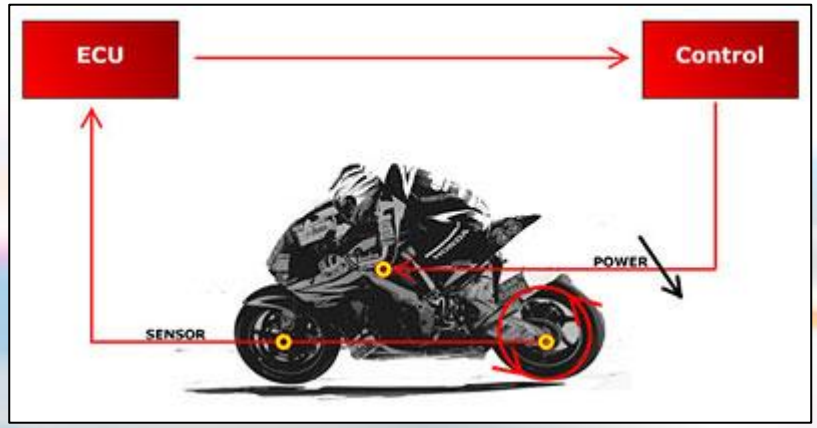
ASME 2013 INTERNATIONAL MECHANICAL ENGINEERING CONGRESS & EXPOSITION
IMECE13

ADVANCED TRACTION CONTROL SYSTEM FOR MOTORBIKES

J. J. CASTILLO AND J. A. CABRERA

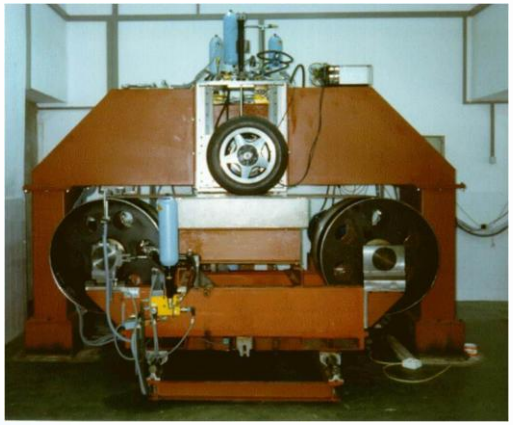
DEPARTMENT OF MECHANICAL ENGINEERING. UNIVERSITY OF MÁLAGA.

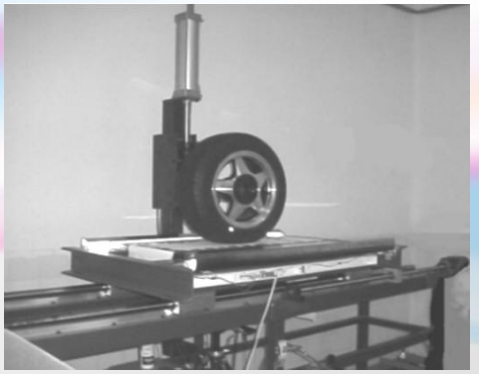


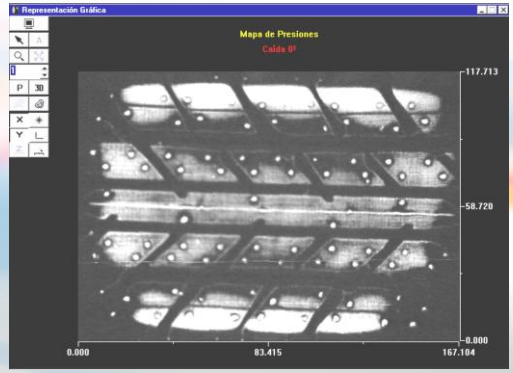
CONTENT

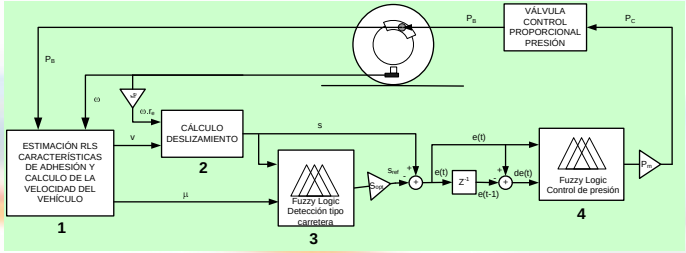
CONTENT

Background









http://immf.uma.es

Motivation

- The Mechanical Engineering group of the University of Málaga took part in 2010 and 2012 in the international competition Motostudent, a challenge among teams from different universities.

- Objectives of the competition: designing and developing a 2-S 125 c.c. (2010) or 4-S 250 c-c (2012) competition motorbike.

Objectives of Motorbike Traction Control Systems

Main:

- Prevent rear wheel from slipping
- Prevents uplift of the front wheel
- Improve safety while leaning over (no oversteering)
- Competition: enhance acceleration and cornering capabilities

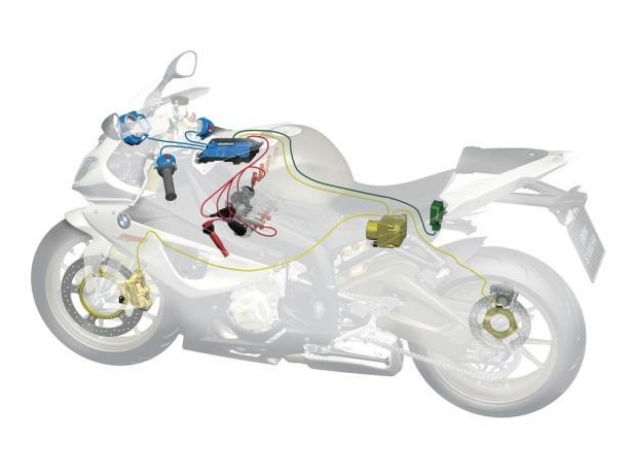
Objectives of Motorbike Traction Control Systems

Main:

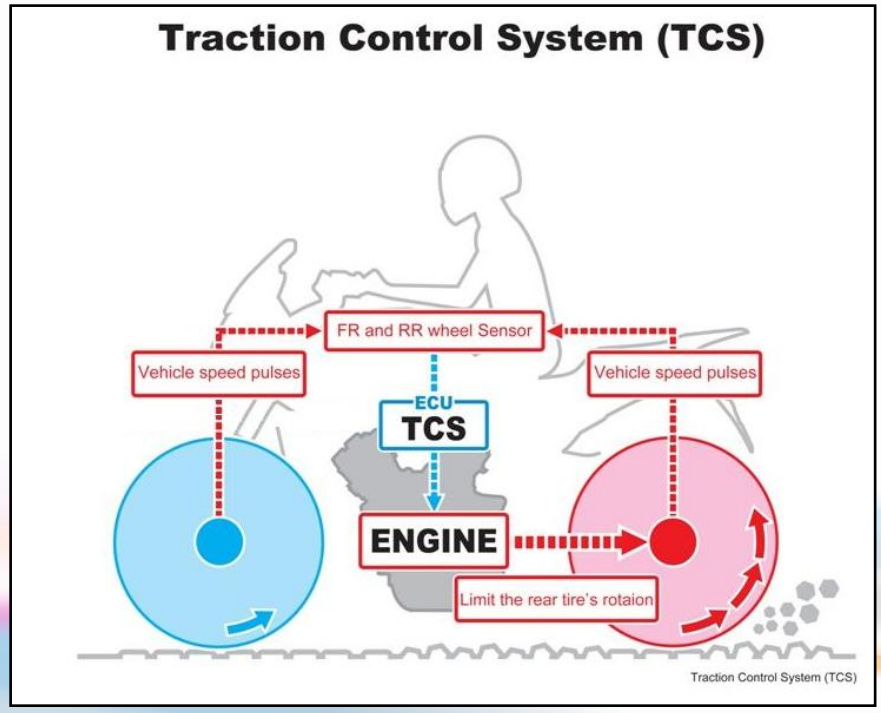
- Prevent rear wheel from slipping
- Prevents uplift of the front wheel
- Improve safety while leaning over (no oversteering)
- Competition: enhance acceleration and cornering capabilities

Desirable:

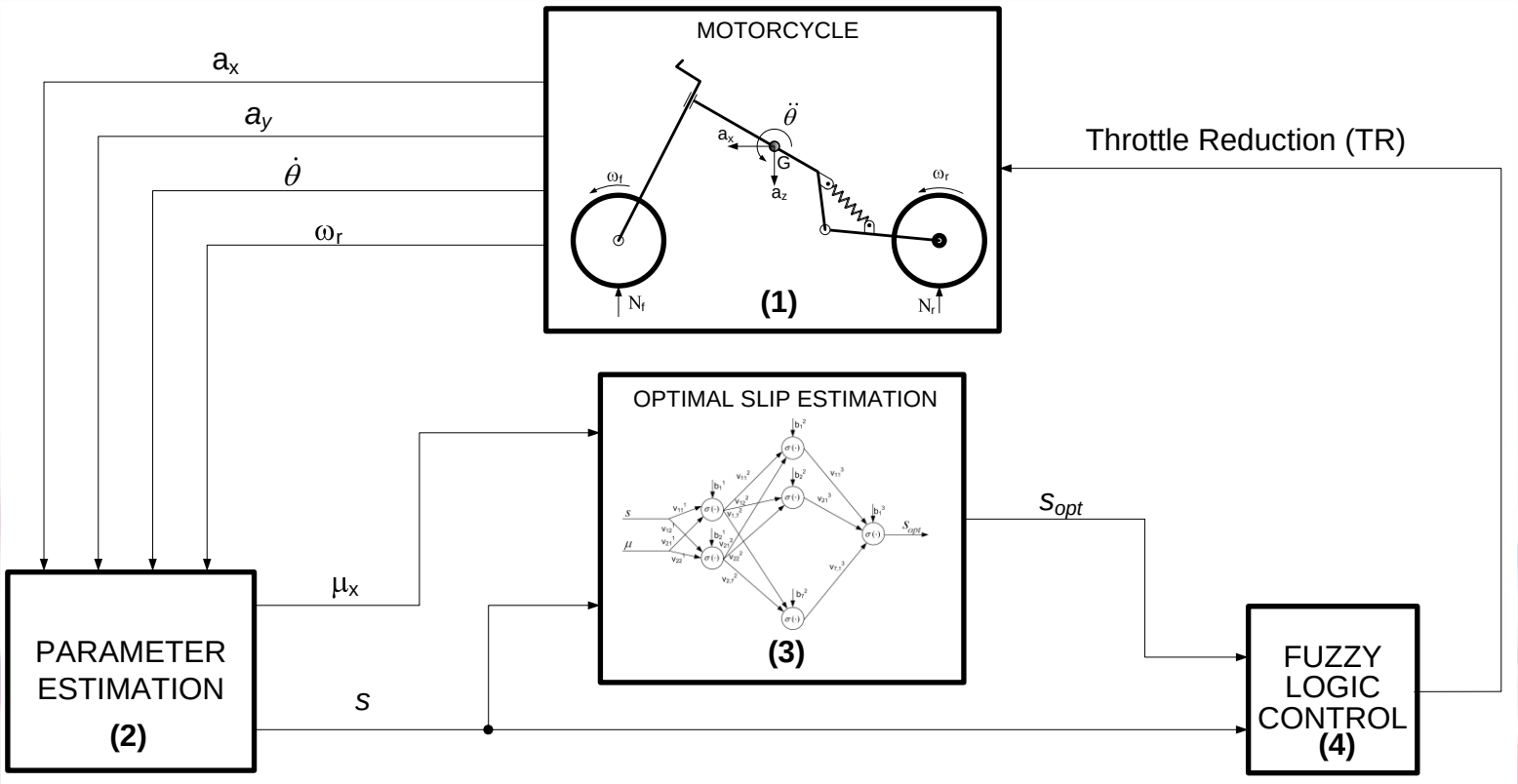
- Low price, low weight
- Good control whichever surface
- Easy to adjust and modify
- Combinable with ABS
- Do not need additional sensors



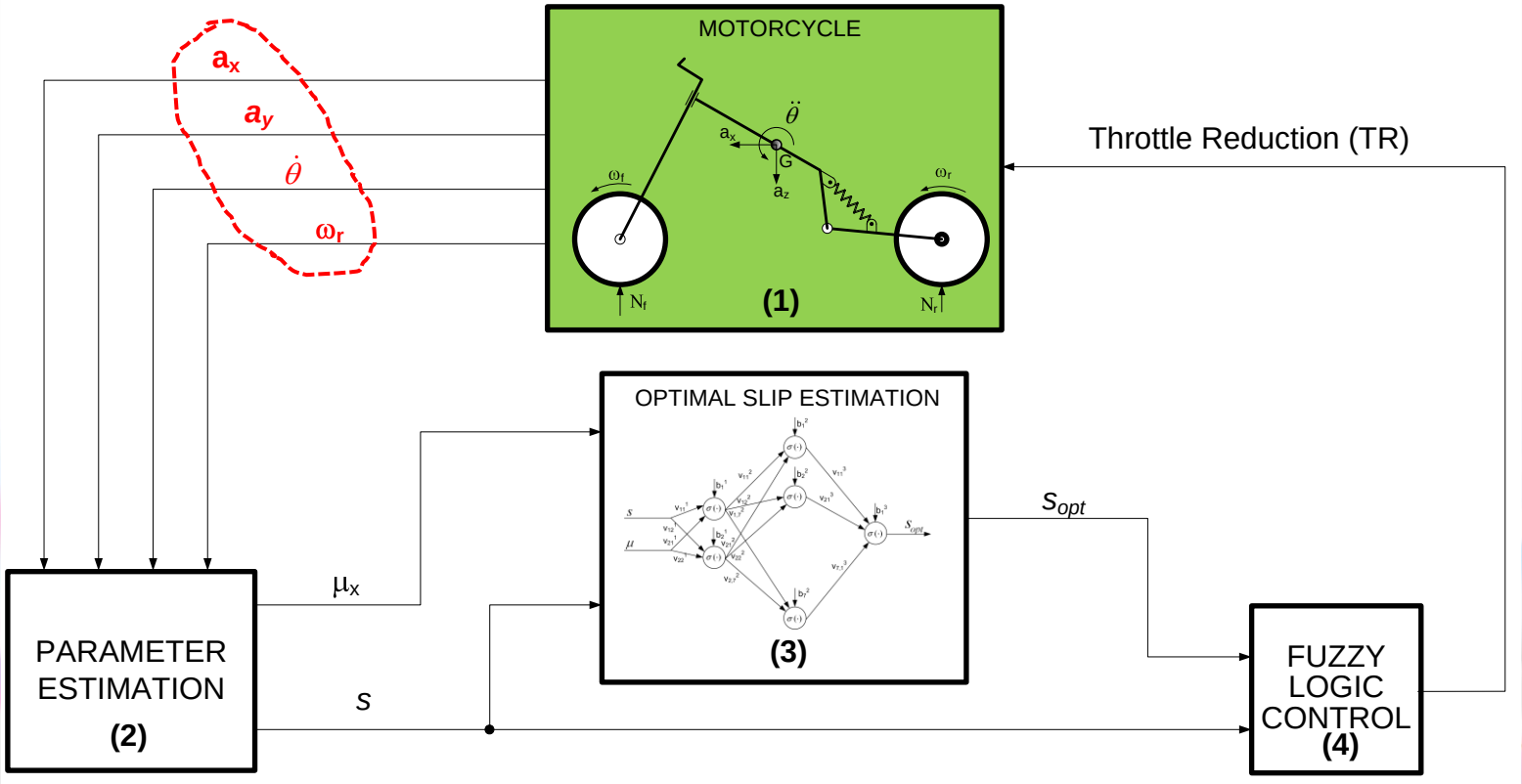
Basic T.C.S.


