

**YAW RATE AND SIDESLIP CONTROL USING  
H-INFINITY-PID CONTROLLER DURING  
AUTOMATED LANE CHANGE MANOEUVRE**

**ZAINAB ZAINAL**



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**YAW RATE AND SIDESLIP CONTROL USING H-INFINITY-PID  
CONTROLLER DURING AUTOMATED LANE CHANGE MANOEUVRE**

by

**ZAINAB ZAINAL**

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Dual-PID controller



## LIST OF ABBREVIATIONS

ABS	Anti-lock Braking System
ADAS	Advanced Driver Assistance System
ADB	Adaptive Driving Beam
AV	Autonomous Vehicle
BSM	Blind Spot Monitor
BO	Butterfly Optimisation
BP	Back-Propagation
CAS	Collision Avoidance System
CL	Closed-Loop
D	Derivative
DLC	Double-Lane-Change
DOF	Degree-of-Freedom
DYC	Direct Yaw Control
ESC	Electronic Stability Control
FWS	Front-Wheel-Steering
GPS	Global Positioning System
I	Integral
ISO	International Organization for Standardization
I/O	Input and Output

LC	Lane Change
LDWS	Lane Departure Warning System
LHP	Left-Half-Plane
LHT	Left-Hand-Traffic
LiDAR	Light Detection and Ranging
LKA	Lane Keeping Assist
LPV	Linear Parameter Varying
MPC	Model Predictive Control
NCSA	National Center for Statistics and Analysis
NHTSA	National Highway Transportation Safety Administration
NN	Neural Network
Z-N	Ziegler-Nichols
OL	Open-Loop
P	Proportional
PI	Proportional-Intergral
PID	Proportional-Intergral-Derivative
PSD	Passing Sight Distance
RWD	Rear-Wheel-Drive
R-H	Routh-Hurwitz
SAE	Society of Automotive Engineering
SISO	single-input-single-output

SITO single-input-two-output

SMC Sliding Mode Control

SSD Stopping Sight Distance

SWA steering wheel angle

TISO two-input-single-output

2D Two Dimension



PTTA UTHM  
PERPUSTAKAAN TUNKU TUN AMINAH

## LIST OF SYMBOLS

$a_y$	Lateral acceleration
$\alpha$	Tire slip angle
$\alpha_f$	Tire slip angle of front wheel
$\alpha_r$	Tire slip angle of rear wheel
$\theta_{Vy}$	Angle of lateral velocity vector
$\beta$	Sideslip angle
$\dot{\beta}$	Sideslip angle rate
$C_{\alpha_f}$	Cornering stiffness of front wheel
$C_{\alpha_r}$	Cornering stiffness of rear wheel
$C_{\alpha_{f_{right}}}$	Cornering stiffness of front-right wheel
$C_{\alpha_{f_{left}}}$	Cornering stiffness of front-left wheel
$\delta$	Steering wheel angle
$\delta_r$	Rear wheel angle
$\delta_f$	Front wheel angle
$F_y$	Lateral force
$F_{yf}$	Lateral force at front tire
$F_{yr}$	Lateral force at rear tire
$G(s)$	Plant transfer function
$g_m$	Gain margin

$\gamma$	Vehicle heading angle
$\gamma_{H_\infty}$	Gamma in $H_\infty$ analysis
$K$	Gain
$K_p$	Proportional gain
$K_i$	Integral gain
$K_d$	Differential gain
$K_u$	Critical gain
$H_\infty$	H-infinity
$H_2$	H-two
$I_z$	Yaw moment of inertia
$l_f$	Distance from c.g. to front axle
$l_r$	Distance from rear axle to c.g.
$M_z$	Yaw moment inertia
$m$	Vehicle mass in kilogram
$\omega$	Frequency
$\phi_m$	Phase margin
$T_u$	Critical time
$\theta$	Angle in radians
$V_x$	Longitudinal velocity or vehicle speed
$V_y$	Lateral velocity
$\dot{y}$	Lateral velocity at c.g. of vehicle

