



**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**

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in fulfillment of the requirement for the degree of Doctor of Philosophy**

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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 : .....

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Date : 21<sup>th</sup> 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

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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  $0^\circ$  to  $25^\circ$  with  $5^\circ$  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 Kenderaan 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  $0^\circ$  ke  $25^\circ$  dengan kenaikan sebanyak  $5^\circ$  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 penggerak baru untuk HILS.*

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## LIST OF SYMBOLS

### VLM

|            |   |   |
|------------|---|---|
| $m$        | - | Vehicle Mass  |
| $h$        | - | Centre of Gravity Height of the Vehicle                 |
| $\theta_g$ | - | 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                    |
| $\omega_i$ | - | 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                        |
| $\mu_i$    | - | 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                          |
| $\rho$      | - | 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                                    |
| $\eta_g$    | - | Current Gear Ratio                            |
| $\eta_f$    | - | Final Drive Ratio                             |
| $\mu_e$     | - | 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                      |
| $\theta_s$ | - | Valve Plate Position Angle            |
| $\omega_m$ | - | 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                         |
| $\theta_{so}$   | - | Spring Default Position                       |
| $\theta_{smax}$ | - | Spring Maximum Position                       |
| $\theta_{smin}$ | - | 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                          |
| $\theta$    | - | Controller Parameter Representation         |
| $\gamma$    | - | Learning Rate                               |

## Repeatability analysis

|           |   |                                  |
|-----------|---|----------------------------------|
| $\sigma$  | - | 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    |