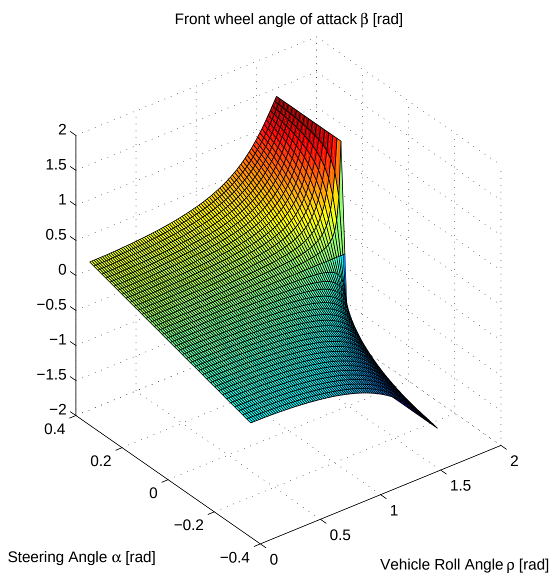

Fig. 4. Angle mapping: Steering angle α vs. effective steering angle β

C. Body dynamics

The vehicle is modelled as depicted in Figure 5. The operating point is chosen as $\dot{\Psi} = \dot{\rho} = \dot{\alpha} = 0$

V. UNCERTAINTY MODELLING

Perturbations are chosen as:

$$W_{rho} = 0.1 \tag{2}$$

$$W_{alpha} = 0.05 \tag{3}$$

Performance weights are:

$$W_{rho,performace} = \frac{10}{10 \cdot s + 1} \tag{4}$$

$$W_{alpha,performance} = \frac{0.04 \cdot (1 + 0.4 \cdot s)}{100 + 0.1 \cdot s} \tag{5}$$

$$W_{rho,noise} = 0.025 \tag{6}$$

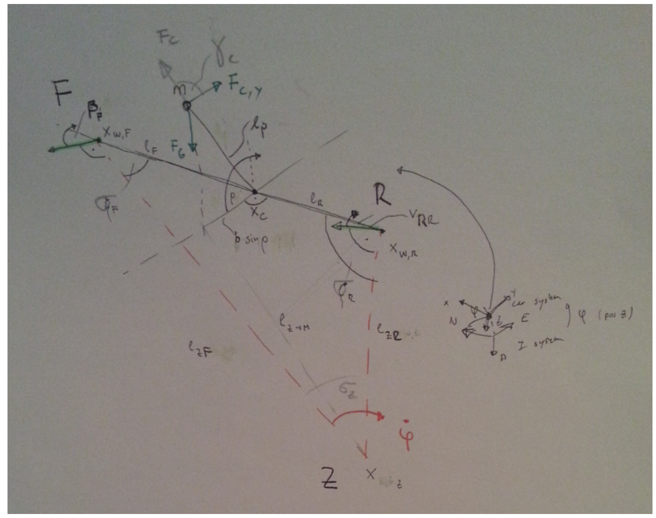

Fig. 5. HPI Sprint

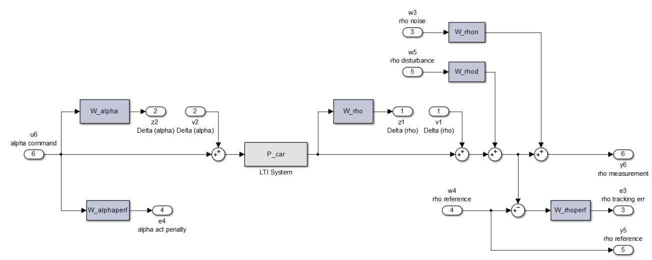

Fig. 6. Two-wheeled driving in a real car

$$W_{rho,disturbance} = \frac{2.5}{5 \cdot s + 1} \tag{7}$$

Potential sources for uncertainty comprise:

- Geometry: Inertia tensor and mass. The weight distribution for instance determines the equilibrium point $\bar{\beta}$
- Steering: The effect of the steering angle is dependent on the vehicles tilt angle β and nonlinear. Uncertainties can cause significant error
- Contact model for wheel - ground interaction
- Engine behaviour
- External disturbances such as wind

VI. STATES

	Input	Output
x	Turning rate $\dot{\psi}$	Steering angle α
MIMO	Turning rate $\dot{\psi}$ Speed v	Steering angle α Acceleration