$W$  Vehicle weight in Newton

$\psi$  Yaw angle

$\dot{\psi}$  Yaw rate



PTTHM  
PERPUSTAKAAN TUNKU TUN AMINAH

**KAWALAN KADAR REWANG DAN GELINCIR SISI MENGGUNAKAN  
PENDEKATAN PENGAWAL H-INFINITY-PID KETIKA PEMANDUAN  
PENUKARAN LORONG AUTOMATIK**

**ABSTRAK**

Pengawal PID klasik digunakan dengan meluas dalam aplikasi sistem kawalan industri. Walaupun struktur sistem pengawal PID senang difahami dan ringkas, didapati bahawa untuk melaras parameter dan kadar pengawalnya adalah sukar, terutama bagi sistem kawalan kenderaan yang terbukti lebih kompleks dan memakan masa. Kajian ini bertujuan untuk mencadangkan algoritma pelarasan PID yang mudah dan menyelidik potensi penggunaan sintesis  $H_\infty$  dalam mengoptimumkan kadar pengawalan PID semasa pemanduan penukaran lorong automatik menggunakan anggaran sudut stereng model pemandu pada kelajuan tetap 80 km/j. Dua algoritma pelarasan telah dicadangkan; Pertama, menggunakan nilai  $K_p K_i$  dari sempadan lokus yang stabil bersama kaedah pelarasan Ziegler-Nichols (Z-N); Kedua, versi lanjutan dari algoritma pertama menggunakan kaedah hibrid  $H_\infty$  dan Chein. Dengan menggunakan model kenderaan sisi satu-masukan-dua-keluaran (SITO) kawalan-stereng-hadapan (FWS), kadar rewang,  $\psi$  dan gelinciran sisi,  $\beta$ , kedua-duanya dikawal menggunakan dua konfigurasi PID; Satu-PID dan Dua-PID. Perbandingan prestasi dilakukan antara PID yang dilaraskan secara automatik menggunakan MATLAB dan PID yang dilaraskan menggunakan kaedah yang dicadangkan. Pengawal  $H_\infty$  PID menunjukkan prestasi yang lebih baik berbanding PID-MATLAB, terutamanya bagi konfigurasi Satu-PID yang menghasilkan hanya 1.71 % ralat pada nilai akhir anjakan sisi. Ia mengurangkan kira-kira 0.58% ralat oleh pengawal Satu-PID tanpa sintesis  $H_\infty$ . Namun, untuk konfigurasi Dua-PID, ia hanya menghasilkan 55% keluaran jejak rujukan. Kesimpulannya, pe-



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## LIST OF PUBLICATIONS

**Zainal Z** and Wan Rahiman (2016) "Concept of Controller Design for Improving Lateral Vehicle Dynamic Model Stability", *In: 6th Electrical And Electronic Postgraduate Colloquium, School of Electrical and Electronic Engineering, USM*

**Zainal Z**, Wan Rahiman and Baharom M.N.R. (2017) "Yaw Rate and Sideslip Control using PID Controller for Double Lane Changing", *In: Journal of Telecommunication, Electronic and Computer Engineering (JTEC), Journal of Telecommunication, Electronic and Computer Engineering (JTEC), 9(3-7), 99-103. (SCOPUS indexed Q4, 3 citations, Researchgate read: 1,929)*

**Zainal Z** and Wan Rahiman (2017) "Study on the Effect of Yaw Rate and Sideslip to Lateral Vehicle Dynamic Stability", *In: 7th Electrical And Electronic Postgraduate Colloquium, School of Electrical and Electronic Engineering, USM.*

**Zainal Z** and Wan Rahiman (2019) "Effect of Yaw Rate and Sideslip to Lateral Vehicle Dynamic Stability", *In: 10th International Conference on Robotics, Vision, Signal Processing and Power Applications (ROVISIP), Lecture Notes in Electrical Engineering, vol. 547, pp. 473-479, Springer, Singapore. (SCOPUS indexed Q3)*