Traction Control System (TCS)
FR and RR wheel Sensor
Vehicle speed pulses
Vehicle speed pulses
ECU
TCS
ENGINE
Limit the rear tire's rotaion
Traction Control System (TCS)

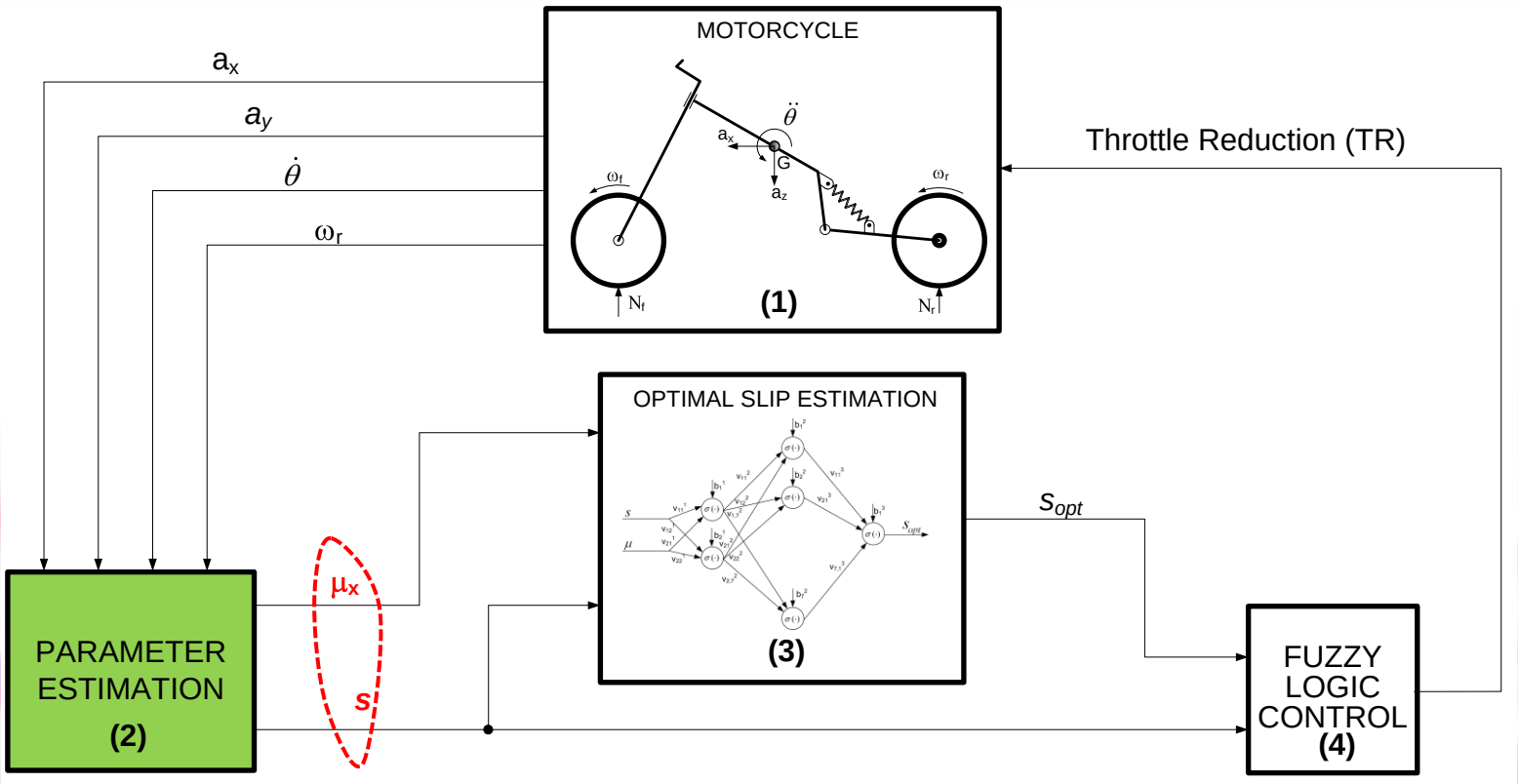
Control Loop



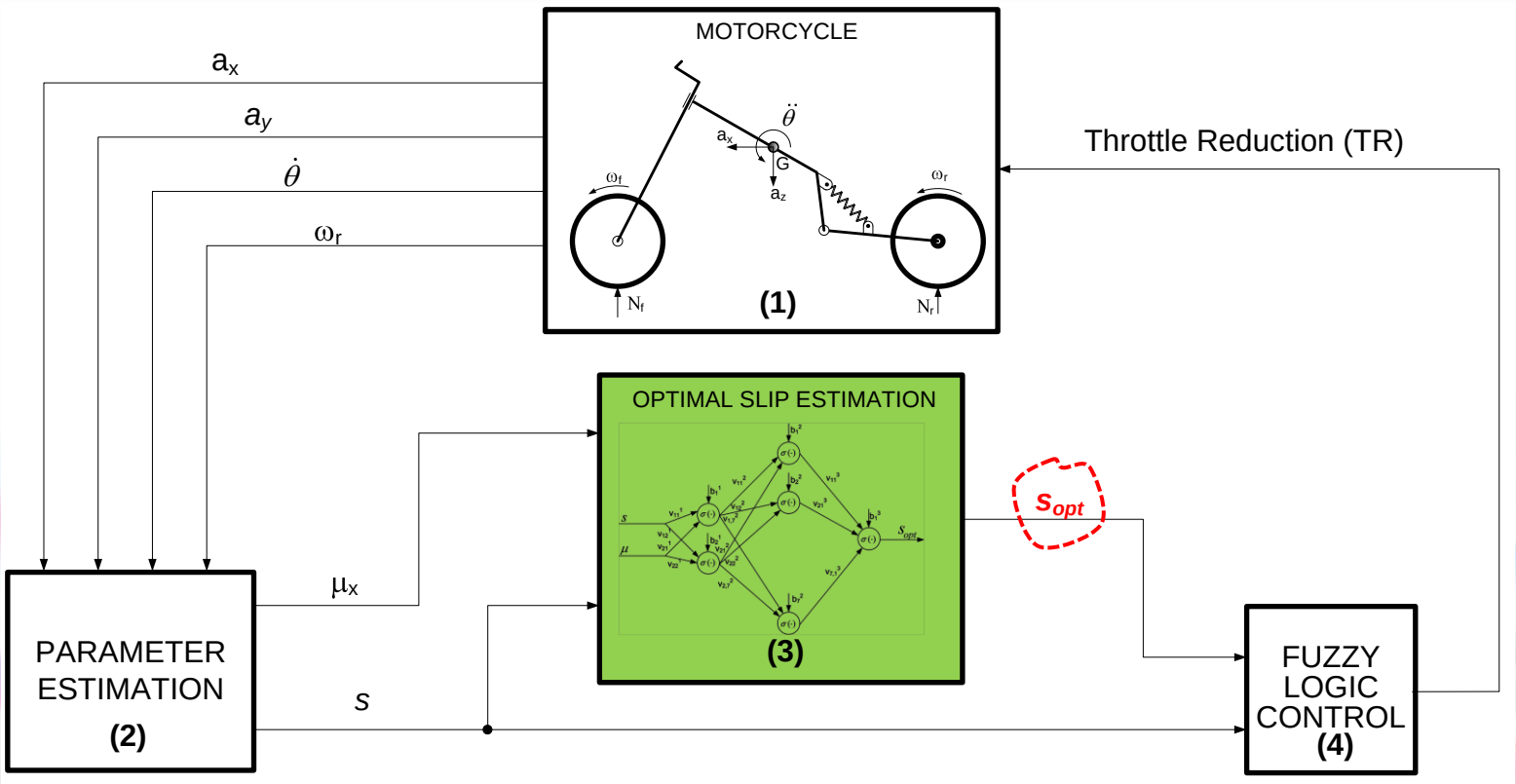
Control Loop



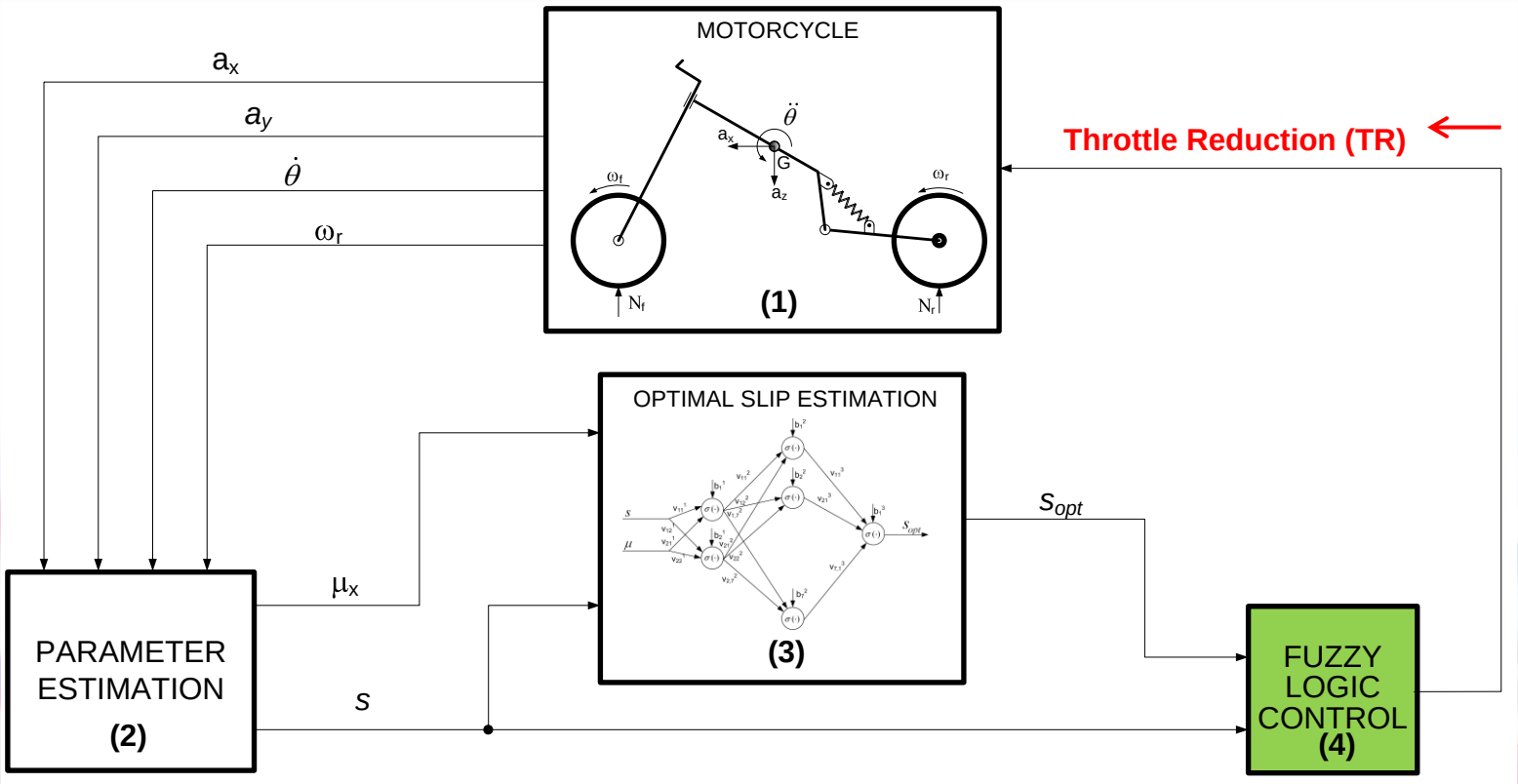
Control Loop



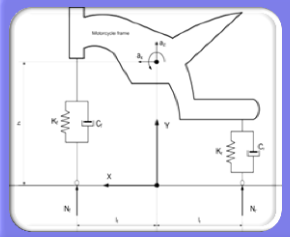
Control Loop

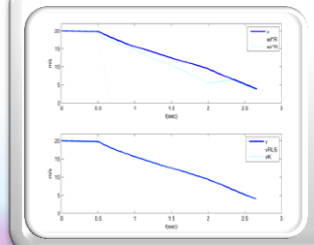


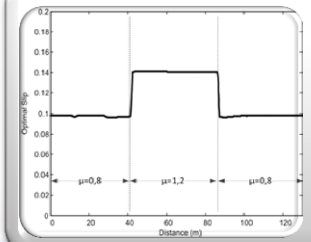
Control Loop

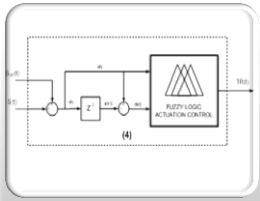


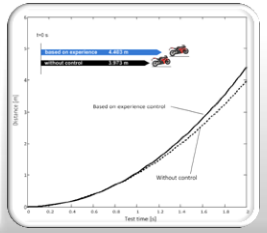
CONTENT





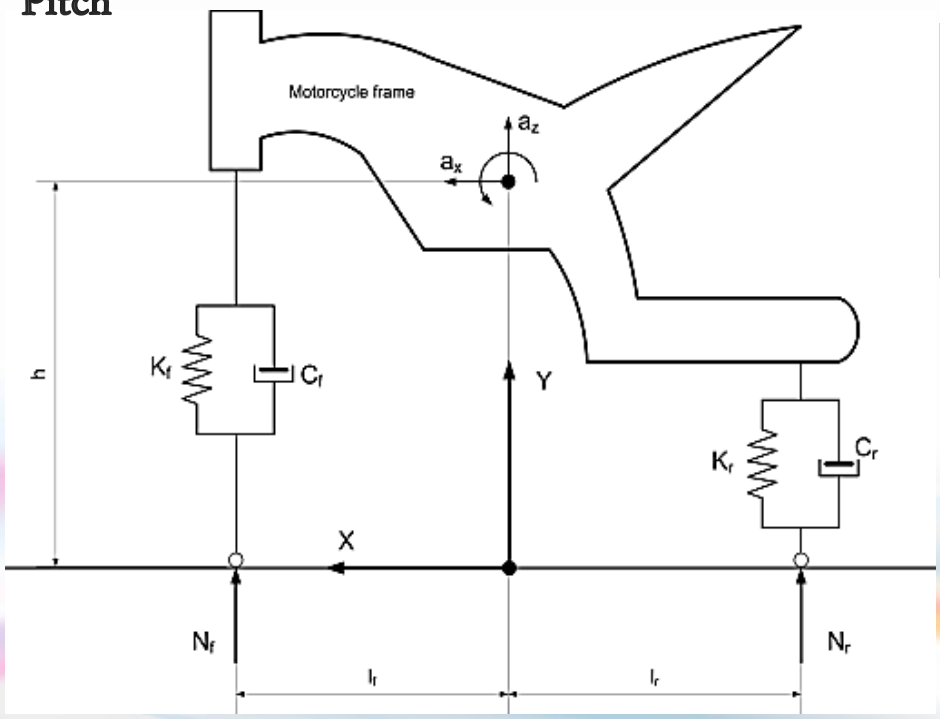






Motorbike Model

- Longitudinal
- vertical
- Pitch



Motorbike Model Equations

$$Ma_x = M\left(\ddot{x} + \dot{\theta} v_z\right) = F_{x,r} - Cv_x^2 - F_{x,f}$$

$$Ma_z = M\left(\ddot{z} - \dot{\theta} v_x + g\right) = N_f + N_r$$

$$I_y \ddot{\theta} = N_r l_r - N_f l_f - \left(F_{x,r} - F_{x,f}\right) z$$

Longitudinal Force

$$F_{x,r} = \mu_x N_r$$

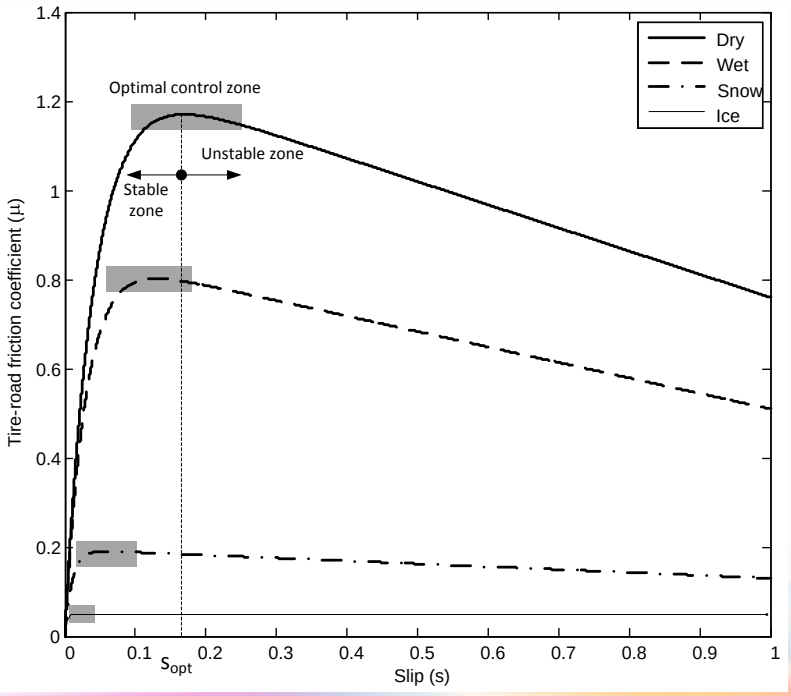
Rolling Resistance Force

