Faculty of Mechanical Engineering

VEHICLE SPEED CONTROL USING MRAC PID STRATEGY FOR GRADIENT DISTURBANCE REJECTION

Faizul Akmar Bin Abdul Kadir

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VEHICLE SPEED CONTROL USING MRAC PID STRATEGY FOR GRADIENT DISTURBANCE REJECTION

FAIZUL AKMAR BIN ABDUL KADIR

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DECLARATION

I declare that this thesis entitled “Vehicle Speed Control Using MRAC PID Strategy For Gradient Disturbance Rejection” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………………
Name : Faizul Akmar Bin Abdul Kadir
Date : 21th February 2018

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy

Signature : ……………………………………

Supervisor Name : Assoc. Prof. Dr. Noreffendy Bin Tamaldin

Date : ……………………………………

DEDICATION

To my beloved father and mother

ABSTRACT

Controlling vehicle speed is a challenging task, moreover when road gradient disturbance is taken into consideration. In this study, Model Reference Adaptive Control PID (MRAC PID) was proposed to handle the task. The study was conducted via simulation in MATLAB-Simulink environment. Vehicle model used was constructed by combining validated Vehicle Longitudinal Model (VLM) and Electronic Throttle Body model (ETB) where VLM act as plant and ETB as the actuator. MRAC PID was utilized as the plant controller whereas Fixed Gain PID (FG PID) controls the actuator. A unique self-induced data was used as the Reference Model for the proposed controller together with MIT Rule as the adjustment mechanism. The performance of MRAC PID was studied by subjecting the vehicle to a set of gradient disturbances ranging from 0° to 25° with 5° increment at a driven speed of 90 kph. The results were compared against Gain Scheduling PID (GS PID) and FG PID control strategies. Simulation results shows that the proposed controller outperform the other controllers in both transient and disturbance region. HILS with Throttle-in-the-Loop was conducted as the means of validating the simulation results. It was observed that the simulations and HILS results shows similar pattern thus conclude that the results are valid. Several HILS data were collected for Repeatability Analysis. The Coefficient of Variance (CV) obtained from the analysis indicates that the HILS has high repeatability and well conducted. For future works, it is recommended that the actual torque curve from dynamometer test is used for the vehicle model and the braking effect is considered as it may offer better result as well as exploring several new actuators for HILS.

ABSTRAK

Kawalan halaju kenderaan merupakan bidang yang mencabar terutama bila gangguan kecerunan diambil kira. Dalam kajian ini, sistem Kawalan Bolehubah dengan Model Rujukan PID (MRAC PID) dicadangkan untuk mengatasi masalah tersebut. Kajian dijalankan secara simulasi menggunakan perisian MATLAB-Simulink. Model kenderaan yang digunakan dihasilkan dengan menggabungkan Model Kenderan Membujur (VLM) dan Badan Pendikit Elektronik (ETB) yang telah disahkan dimana masing-masing berfungsi sebagai perumah dan penggerak. MRAC PID digunakan untuk mengawal perumah manakala kawalan Pekali Tetap PID (FG PID) mengawal penggerak. Sistem kawalan yang dicadangkan dilengkapi dengan data janaan-kendiri yang unik sebagai Model Rujukan serta Undang-undang MIT sebagai mekanisma perubahan. Prestasi MRAC PID dikaji dengan mengenakan gangguan kecerunan dalam julat 0° ke 25° dengan kenaikan sebanyak 5° setiapkali pada kenderaan yang bergerak dengan kelajuan 90 km/j. Keputusan yang diperolehi dibandingkan dengan kawalan jenis Pekali Berjadual PID (GS PID) dan FG PID. Keputusan simulasi menunjukkan prestasi sistem kawalan yang dicadangkan adalah yang lebih baik berbanding pesaingnya. HILS menggunakan Simulasi-Pendikit-dalam-Gegelung telah dilancarkan bagi mengesahkan keputusan simulasi. Didapati keputusan simulasi adalah bertepatan dengan keputusan HILS dari segi sifatnya sekaligus mengesahkan keputusan tersebut. Beberapa data HILS telah dikumpulkan untuk Analisa Kebolehulangan. Pekali Varian (CV) yang diperolehi dari analisa tersebut menunjukkan HILS telah dilaksanakan dengan baik dan mempunyai kebolehulangan yang tinggi. Untuk kajian dimasa hadapan, dicadangkan lengkung dayakilas kenderaan sebenar yang diperolehi dari ujian dinamometer digunakan pada model kenderaan dan kesan brek juga diambil kira. Ia diharap dapat memberi keputusan yang lebih baik disamping membuka ruang kepada menggunakan beberapa pengerak baru untuk HILS.

