Institute for Design and Control of Mechatronical Systems

Diploma Thesis:

Stability Control by Advanced Full-Braking Systems of 2-wheel Motorbike Vehicles

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Abstract

Motorcycle riding, to cope with the continuously increasing traffic in urban area or simply to enjoy the freedom on two wheels, is becoming more and more popular in Europe. Stability control of these vehicles during braking is extremely critical, and so the lack of such control represents a major obstacle for the diffusion of single-track vehicles, as well as a substantial safety problem. To overcome this lack of safety, alternative concepts for a curve-safe brake control of 2-wheel vehicles are investigated.

The main object of this diploma thesis is to build up a controller which guarantees safety during braking, based on an estimator for the roll angle of single-track vehicles (motorbikes and scooters). Different strategies for this estimator are treated and tested in reality. The dimensioning of the brake controller, which is based on ABS-control-strategies of four wheel vehicles, is done on a software simulator. The proper behaviour of this simulator is of essential importance for the controller development and design. To ensure the right behaviour of this simulator validations are done.

Introduction:

ABS controllers for single-track vehicles are based on the ABS strategies used in 4-wheel vehicles. Although the use of ABS for motorcycles is clear, stability and therefore a prevention of an accident can only be achieved on straight road by implementing such controllers.

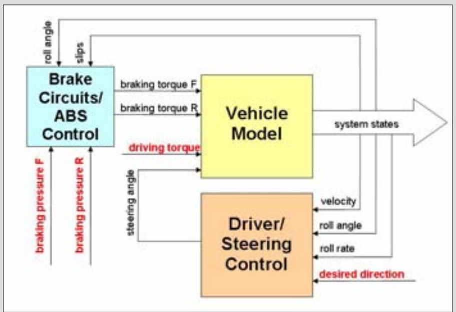
Contrary to car tires, lateral forces at motorcycles are not only generated by lateral slip, but also by the roll angle. Large lateral slip at motorcycles normally causes stability problems and so is very dangerous, especially at the front wheel. These essential aspects for motorcycle brake control strategies are implicated in the control design of this work and therefore, stability of braking also during curves can be guaranteed.

Simulator:

- First principles model
- Built up in SIMULINK
- Includes all important effects during braking:
  longitudinal slip
  lateral slip
  suspension

3 main parts:

- Vehicle model
- Steering controller
- Brake circuits



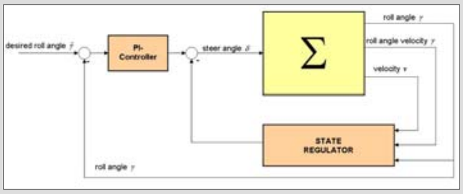
Vehicle Model

Contains:

- Longitudinal, lateral and vertical body dynamics
- Rotatory dynamics (pitch, roll and yaw)
- Wheel dynamics
- Longitudinal slip definition $\kappa = \frac{v_x - \omega \cdot r}{\max(v_x, \omega \cdot r)}$
- Side slip angle definition
- Tire force computation $\alpha = \arctan\left(\frac{v_y}{v_x}\right)$
- Trajectory computation

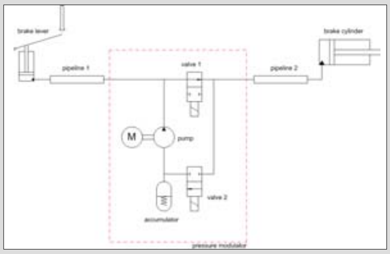
Driver / Steering Control

Roll dynamcis:
- Statically unstable
- Nonlinear
- Nonminimum phase steering behavior



Brake

Hydraulic model developed by the Institute of Machine Design and Hydraulic Drives



Roll Angle Estimation:

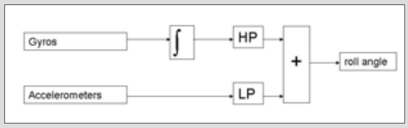
The roll angle estimator is based on the signals of the Inertial Measurement Unit (IMU), a sensor combination for angular rates (gyros) and accelerations (accelerometers), which was mounted on the test-vehicle (KTM Adventure 950).

