MODELING AND CONTROL OF LANE KEEPING SYSTEM FOR AUTONOMOUS VEHICLE

SHARMIN AHMED

UNIVERSITI SAINS MALAYSIA

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by

SHARMIN AHMED

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LIST OF ABBREVIATIONS

ASM	Active Set methods
ASTM	American Society for Testing and Materials
AHS	Automated Highway System
CG	Center of Gravity
CCD	Charge Coupled Devices
CMOS	Complementary Metal Oxide Semiconductor
DARPA	Defense Advanced Research Projects Agency
Dist	Disturbance
GM	General Motor
KF	Kalman Filter
LDWS	Lane Departure Warning System
LKAS	Lane Keeping Assista System
lim	limit
MPC	Model Predictive Controller
min	Minimum
max	Maximum
MIMO	Multi Input Multi Output
MV	Manipulated Variable
PI	Proportinal Integral
PO	Percentage of Overshoot
PID	Proportinal Integral and Derivative
QP	Quadratic Programming
Ref	Reference
SSV	Structured Singular Value
SISO	Single Input Single Output
SITO	Single Input Two Output Motor
SAE	Society of Automotive Engineers
sup	Supremum
TISO	Two Input Single Output

LIST OF SYMBOLS

A	System matrix
a_y	Inertial acceleration of the vehicle
A_k	System matrix at time k
A_o	Nominal system matrix
A_i	Uncertain system matrix
A_c	Real matrix
B_o	Nominal input matrix
B_i	Uncertain input matrix,
B	Input matrix
b	Real vector
B_k	Input matrix at time k
C	Output matrix
C_o	Nominal output matrix
C_i	Uncertain output matrix
$\mathscr{C}$	Observability matrix
c^T	Transpose of vector c
C_α	Cornering stiffness
C_{α_f}	Cornering stiffness of the fornt tire
C_{α_r}	Cornering stiffness of the rear tire
C_m	Output matrix for measured variable
D_o	Nominal feedthrough matrix
D_i	Uncertain feedthrough matrix
D_m	Feedthrough matrix for measured variable
d_{o_1}	Disturbance to y_1
d_{o_2}	Disturbance to y_2
d_1	Disturbance to input
D	Feedthrough matrix
$d(s)$	Disturbance of plant in s-domain

D_s	Denominator of the transfer function of a system
e	Exponential
$\dot{e}_y$	Derivative of lateral error variable of the vehicle
$\dot{e}_p$	Derivative of angular error of the vehicle
e_1	Error for $output_1$
e_2	Error for $output_2$
$e_{y_{min}}$	Lower limit of lateral error variable constraint
$e_{y_{max}}$	Upper limit of lateral error variable constraint
e_p	Angular deviation of the vehicle with respect to lane centerline
e_y	Lateral deviation of the vehicle with respect to lane centerline
$e(t)$	Error variable vector at time t
f	Vector function
F_x	Longitudinal force acting on the tire
F_x	Lateral force on the tires
F_y	Lateral force acting on the tire
F_{x_r}	Longitudinal force acting on the rear tire
F_{y_r}	Lateral force acting on the rear tire
F_{x_f}	Longitudinal force acting on the front tire
F_{y_f}	Lateral force acting on the front tire
f_c	Continuous time domain vector function
f_d	Discrete time domain vector function
$F_t(s)$	Transfer function of a system
g	Vector function
G_p	Plant transfer function
G_c	Controller transfer function
G_d	Output to disturbance transfer function
G_y	output to control input transfer function
G_{y_1}	$Output_1$ to control input transfer function

G_{y_2}	$Output_2$ to control input transfer function
$G(s)$	Overall transfer function of plant
$G_{d_1}(s)$	$Output_1$ to disturbance input transfer function
$G_{d_2}(s)$	$Output_2$ to disturbance input transfer function
G_r	Transfer function of regulator
H	Hessian matrix
H_p	Prediction horizon
H_c	Control horizon
h	Vector function
H_k	Hessian matrix at time k
i	Lower limit of constraint
I_{zz}	Moment of inertia of the vehicle
$\tilde{I}_{zz}$	Normalized moment of inertia of the vehicle
I	Identity matrix
J	Cost function
j	Laplace variable
K_d	Controller
K	Compensation matrix for pole placement
K_k	Kalman gain at time k
K_p	Proportional coefficient
K_c	Integral coefficient
K_d	Derivative coefficient
L_i	Uncertain look ahead distance
$-\bar{L}_i$	Lower limit of interval of parameter L_i
$\bar{L}_i$	Upper limit of interval of parameter L_i
l_x	Lower limit of constraint
l_f	Distance between the vehicle CG from the front axle of the vehicle
l_r	Distance between the vehicle CG from rear axle of the vehicle