$$F_{x,f} = \left(C_1 + C_2 v_x^{\,2}\right) N_f$$

CONTENT

Adhesion coefficient vs slip

$$\mu_r = \frac{F_{x,r}}{N_r}$$



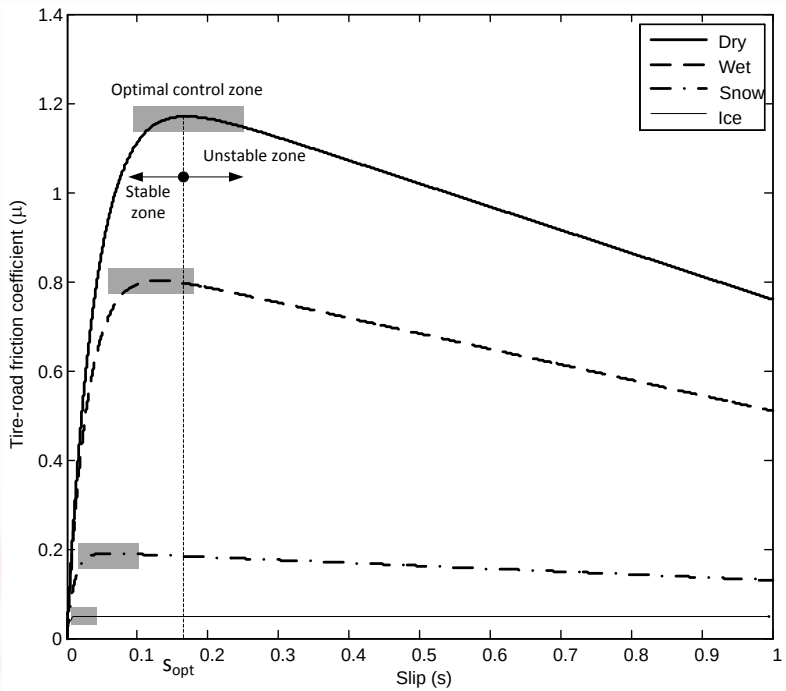
$$s = 1 - \frac{v_x}{\omega R_r}$$

WHAT DO WE NEED TO KNOW

- Slip between the tire and the road
- Road type or road conditions

Adhesion coefficient vs slip

$$\mu_r = \frac{F_{x,r}}{N_r}$$



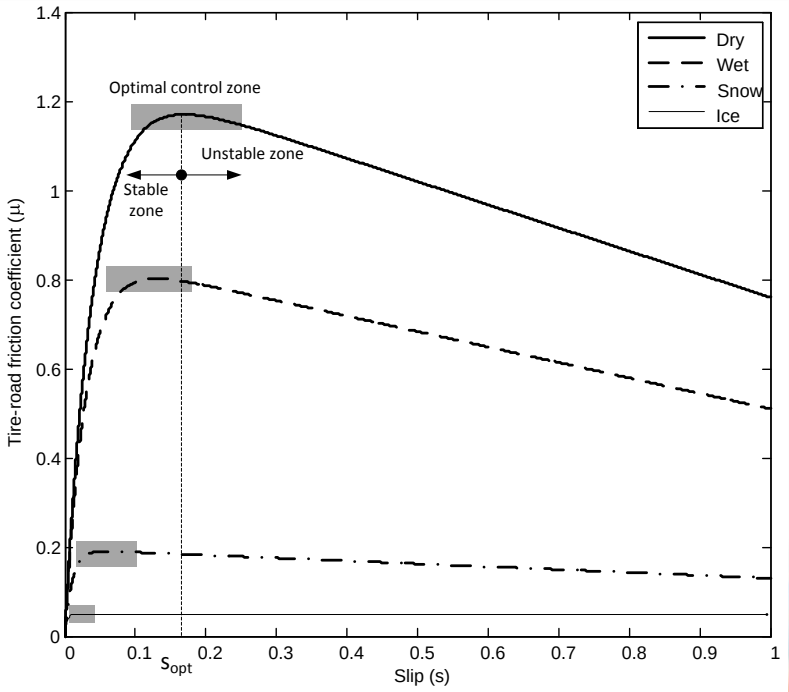
$$s = 1 - \frac{v_x}{\omega R_r}$$

NEED TO ESTIMATE

- Vertical and Horizontal forces
- Adhesion coefficient
- Speed
- Slip angle
- Slip

Adhesion coefficient vs slip

$$\mu_r = \frac{F_{x,r}}{N_r}$$



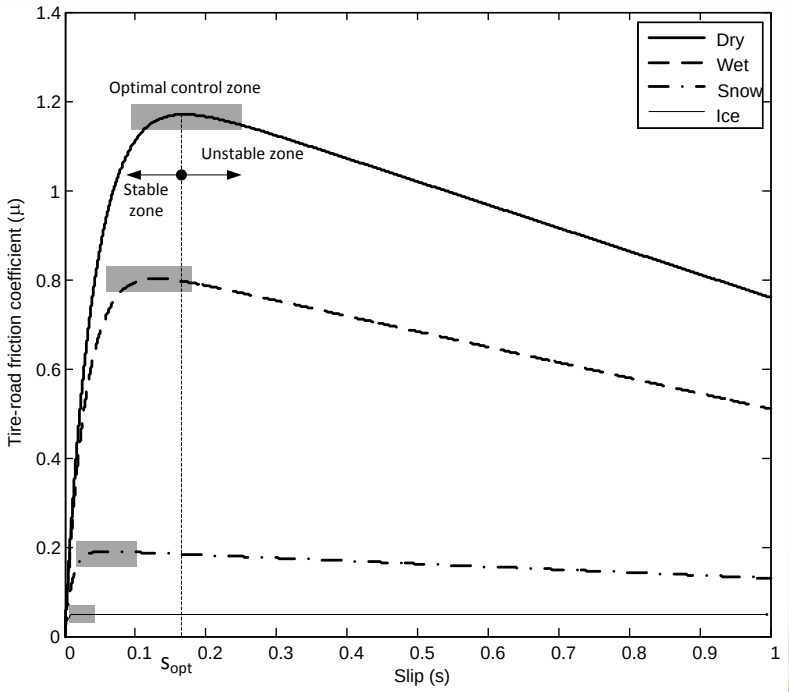
$$s = 1 - \frac{v_x}{\omega R_r}$$

NEED TO ESTIMATE

- Vertical and Horizontal forces
- Adhesion coefficient
- Speed
- Slip angle
- Slip

Adhesion coefficient vs slip

$$\mu_r = \frac{F_{x,r}}{N_r}$$



$$s = 1 - \frac{v_x}{\omega R_r}$$

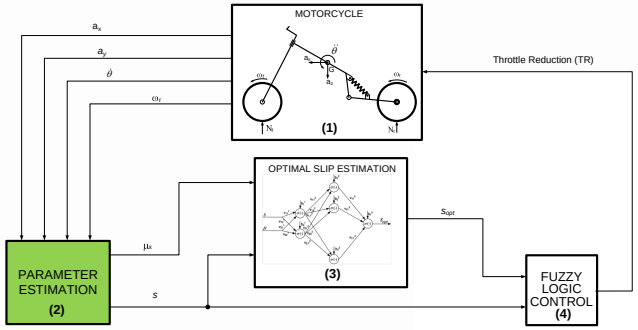
NEED TO ESTIMATE

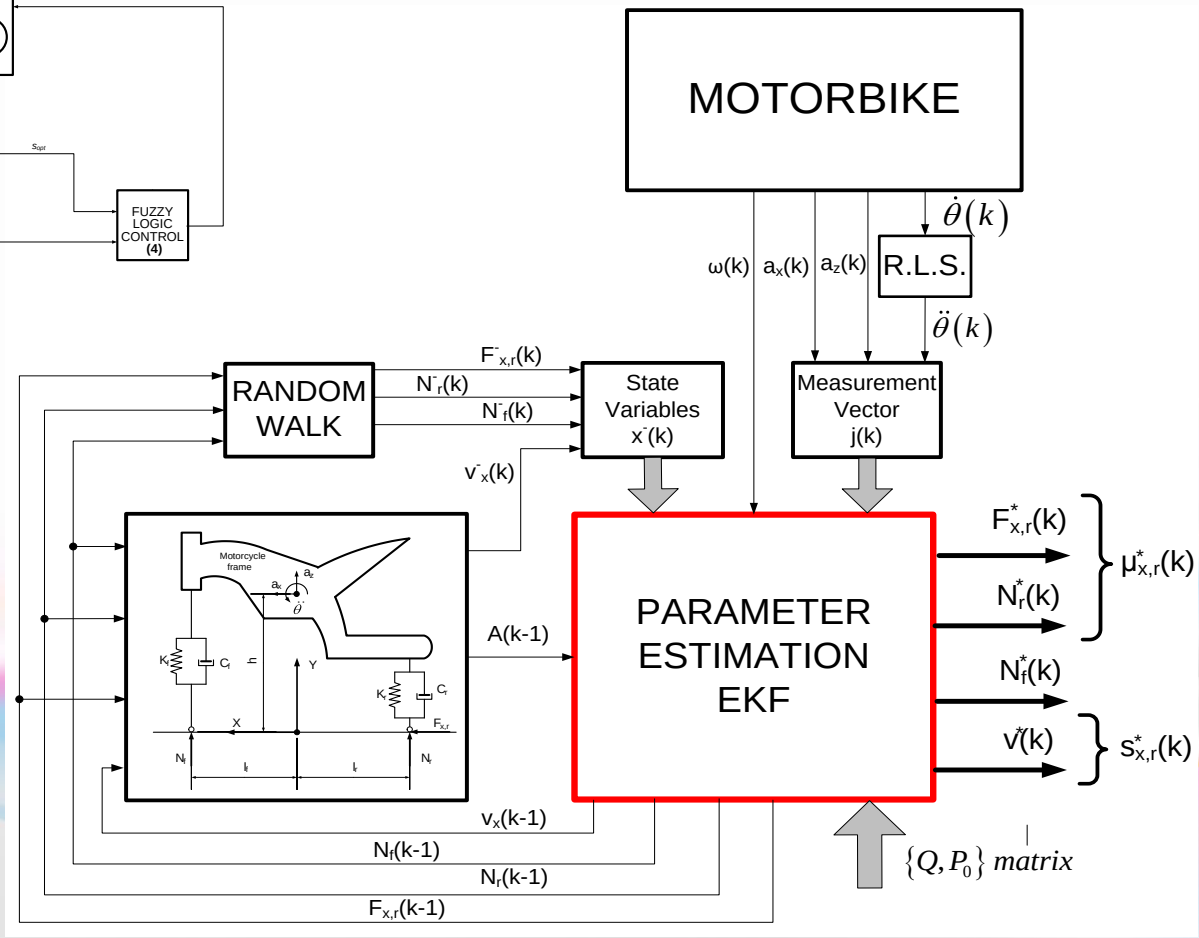
- Vertical and Horizontal forces
- Adhesion coefficient
- Speed
- Slip angle
- Slip