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VLM

m - Vehicle Mass

h - Centre of Gravity Height of the Vehicle

θ_g - Road Grade

V - Forward Velocity of Vehicle

R_i - Rolling Radius of The Wheel

$i=f,r$ - Front or Rear Wheel

I_i - Polar Moment of Inertia of the Wheel

ω_i - Wheel Angular Speed

L - Wheelbase of the Vehicle

a - Distance from c_og to Front Axle of the Vehicle

b - Distance from c_og to Rear Axle of the Vehicle

c_og - Centre of Gravity of The Vehicle

μ_i - Friction between Tire Contact Surfaces to Road Surface

F_{xT} - Total Force Acting on Tire Contact Point in X-Direction

F_d - Forces Due to Drag

F_{xi} - Front Force Acting on Tyre in X-Direction

N_i - Normal Force Acting on Tyre Contact Point

F_a - Drag due to Aerodynamic Effect

F_r - Drag due to Tire Rolling Resistant

C_a - Coefficient of Aerodynamic Drag

C_r - Coefficient of Rolling Resistant

A - Vehicle Frontal Area

ρ - Air Density

C_1 - Pacejka's Coefficient

C_2 - Pacejka's Coefficient

C_3 - Pacejka's Coefficient

C_4 - Pacejka's Coefficient

S - Longitudinal Slip Ratio

T_e - Engine Torque

T_r - Reaction Torque due to Tire Tractive Force

T_b - Brake Torque

T_{vf} - Torque due to Viscous Friction on the Wheel

C_{vf} - Coefficient of Viscous Friction on Each Wheel

$T_{e\max}$ - Maximum Engine Torque

R - Engine RPM

η_g - Current Gear Ratio

η_f - Final Drive Ratio

μ_e - Energy Transfer Coefficient

t_{eq} - Equivalent Time Lag for Energy Conversion

u_{thr} - Throttle Setting Input

hf - Road Elevation Measured by Front GPS

hr - Road Elevation Measured by Front GPS

ETB

u_m - Voltage of Motor

θ_s - Valve Plate Position Angle

ω_m - Rotor Angular Velocity

T_m - Torque Supply by Motor

T_i - Torque Contribute from Inertia Force

T_d - Torque Contribute from Damping Force

T_f - Torque Contribute from Friction Force

T_s - Torque Contribute from Spring Force

K_t - Motor Torque Constant

z - Current through the DC Motor Winding

J_{tot} - Total Inertia

B_{tot} - Total Damping

F_c - Positive Constant for Friction

J_m - Inertia of Rotor

J_{int} - Inertia of Intermediate Gear

J_o - Inertia off Output Shaft

J_{ps} - Inertia of Plate and Shaft

B_m - Viscous Damping Constant of Rotor

B_{int} - Viscous Damping Constant of Intermediate Gear

B_o - Viscous Damping Constant of Plate and Shaft

gt_1 - Tooth Number of Gear 1

gt_2 - Tooth Number of Gear 2

gt_3 - Tooth Number of gear 3

gt_4 - Tooth Number of Gear 4

L_m - Motor Inductance

R_m - Motor Resistance

K_{emf} - Motor Back Emf Constant

p_o - Relative Displacement Limit

K_r - Reset Integrator Gain

θ_{so} - Spring Default Position

θ_{smax} - Spring Maximum Position

θ_{smin} - Spring Minimum Position

D - Spring Offset

m_{s1} - Spring Gain

m_{s2} - Spring Limit Stop Gain

$n_{1/2}$ - Ratio Of Gear 3 To Gear 4

$n_{3/4}$ - Ratio Of Gear 1 To Gear 3

MRAC PID

G_m - Reference Model

G_p - Plant Model

u_d - Desired Speed

y_p - Output From the Simulation

y_m - Reference Output

e_m - Error between Real Result and Ideal Result.

$J(\theta)$ - Form Cost Function

Θ - Controller Parameter Representation

γ - Learning Rate

Repeatability analysis

σ - Standard Deviation

y_i - Output Result

$\bar{y}$ - Mean Value

n - Number of Repetitive Measurement

LIST OF ABBREVIATION

ACC	-	Adaptive Cruise Control
IC	-	Internal Combustion (Engine)
CI	-	Compression Ignition
SI	-	Spark Ignition
CVT	-	Continuously Variable Situation
ETB	-	Electronic Throttle Body
VLM	-	Vehicle Longitudinal Model
VLM-ETB	-	Vehicle Longitudinal Model-Electronic Throttle Body
PID	-	Proportional-Integral-Derivative
FG PID	-	Fixed Gain Proportional-Integral-Derivative
GS PID	-	Gain Scheduling Proportional-Integral-Derivative
MRAC PID	-	Model Reference Adaptive Control Proportional-Integral-Derivative
C-H-R	-	Chien, Hrones and Reswich
IFE	-	Incremental Fuzzy Expert PID Control
SSP	-	Fuzzy Self-Tuning of A Single Parameter
FGS	-	Fuzzy Gain Scheduling
FSW	-	Fuzzy Set-Point Weighting
GA	-	Genetic Algorithm
Kph	-	Kilometre Per Hour

ACC - Adaptive Cruise Control

AFS - Active Front Wheel Steer

GPS - Global Positioning System

HILS - Hardware-in-the-Loop Simulation

ECU - Electronic Control Unit

DC - Direct Current

V - Volt

RMS - Root Mean Square

DAQ - Data Acquisition

CV - Coefficient of Variance

RAM - Random Access Memory

MRAE - Mean Relative Absolute Error