L	Look ahead distance
m_1	Dimension of output matrix
m	Mass of vehicle
$\tilde{m}$	Normalized mass of vehicle
M	Nominal closed loop system
M_z	Rotating moment of the vehicle around z axis
$\mathscr{M}$	Matrix containing all uncertainties
n_{y_1}	Noise input to y_1
n_{y_2}	Noise input to y_2
N_z	Normal force acting on tire
n_1	Dimension of matrix
n	Number of dimensional space
N_s	Nominator of the transfer function of a system
$\mathscr{O}$	Controllability matrix
P	Point
P_d	Interconnection matrix
p_1	Dimension of input matrix
P_k	Predicted estimated covariance matrix at time k
P_o	Predicted estimated covariance matrix at time 0
$P_{k\|k-1}$	Predicted estimated covariance matrix
p_n	Poles of a system
Q	Upper limit of constraint
Q_k	Process noise covariance matrix at time k
R	Road radius
R_1	Lower limit of constraint
R_2	Upper limit of constraint
$\dot{r}$	Derivative of yaw rate of the vehicle
r_1	Reference signal $output_1$
r_2	Reference signal $output_2$

r	Yaw rate
r_{des}	Desired yaw rate
$\mathbb{R}$	Set of all real numbers
R_k	Measured noise covarianlce at time k
S_k	Innovation covariance matrix at time k
s_1	Path length coordinate
S	Frequency domain
S_I	Input sensitivity
S_f	Scale factor
T_s	Settling time
t	Time
T_i	Time unit for integral control
t_0	Initial time
T_d	Time unit for derivation control
T_s	Discretization time interval
t_k	Time step
t_w	Distance in betwwen steering wheels of ground vehicle
u	Control input
u_x	Upper limit of constraint
u_{min}	Longitudinal force acting on the rear tire
u_{max}	Lateral force acting on the rear tire
$u(t_k+1)$	Discrete time domain input vector function at time t_k+1
$u(t_k)$	Discrete time domain input vector function at time t_k
U_k	Control input at time k
$u(s)$	Control input of plant in s-domain
$\mathbf{u}$	Input vector
v	Feedback signal vector
V_x	Longitudinal velocity of vehicle
V_y	Lateral velocity of vehicle

w	Noise and disturbances
w	White gaussian noise
w_1	Noise $output_1$
w_2	Noise $output_2$
$w(k)$	White noise at time k
x	Horizontal axis
x_0	State vector at initial time
$x(t)$	State vector at time t
$x_c(k+1)$	Controller state at time $k+1$
$x_c(k)$	Controller state at time k
x_n	State vector of dimension n
$\hat{x}_k$	Estimation of vector x at time k given all measurements available
$\hat{x}_{k\|k-1}$	Estimation of vector x at time k given first $k-1$ measurements
$\hat{x}_{k-1\|k-1}$	Estimation of vector x at time $k-1$ given first $k-1$ measurements
$\hat{x}_o$	State vector x at time 0
x_l	Lane width
x^T	Transpose of vector x
$\hat{x}$	State vector
X	Global Cordinate along horizon
$\dot{x}(t)$	Derivative of state vector at time t
y	Output vector
y_1	$Out\,put_1$
y_2	$Out\,put_2$
$y(t)$	Output vector at time t
$y_{meas}(k)$	Measured plant output at time k
$y(s)$	Output of plant in s-domain
y_l	Car width

$\hat{y}_k$	Innovated output variable at time k
$\dot{y}$	Lateral velocity in temrs of lateral position of the vehcile
y	Verticle axis
Y	Global corodinate along verticle
z_r	Vector including reference signal, controlled signal and error signal
z	Plane
z_l	Avaibale space in the lane
z	Right angle axis
Z	Global corodinate along right angle
$\hat{z}_k$	Measurements at time k
z_n	Zeros of a system
α_d	Disturbance attenuation coefficient
β_f	Side-slip angle of the front tire of the vehicle
$\dot{\beta}$	Derivative of the side-slip angle of the vehicle
β_m	Real Number
β	Side-slip angle
δ	Steering angle
Δ	Uncertain transfer matrix
Δ_i	Uncertain element
δ_{i_L}	Uncertain element for L
δ_{i_μ}	Uncertain element for μ
Δu_{min}	Lower limit of rate of change of control input constraint
Δu_{max}	Upper limit of rate of change of control input constraint
δ_i	Inner wheels steering angle
δ_o	Outer wheels steering angle
δ_1	Output of PID_1
δ_1	Output of PID_1
δ_2	Output of PID_2

Δ_{u_p}	Optimization variable
$\eta(t_k+1)$	Discrete time domain output vector function at time t_k+1
$\eta(t_k)$	Discrete time domain output vector function at time t_k
η	Output vector
η_d	Uncertainty vector
$\eta_{t+i,t}$	Lower limit of lateral error variable constraint
$\eta_{ref_{t+i,t}}$	Upper limit of lateral error variable constraint
$\in$	Is an element of
ε	Vector of cotinuous time domain
$\dot{\gamma}$	Parameterized curve
μ_i	Uncertain road-tire friction coefficient
$-\bar{\mu}_i$	Lower limit of interval of parameter μ_i
$\bar{\mu}_i$	Upper limit of interval of parameter μ_i
μ_Δ	Analysis parameter for measuring robustness
μ	Road tire friction coefficient
ω	Laplace variable
ω_n	Natural frequency
ψ	Orientation of the vehicle
Π	Uncertainty model set
ρ	Road curvature
τ	Time coordinate
θ	Orientation angle
θ_i	Parameter of a system
$-\bar{\theta}_i$	Lower limit of interval of parameter θ_i
$\bar{\theta}_i$	Upper limit of interval of parameter θ_i
θ_{v_f}	Velocity vector angle of front tire
θ_{v_r}	Velocity vector angle of rear tire
ζ	Damping ratio