MOST USED ALGORITHMS

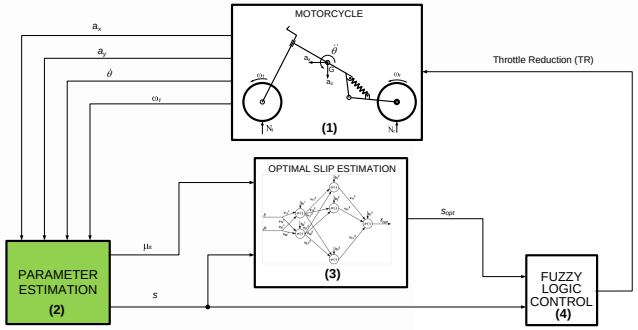
- Recursive Least Squares (RLS)
- Sliding Mode Observers
- Kalman Filter (KF, EKF y UKF)

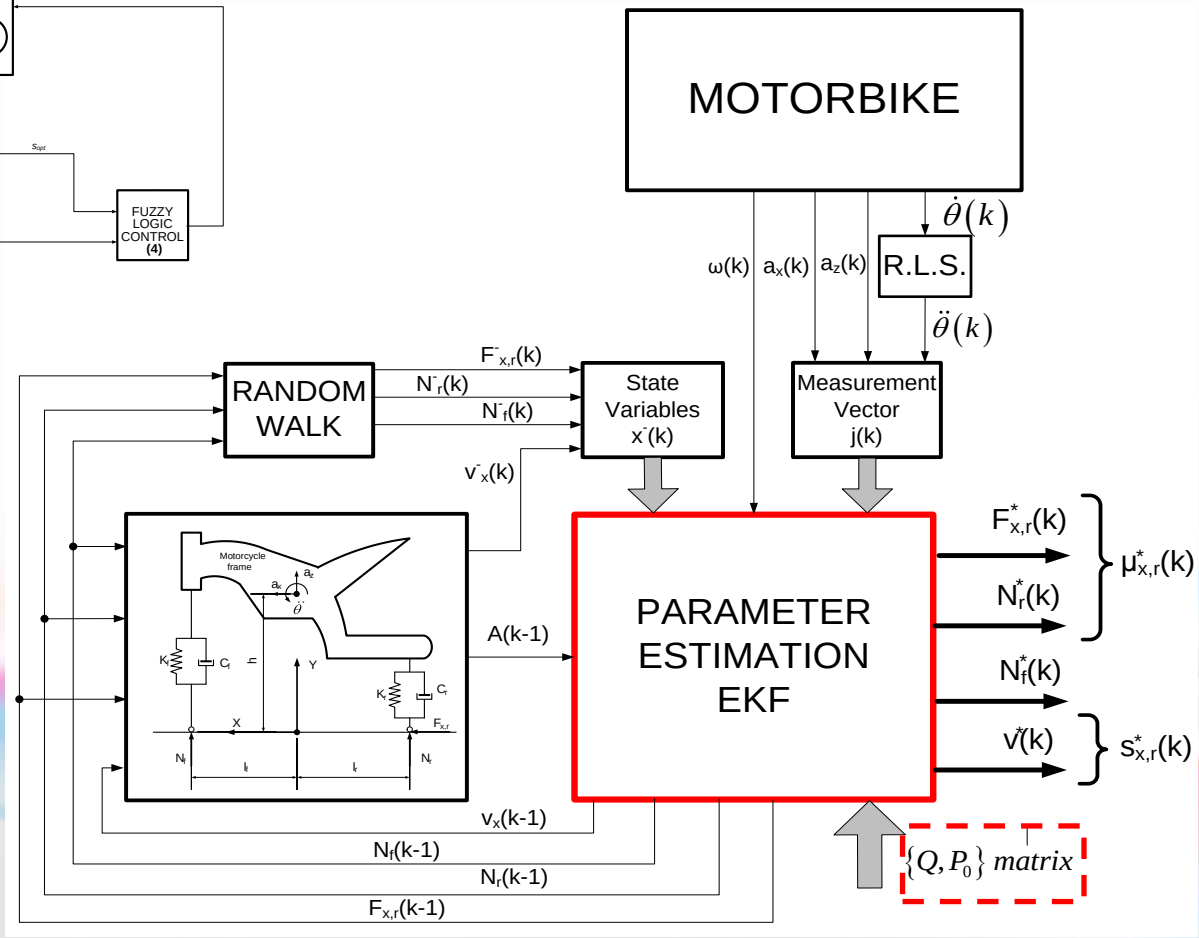
Parameter Estimation





Parameter Estimation





Parameter Estimation (EKF)

Discrete time Model

$$x_k = f_{k-1}(x_{k-1}) + w_{k-1}$$

$$j_k = h_k(x_k) + v_k$$

Prediction

$$x_k^- = f_{k-1}(x_{k-1})$$

$$P_k^- = A_{k-1}P_{k-1}A_{k-1} + Q$$

Correction

$$K_k = P_k^- H_k^T \left(H_k P_k^- H_k^T + R\right)^{-1}$$

$$x_k = x_k^- + K_k(j_k - h_k(x_k^-))$$

$$P_k = \left(I - K_k H_k\right)P_k^-$$

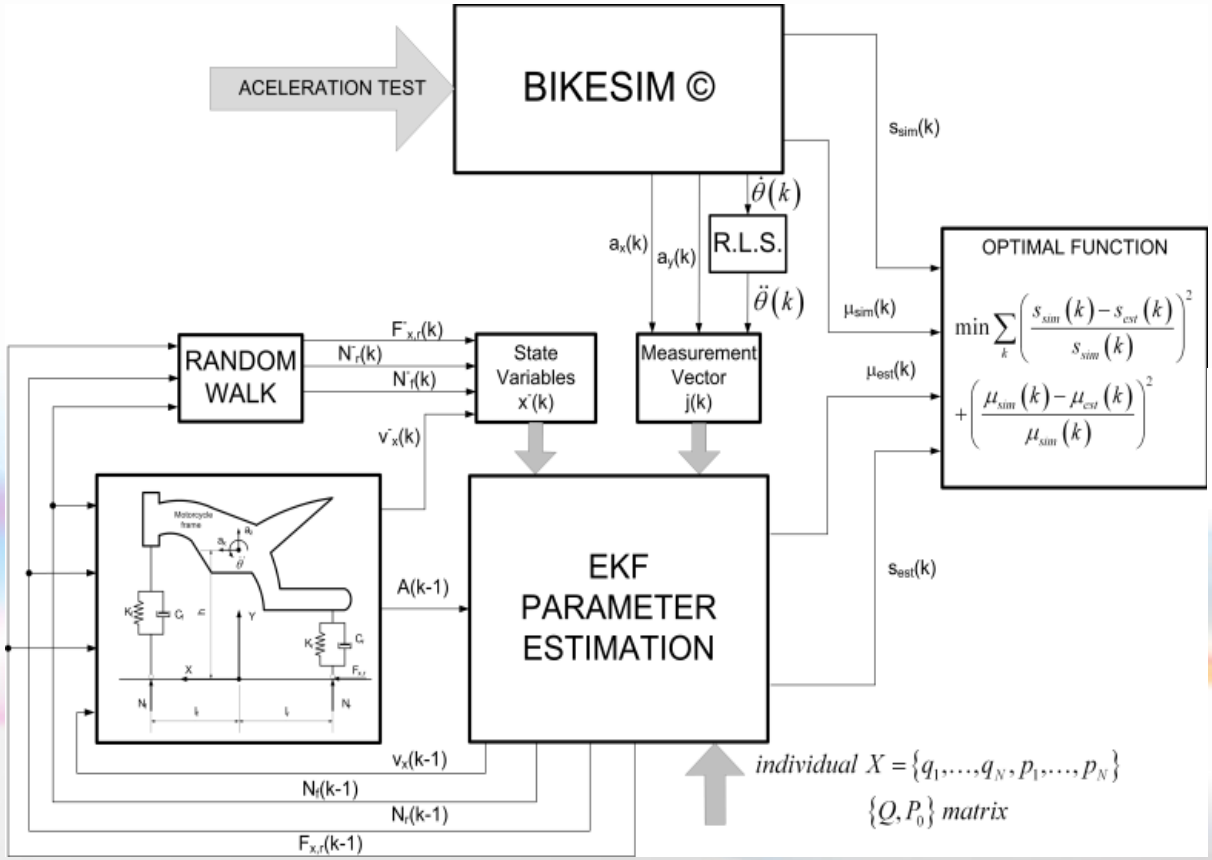
Model eq.

$$x(k) = \begin{bmatrix} F_{x,r}(k) \\ N_r(k) \\ N_f(k) \\ v_x(k) \end{bmatrix} = \begin{bmatrix} F_{x,r}(k-1) \\ N_r(k-1) \\ N_f(k-1) \\ v_x(k-1) + \Delta t\left(\dfrac{F_{x,r}(k-1) - Cv_x^2(k-1) - \left(C_1 + C_2 v_x^{\,2}(k-1)\right)N_f(k-1)}{M} - \dot{\theta} v_z\right) \end{bmatrix}$$

Measurement eq.

$$j(k) = \begin{bmatrix} a_x(k) \\ a_z(k) \\ \ddot{\theta}(k) \end{bmatrix} = \begin{bmatrix} \dfrac{F_{x,r}(k) - Cv_x^2(k) - \left(C_1 + C_2 v_x^{\,2}(k)\right)N_f(k)}{M} \\ \dfrac{N_f(k) + N_r(k) - Mg}{M} \\ \dfrac{N_r(k)l_r - N_f(k)l_f - \left(F_{x,r}(k) - \left(C_1 + C_2 v_x^{\,2}(k)\right)N_f(k)\right)z(k)}{I_y} \end{bmatrix}$$