TABLE II

IN- AND OUTPUTS OF THE CONTROL SYSTEMS

- x
- ψ
- α
- ρ

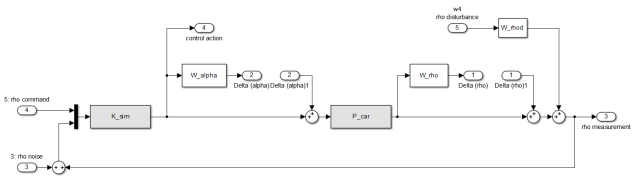

Fig. 7. Two-wheeled driving in a real car

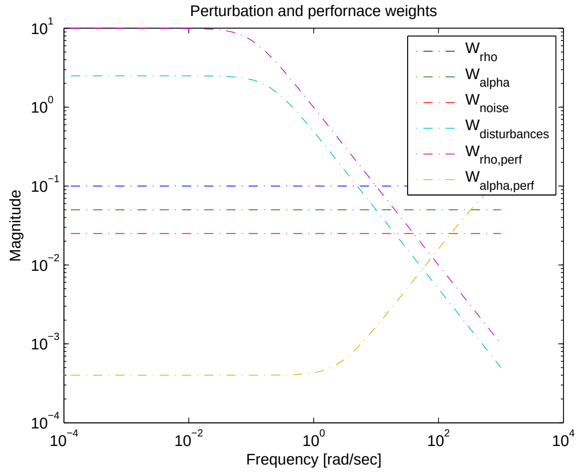

Fig. 8. Two-wheeled driving in a real car

VII. Robust H_{inf} Controller Design

VIII. D-K iteration

References

[1] Arndt D. et al.: *Two-Wheel Self-Balancing of a Four-Wheeled Vehicle*. Article in IEEE Control Systems, 2011

[2] Liu K. et al.: *Two-wheel self-balanced car based on Kalman filtering and PID algorithm*. Conference Paper, IEEE IE&EM 2011

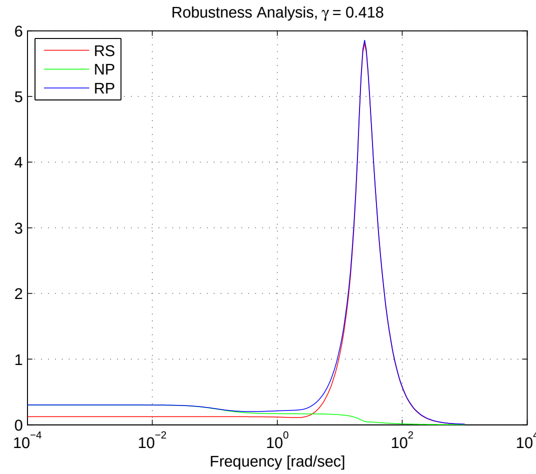

Fig. 9. Two-wheeled driving in a real car

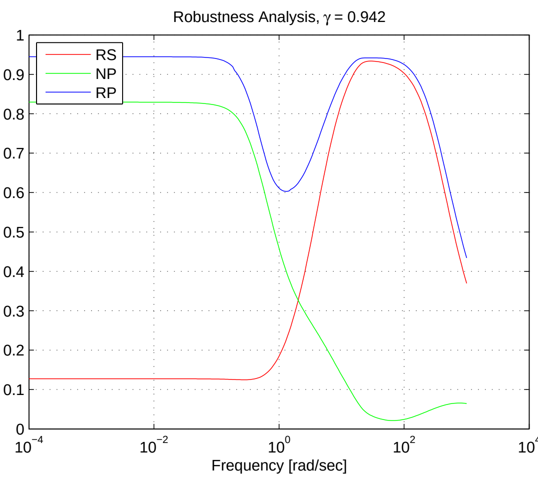

Fig. 10. Two-wheeled driving in a real car

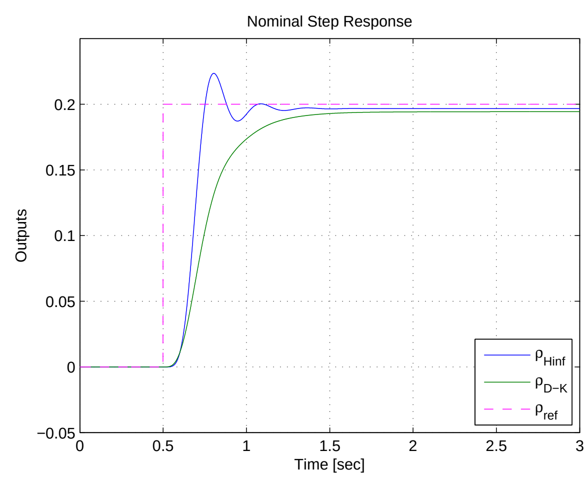

Fig. 11. Two-wheeled driving in a real car