Roll angle definition due to the integrated gyro signal:

- Works accurate at dynamic areas → HIGH PASS
- Problem: Integrator offset
  Gyros are very sensitive to temperature

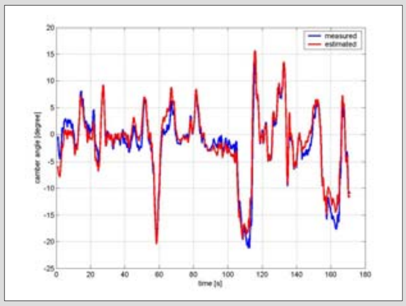
Roll angle definition due to accelerometer signals: → LOW PASS

- Works exact at stationary conditions
- Problem: noise due to road



Results:

maximal error: $e_{\max} \approx 5°$ standard deviation: $\sigma \approx 2°$



Curve-Safe Brake Control:

The Lateral friction coefficient is based on a part due to camber as well as a part due to lateral friction:

$$\mu_y(\alpha,\gamma) = D_y \sin(C_y \arctan\left(B_y\alpha - E_y\left(B_y\alpha - \arctan B_y\alpha\right)\right) + C_\gamma \arctan\left(B_\gamma\gamma - E_\gamma\left(B_\gamma\gamma - \arctan B_\gamma\gamma\right)\right))$$

Braking produces a increase of he longitudinal slip, which causes that the lateral slip part due a defined roll angle as well as the one due to a defined side slip angle decreases. As the required lateral friction coefficient will not change immediately as well as the roll angle, side slip has to arise for stability. If the side slip increases to much the friction part due to this saturates and loose of lateral stability causes the accident.

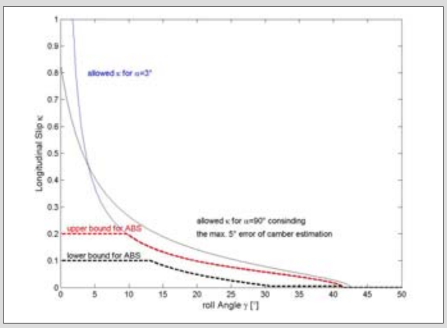
Due to the equations of motions the required value for the lateral friction coefficient, depending on the roll angle, can be calculated. Therefore, the maximal allowed longitudinal slip for curves is defined.

Two different controller strategies, a two point controller (one condition for building up the brake pressure and one for decreasing it) as well as a three point controller (third condition: hold pressure), were designed for the rear and the front wheel.

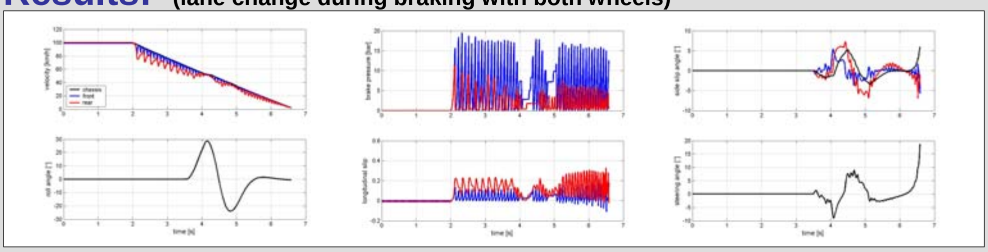
For not overturning around the front wheel the deflection of the rear suspension was an additional input to the front brake controller.

The maximum error of the estimated roll angle was considered in designing the control levels.

The adaptation of the hydraulic model's parameter was necessary to ensure fast pressure decrease.



Results: (lane change during braking with both wheels)



Conclusion / Prospect:

This work presents a well working motorcycle simulator which can be used for other simulations too. Validations show that the simulator is close to reality. The estimator for the roll angle is working well and has been tested in reality. Therefore this work presents a good starting point for the real implementation of a curve safe brake controller.

Future Prospect:

For realization a lot of effects have to be analyzed. For example the coupling of the front and the rear suspension was not included in this work. The effects on the steer dynamic and the behaviour of the driver has to be analyzed.

In the simulations it was assumed that street properties are constant. A friction curve estimator will be necessary for changes of the road condition. A big challenge possible will be the estimation of the certain vehicles speed for the longitudinal slip calculation.

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