Parameter Estimation

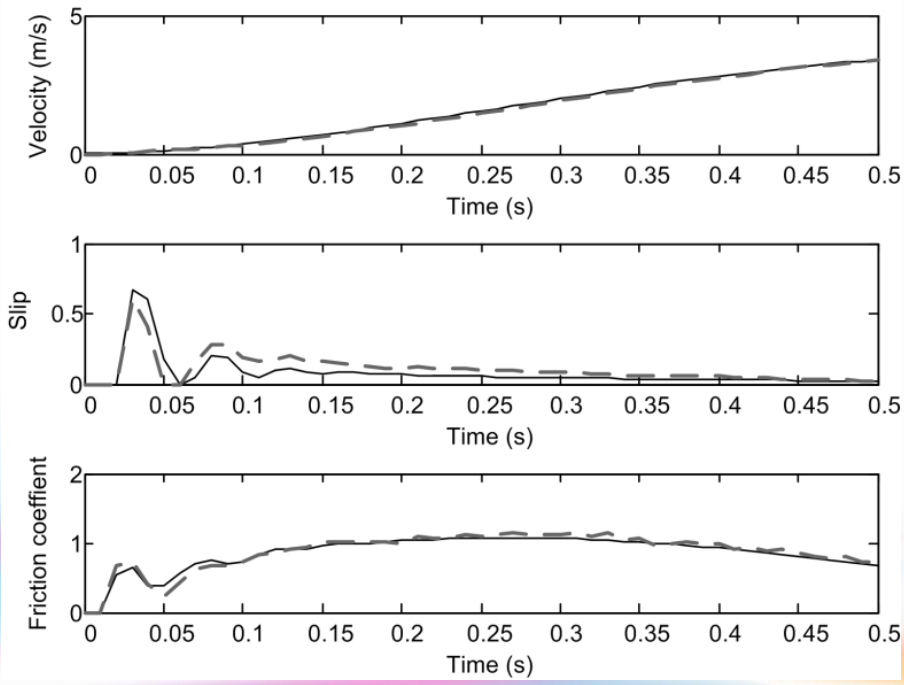


Optimization of Q and Po Matrix

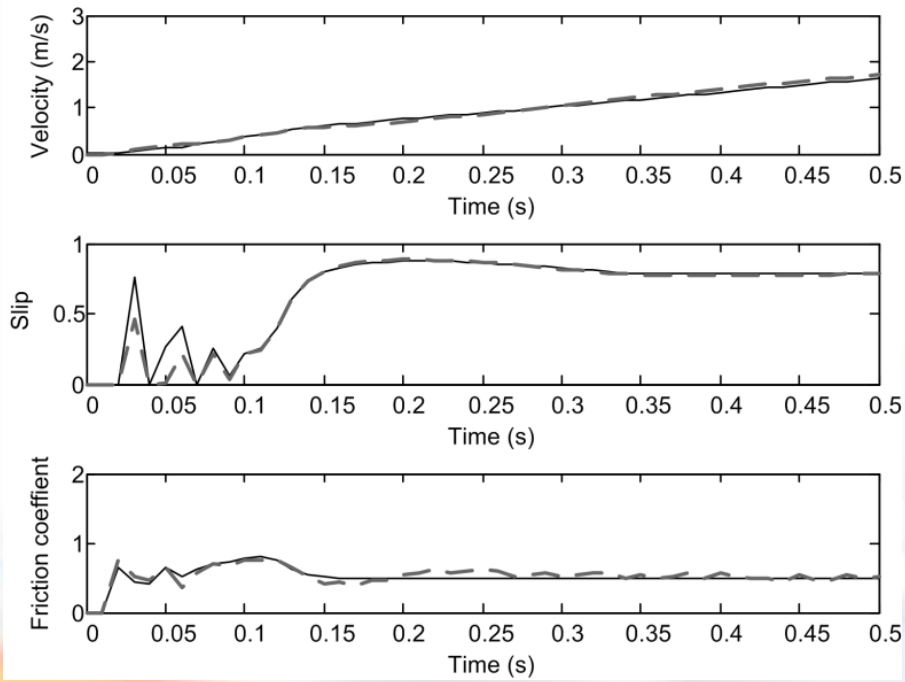
$$\left(\qquad \right)$$

$$\left(\qquad \right)$$

Parameter Estimation

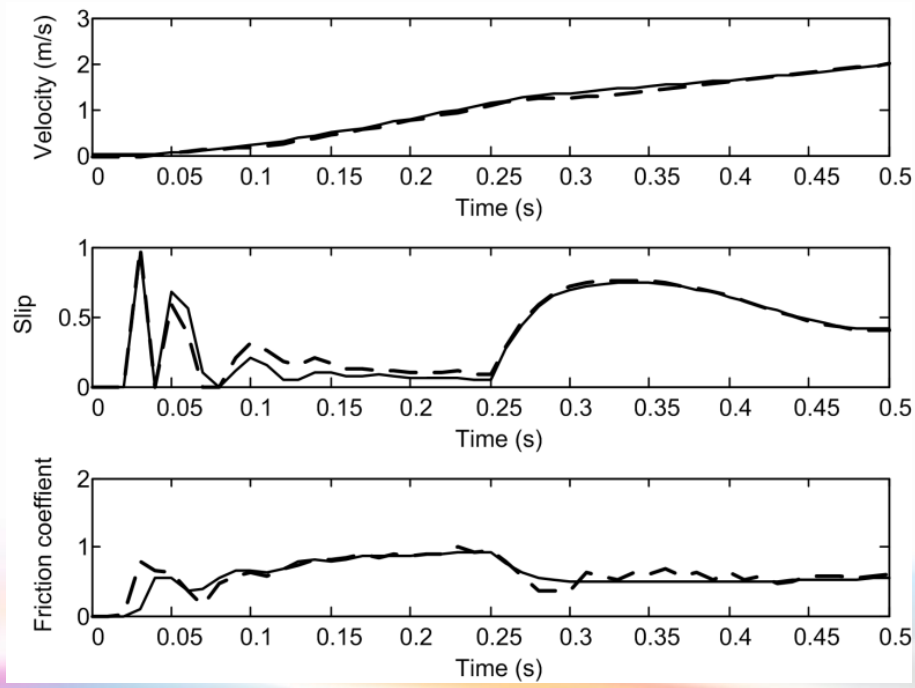


Road of friction coefficient □=1.2



Road of friction coefficient □=0.6

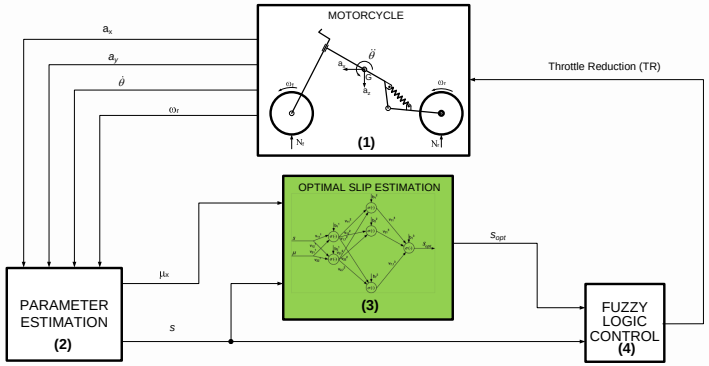
Parameter Estimation

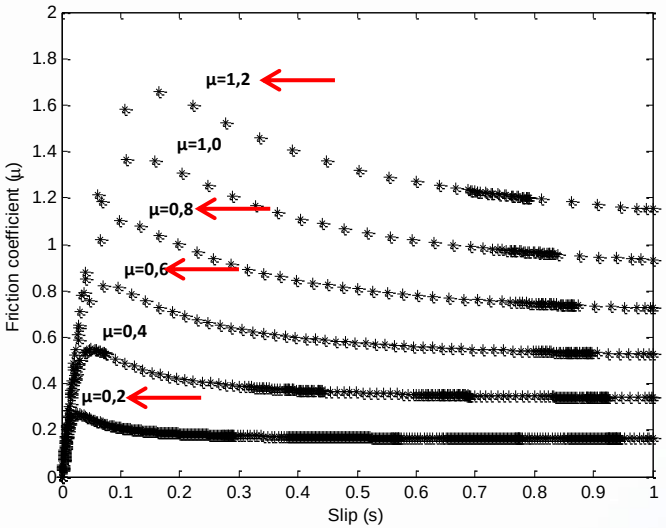


Road of friction coefficient μ=1.2 and 0.6

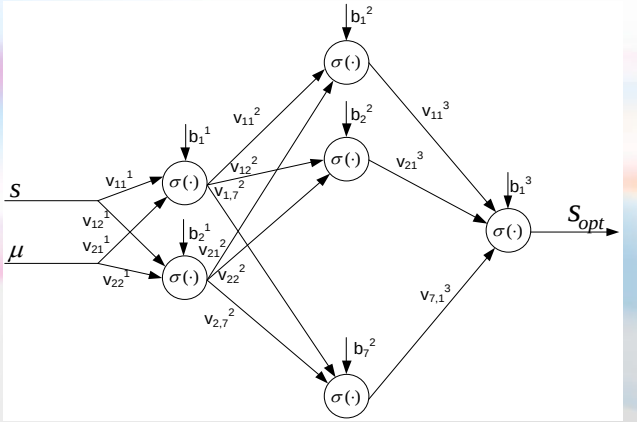
CONTENT

ADVANCED TRACTION CONTROL SYSTEM FOR MOTORBIKES



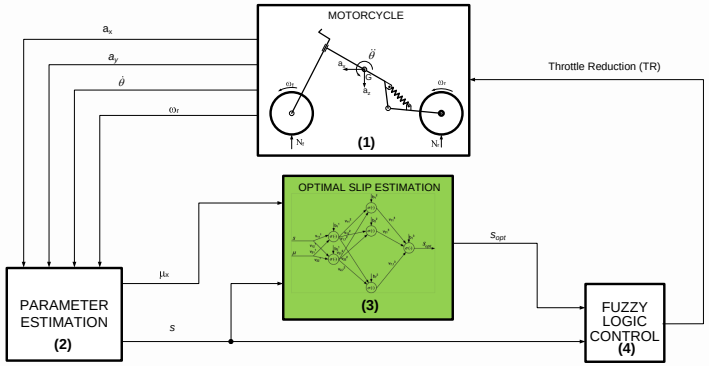


Neural Network

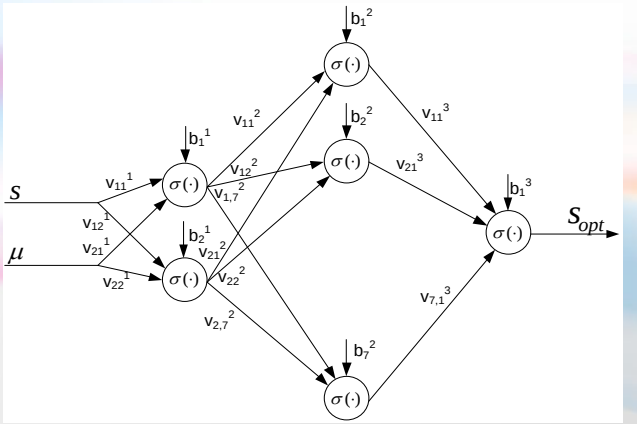


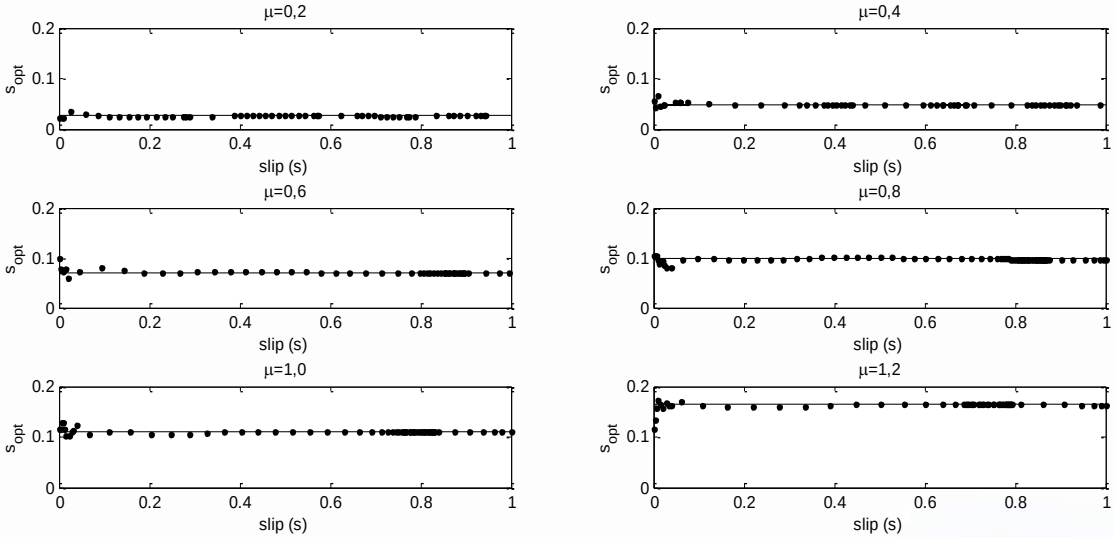
Adhesion curves calculated from simulations in BikeSim 3.1© have been used to train the proposed neural network. These curves provide the change of the friction coefficientvs slip for different surfaces, named $\mu = 0.2$ to $\mu = 1.2$ in BikeSim©.

ADVANCED TRACTION CONTROL SYSTEM FOR MOTORBIKES

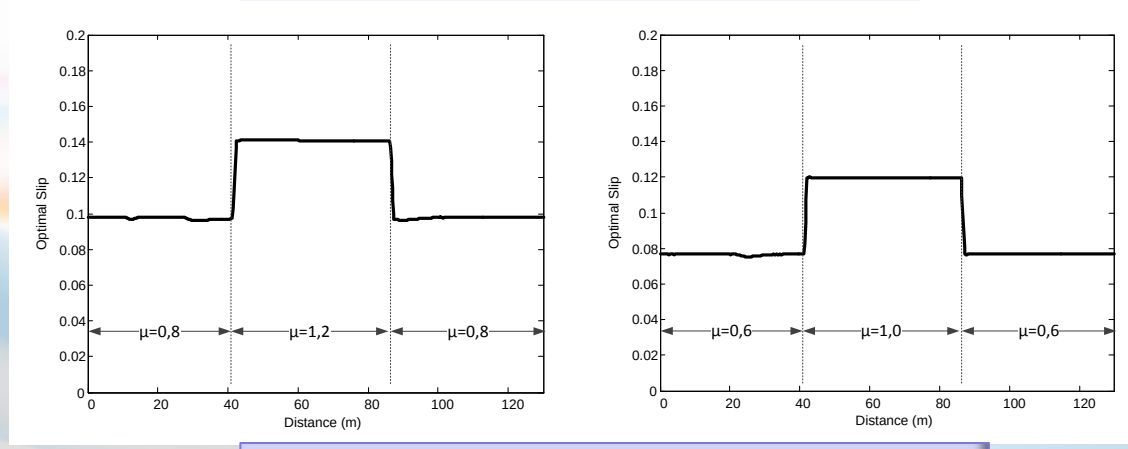


Neural Network





Network Output for different surfaces

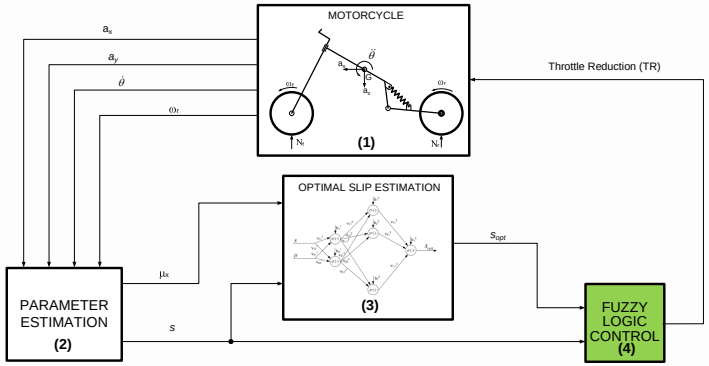


Network Output with changing conditions

DEPARTMENT OF MECHANICAL ENGINEERING. UNIVERSITY OF MÁLAGA

CONTENT

Fuzzy Logic Control Block



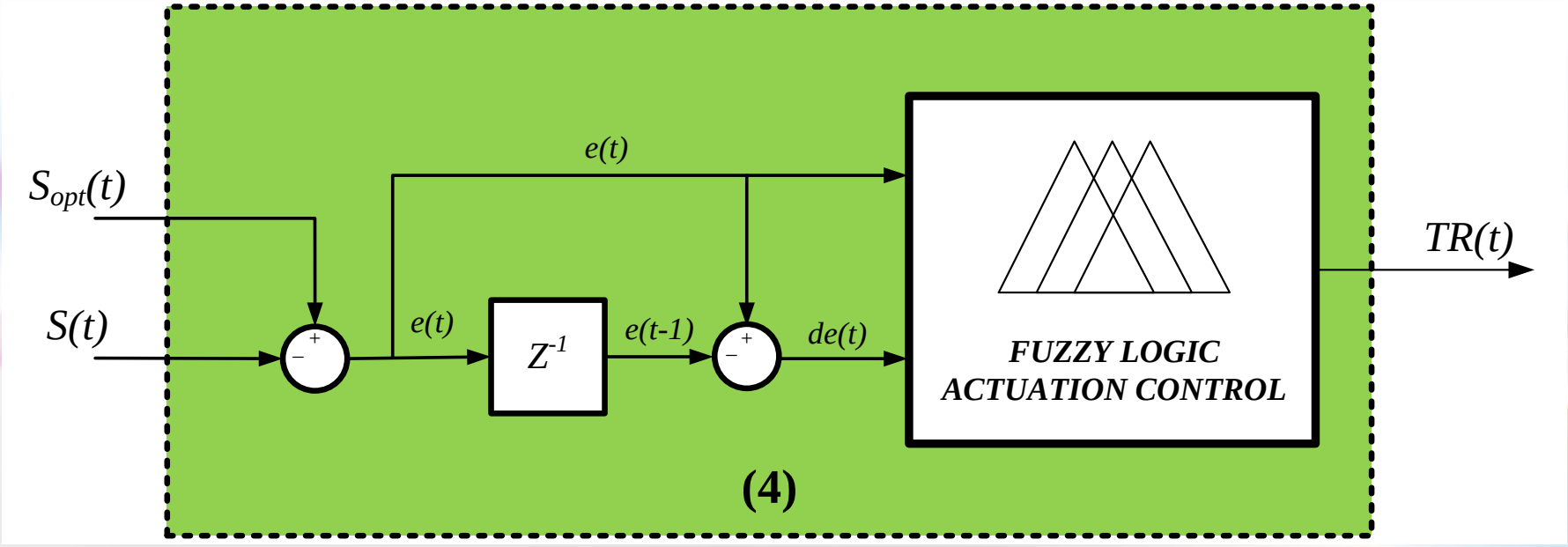
Inputs

$$e(t) = s_{opt}(t) - s(t)$$

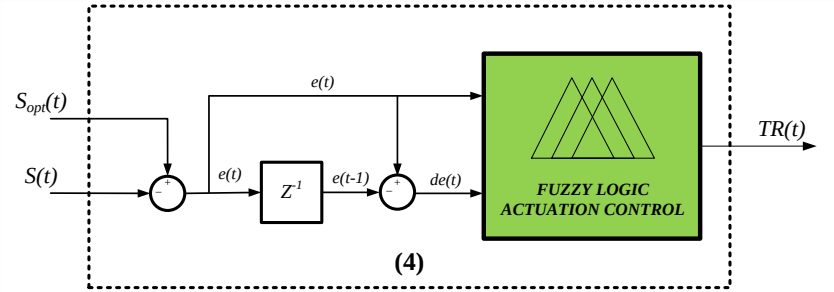
$$de(t) = e(t) - e(t-1)$$

Output

$$TR(t) = Throttle\ Reduction$$



Fuzzy Logic Control Block



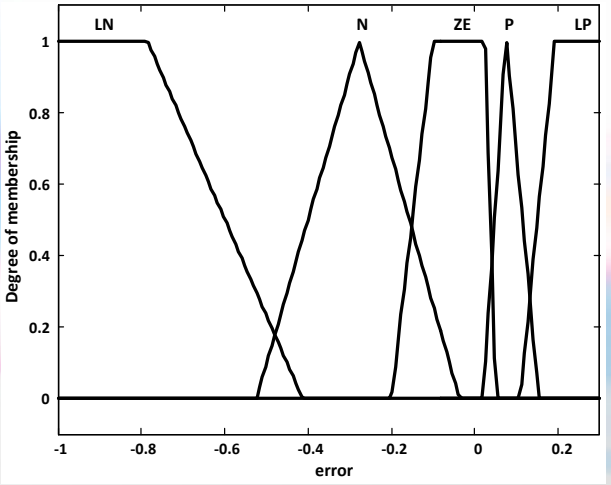
Inputs

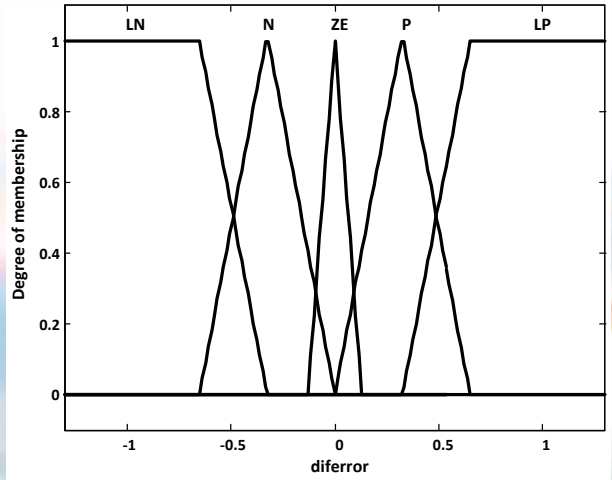
$$e(t) = s_{opt}(t) - s(t)$$

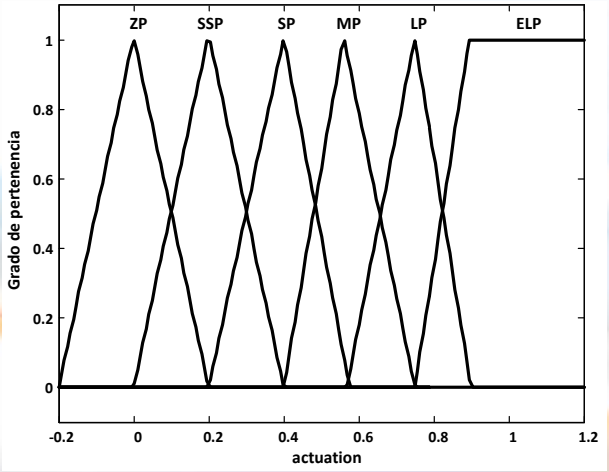
$$de(t) = e(t) - e(t-1)$$

Output

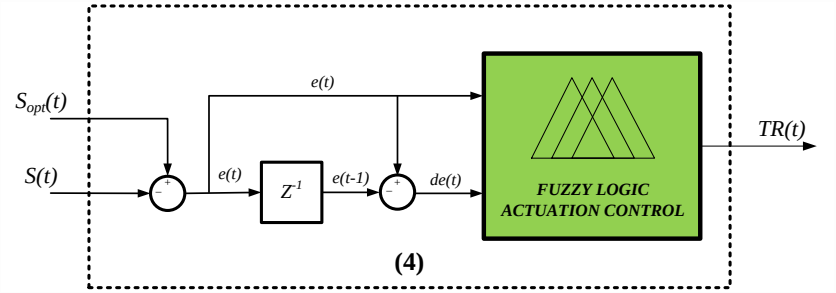
$$TR(t) = Throttle\ Reduction$$





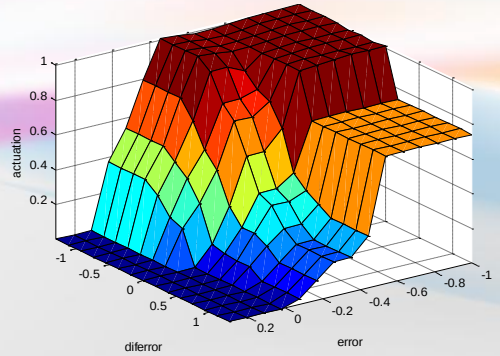


Fuzzy Logic Control Block

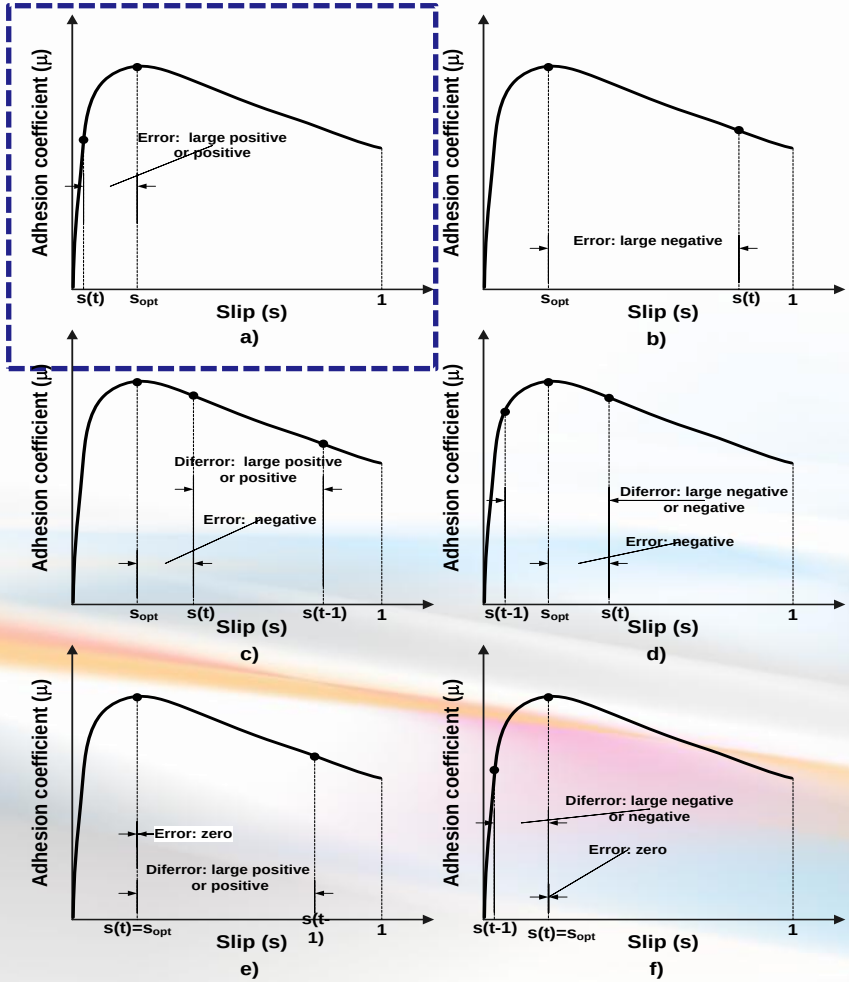


diferror

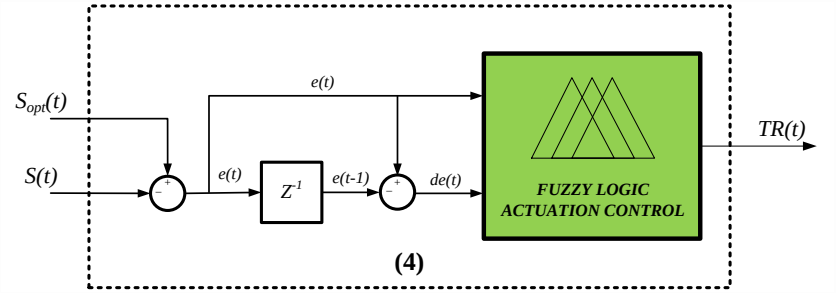
error	LN	N	ZE	P	LP
LN	ELP	ELP	ELP	LP	LP
N	ELP	LP	MP	SP	SSP
ZE	SP	SSP	ZP	ZP	ZP
P	ZP	ZP	ZP	ZP	ZP
LP	ZP	ZP	ZP	ZP	ZP



Rules

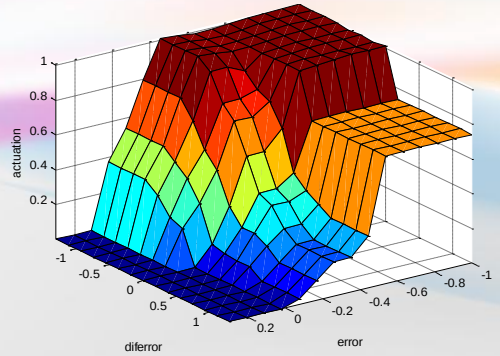


Fuzzy Logic Control Block

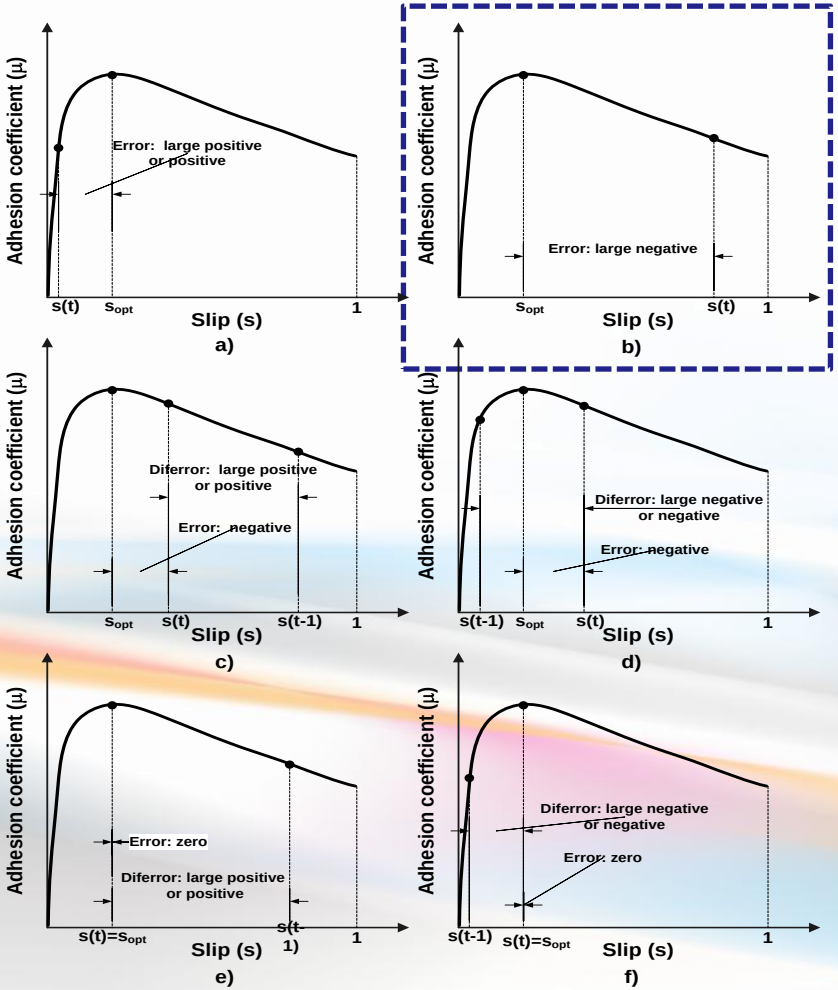


diferror

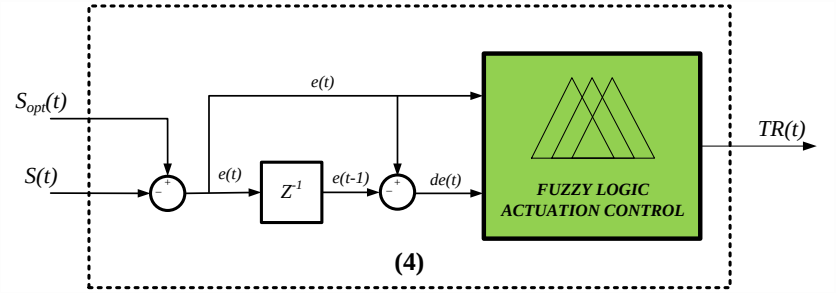
error	LN	N	ZE	P	LP
LN	ELP	ELP	ELP	LP	LP
N	ELP	LP	MP	SP	SSP
ZE	SP	SSP	ZP	ZP	ZP
P	ZP	ZP	ZP	ZP	ZP
LP	ZP	ZP	ZP	ZP	ZP



Rules

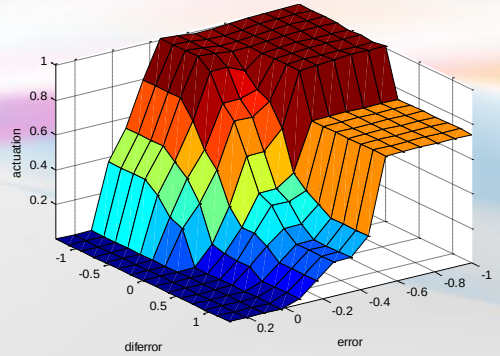


Fuzzy Logic Control Block

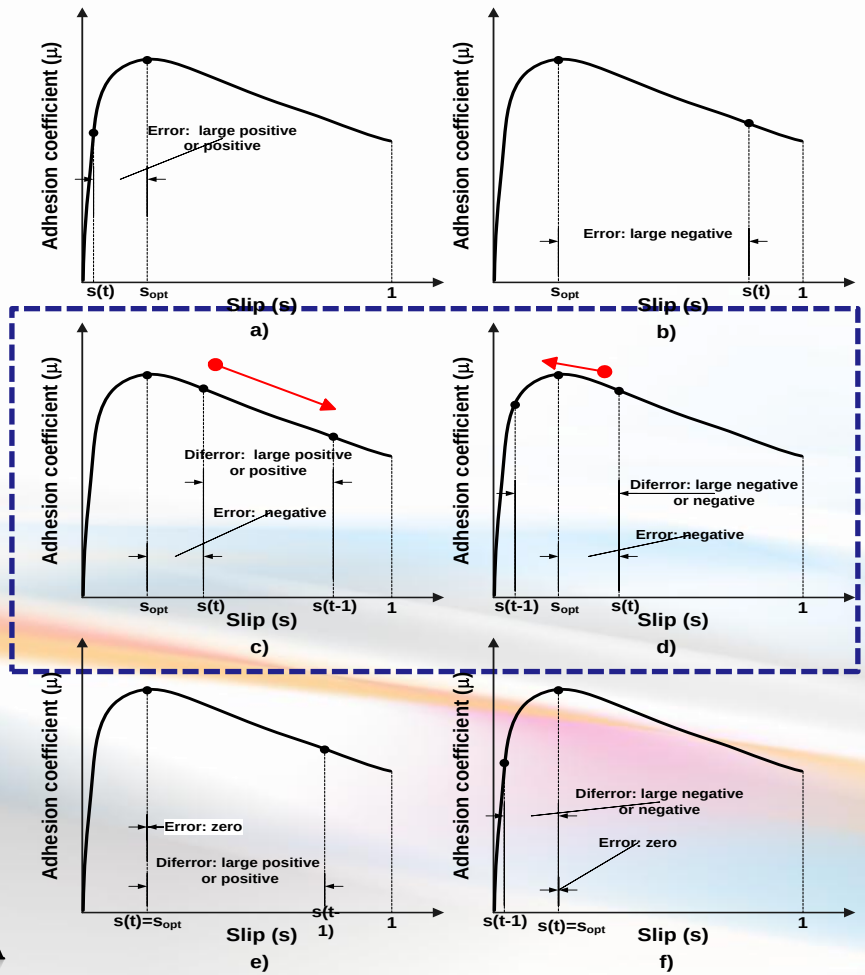


diferror

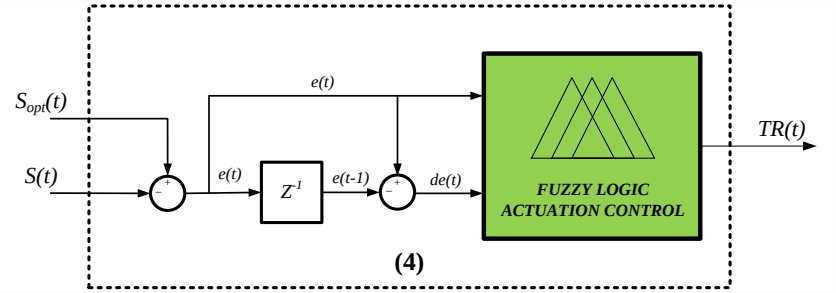
error	LN	N	ZE	P	LP
LN	ELP	ELP	ELP	LP	LP
N	ELP	LP	MP	SP	SSP
ZE	SP	SSP	ZP	ZP	ZP
P	ZP	ZP	ZP	ZP	ZP
LP	ZP	ZP	ZP	ZP	ZP



Rules

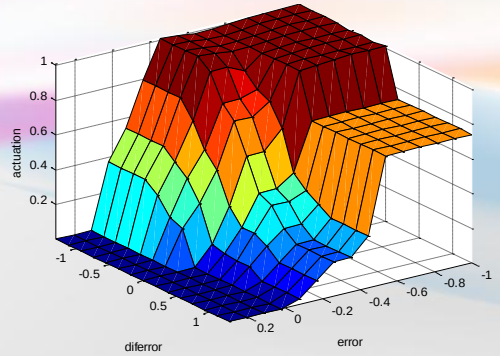


Fuzzy Logic Control Block

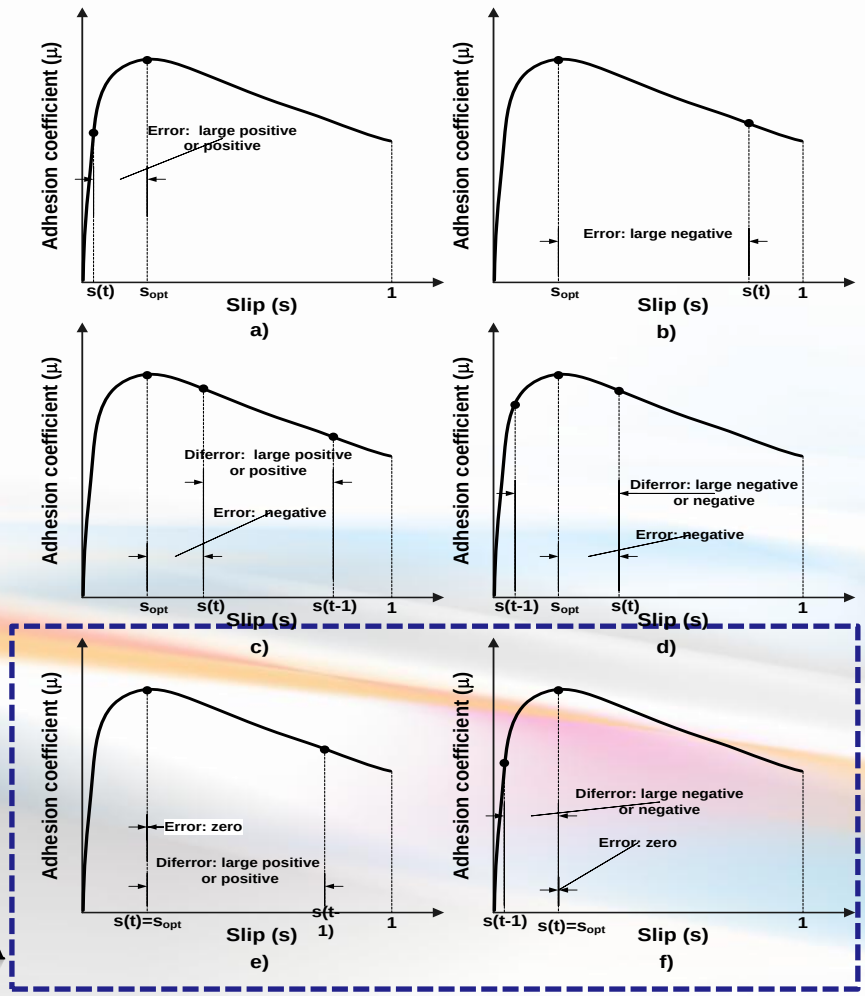


diferror

error	LN	N	ZE	P	LP
LN	ELP	ELP	ELP	LP	LP
N	ELP	LP	MP	SP	SSP
ZE	SP	SSP	ZP	ZP	ZP
P	ZP	ZP	ZP	ZP	ZP
LP	ZP	ZP	ZP	ZP	ZP

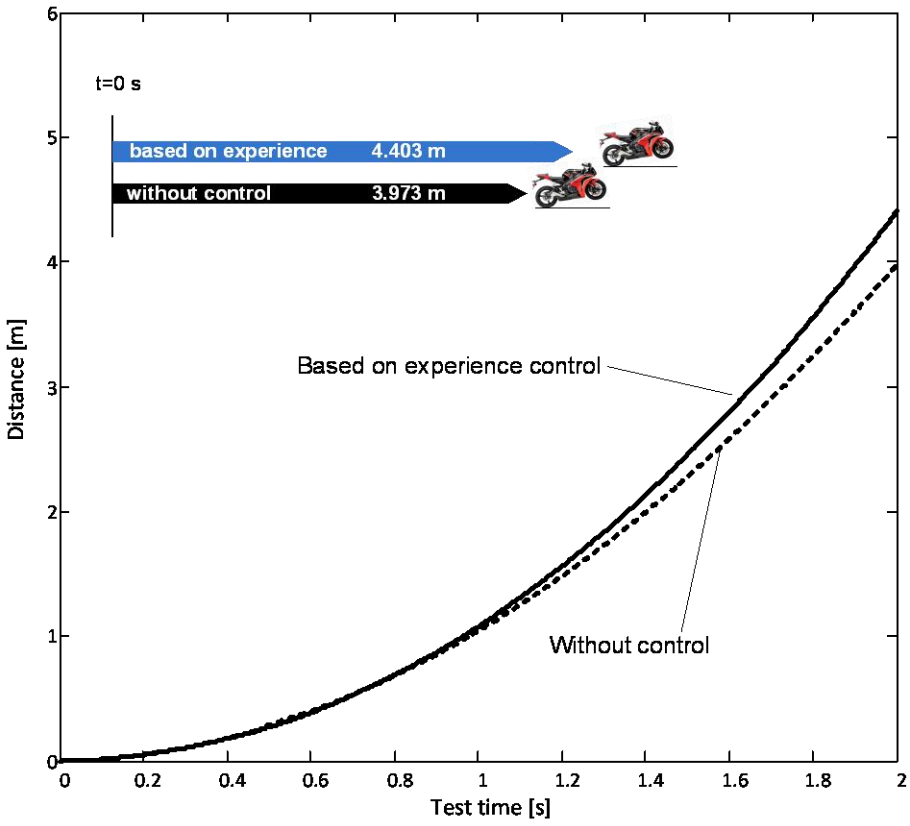


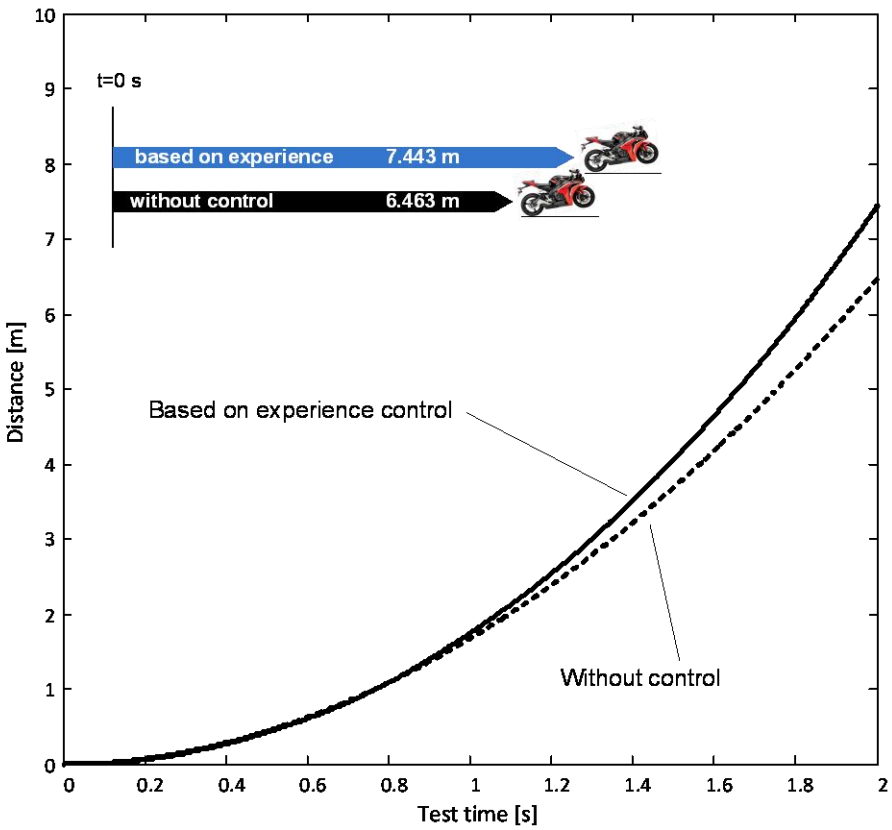
Rules



CONTENT

Straight Line Simulations



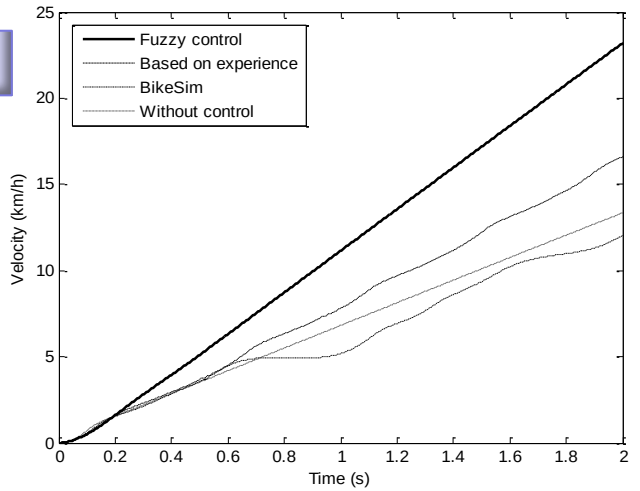


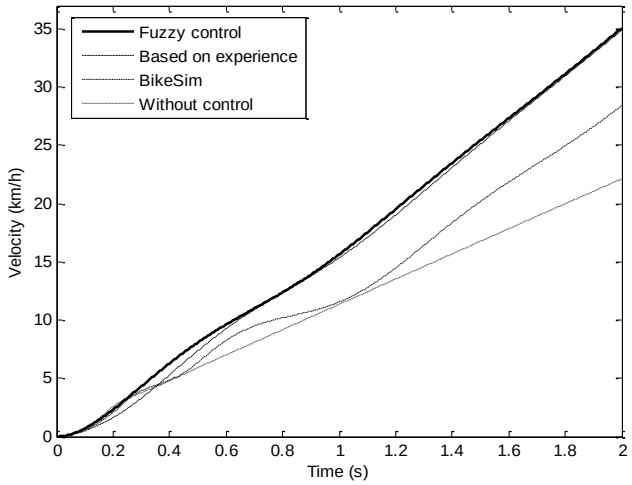
$\square = 0.4$

$\square = 0.6$

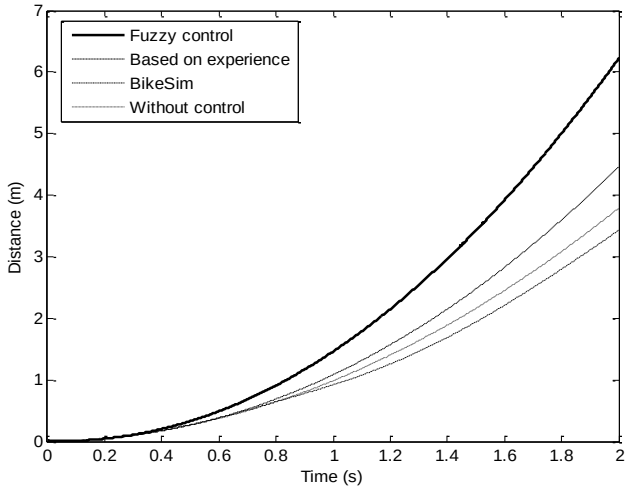
Straight Line Simulations

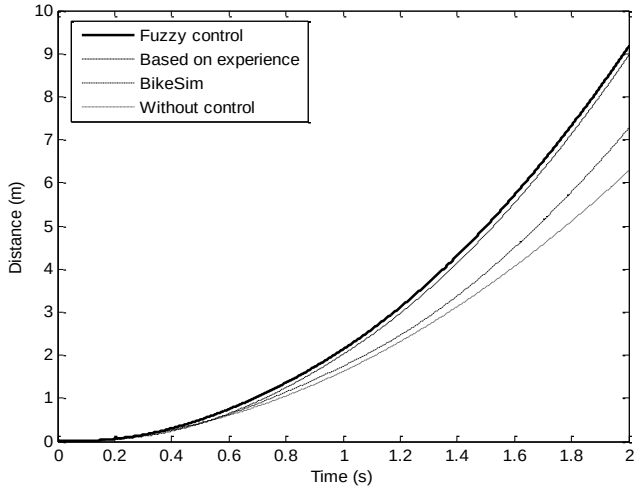
$\square = 0.4$



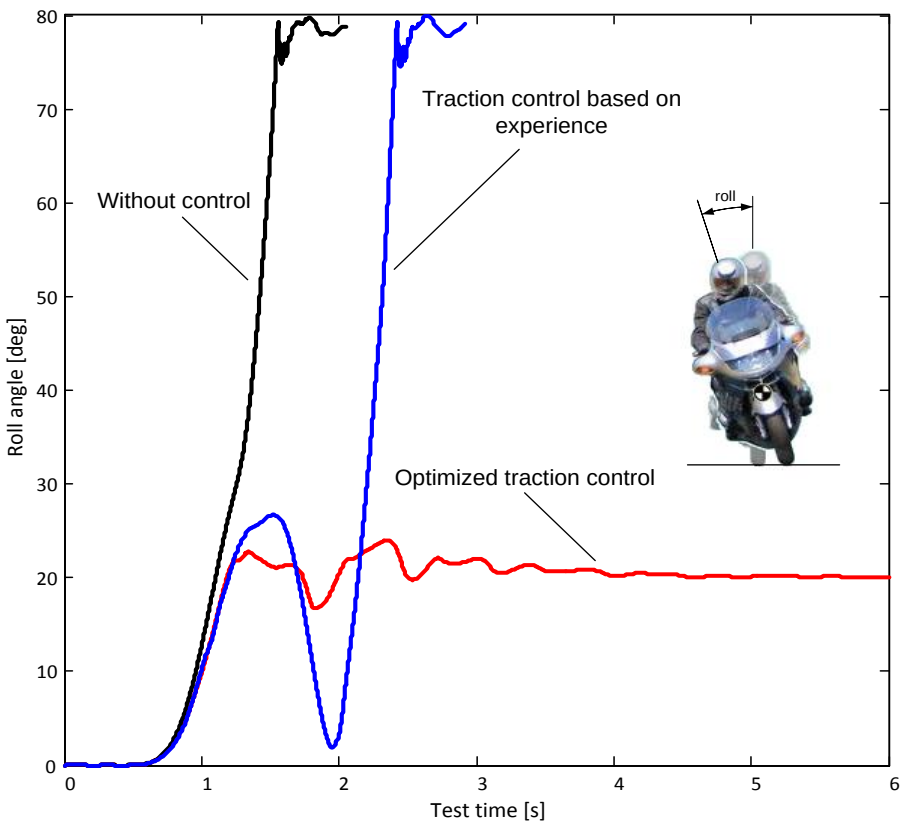


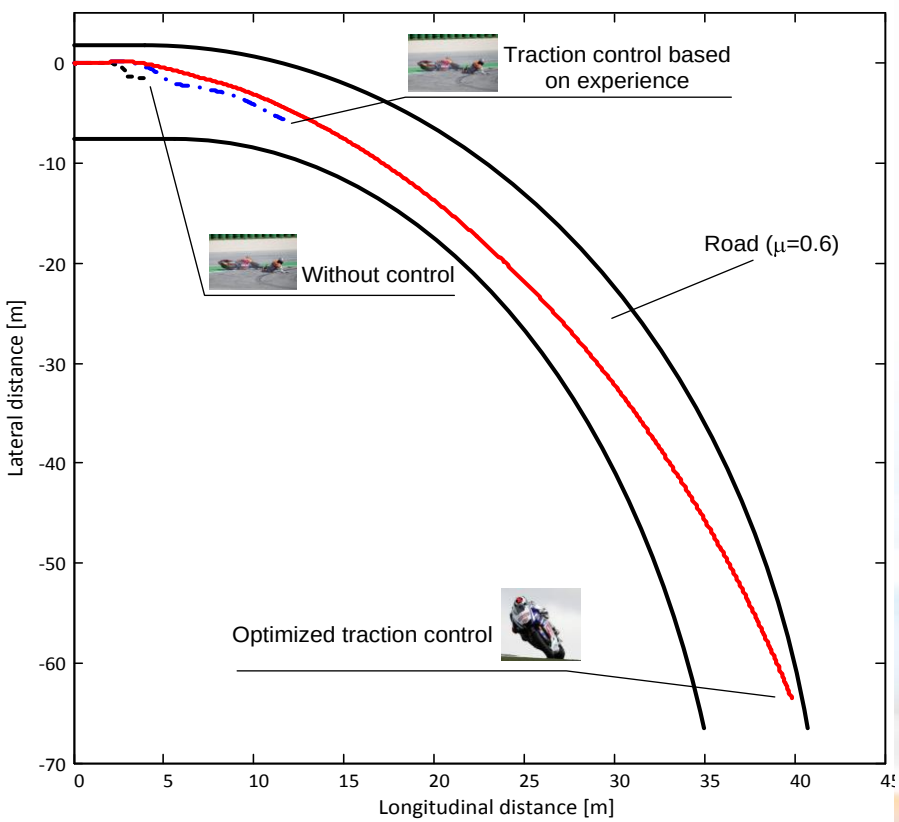
$\square = 0.6$





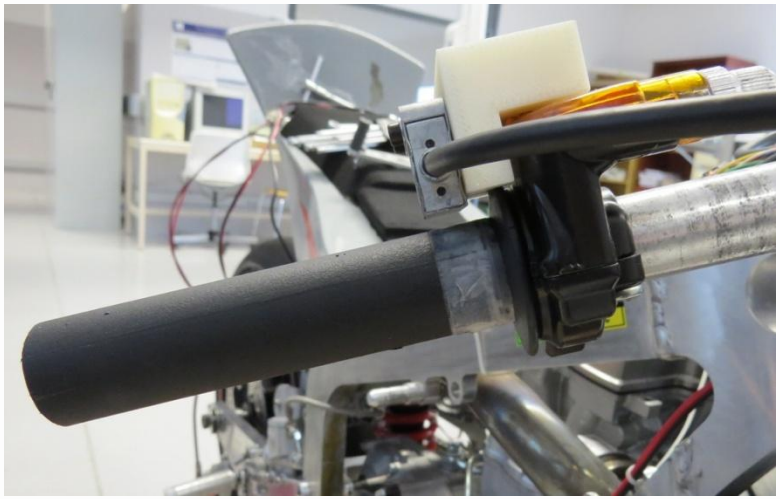
Curved Path Simulations



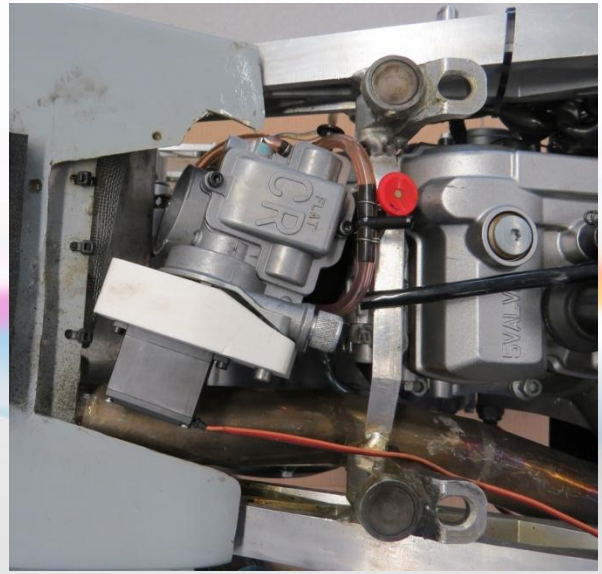


ADVANCED TRACTION CONTROL SYSTEM FOR MOTORBIKES

Ride By-Wire



Throttle valve control



Continuous Braking Pressure Control

Summary

- A method to estimate parameters needed for motorcycle T.C.S. is presented. The method is based on the use of EKF.

- The optimal slip, this is the slip that causes the highest adhesion, is determined by means of a neural network. The ANN provides the optimal slip of the surface where the motorcycle is moving having as inputs the estimated slip and adhesion coefficient.

- The throttle reduction to be applied is obtained from a fuzzy logic control block. The membership functions and rules of the FLC block have been set by an expert operator.

- Simulations with BikeSim© confirm the accuracy of the parameter estimation method and the performance of the proposed T.C.S.

Thank you for your attention

J. J. CASTILLO AND J. A. CABRERA

Dept. of Mechanial Engineering and Fluid Mechanics

School of Engineerings

C/ Dr. Ortiz Ramos s/n

29071 – Málaga (Spain)

Tf. +34 951952372

Fax +34 951952605

E-mail: juancas@uma.es

http: //immf.uma.es/