# DEVELOPMENT OF FOUR WHEEL STEERING FOR VEHICLE HANDLING ENHANCEMENT

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**SUPERVISOR DECLARATION**

"I hereby declare that I have read this thesis and in my opinion this report in sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)."

Signature: ……………………………..

Supervisor: ……………………………..

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**LAI QILI**

**This report is submitted in partial fulfillment of the requirements for the award of a Bachelor of Mechanical Engineering (Automotive)**

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**DECLARATION**

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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Special thanks to my parents and my supervisor

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# ABSTRAK

kenderaan pacuan empat roda juga dikenali sebagai kenderaan pacuan semua roda yang digunakan untuk meningkatkan pengendalian stereng dan meningkatkan kestabilan kenderaan. Dalam projek ini, kesilapan kadar rewang dan kesilapan sudut slip sisi kenderaan 4WS yang dikaji. Apabila kenderaan 2WS menjalani selekoh tajam atau lorong berubah pada kelajuan tinggi, ia akan mempunyai kecenderungan untuk berlaku understeer dan oversteer. Dengan adaptasi sistem stereng empat roda, ia akan mengurangkan kesilapan kadar rewang dan sudut slip sisi kenderaan dan mengurangkan masalah oversteer dan understeer. Objektif projek ini adalah untuk membangunkan model dinamik kenderaan dan membangunkan strategi kawalan stereng aktif empat roda. Skop projek ini termasuk pembangunan model matematik dan Matlab/SIMULINK untuk mewakili kelakuan dinamik kenderaan dalam arah membujur, pengesahan model kenderaan disahkan dengan perisian dinamik dan pembangunan aktif kenderaan pacuan empat roda untuk penambahbaikan pengendalian kenderaan. Model basikal 2 DOF dibangunkan, pengesahan dilakukan ke atas model kenderaan dengan CarSim dengan dua ujian iaitu ujian perubahan lorong dan ujian stereng step. Pengawal PID dan pengawal logik fuzzy dibangunkan dalam model kenderaan, dan simulasi dilakukan untuk membuat perbandingan. Ia mendapati bahawa kedua-dua pengawal P dan pengawal logik fuzzy dapat mengurangkan kadar rewang dan sudut slip sisi kenderaan semasa membelok. Pengawal P melakukan lebih baik daripada pengawal logik fuzzy dalam mengawal input tunggal manakala pengawal logik kabur prestasinya lebih baik dari segi mengawal dua input pada masa yang sama. Hasil telah membuktikan keupayaannya untuk mengurangkan sudut slip sisi kenderaan dan kesilapan kadar rewang dan dengan itu mengurangkan kecenderungan untuk berlaku understeer dan oversteer.

# ABSTRACT

Four wheel steering is also known as all wheel which is used to improve handling and improve the vehicle stability. In this project, the yaw rate error and vehicle side slip angle error of a 4WS vehicle are been studied. When a 2WS vehicle undergoes sharp cornering or lane changing at high speed, it will have the tendency to occur understeer and oversteer. With adaption of four wheel steering system, it will reduce the yaw rate error and vehicle side slip angle error thus reducing the oversteer and understeer problems. The objectives of this project are to develop vehicle dynamics model and develop active four wheel steering control strategy. The scope of this project includes development of the mathematical model and Matlab/SIMULINK to represent dynamic behavior of the vehicle in longitudinal direction, validation of vehicle model with validated vehicle dynamics software and development of active four wheel steering for vehicle handling improvement. 2 DOF bicycle model was developed, validation was done on the vehicle model with CarSim with double lane change test and step steer test. PID controller and the fuzzy logic controller were developed in the vehicle model, and simulation was done to do comparison. It is found out that both P controller and fuzzy logical controller can able to reduce the yaw rate and the vehicle side slip angle of the vehicle during cornering. P controller performs better than fuzzy logic controller in term of controlling single input while fuzzy logic controller perform better in term of controlling two inputs at the same time. The developed has proven the its capability to reduce the vehicle side slip angle and yaw rate errors and hence reduced the tendency to understeer and oversteer.

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| $\omega$ | = | Angular Velocity of Wheel, $rad/s$ |
| $R_w$ | = | Tire Size, $m$ |
| $V_{wx}$ | = | Longitudinal Velocity of Wheel, $m/s$ |
| $\sigma$ | = | Total Slip |
| $\sigma_y$ | = | Lateral Slip |
| $\sigma_x$ | = | Longitudinal Slip |
| $F_z$ | = | Tire Normal Force, $N$ |
| $\sigma_m$ | = | Total Slip where sliding occurs in Fiala Tire Model |
| $\alpha$ | = | Tire Slip Angle, $rad$ |
| $\mu$ | = | Coefficient of Friction of Tire |
| $F_x$ | = | Longitudinal Tire Force, $N$ |
| $F_y$ | = | Lateral Tire Force, $N$ |
| $B$ | = | Stiffness Factor |
| $C$ | = | Shape Factor |
| $D$ | = | Peak Factor |
| $E$ | = | Curvature Factor |
| $S_h$ | = | Horizontal Shift, $m$ |
| $S_v$ | = | Vertical Shift, $m$ |
| $X$ | = | Slip Input Variable |
| $Y$ | = | Output Variable |
| $M_x$ | = | Overturning Moment, $Nm$ |
| $M_y$ | = | Rolling Resistance Moment, $Nm$ |
| $M_z$ | = | Aligning Moment, $Nm$ |

| | | |
|---|---|---|
| $C_{\alpha f}$ | = | Cornering Stiffness of Front Tire, $Ns/rad$ |
| $C_{\alpha r}$ | = | Cornering Stiffness of Rear Tire, $Ns/rad$ |
| $M_T$ | = | Total Mass of Car, $kg$ |
| $\dot{V}_x$ | = | Longitudinal Acceleration of Car, $m/s^2$ |
| $V_y$ | = | Lateral Velocity of Car, $m/s$ |
| $V_x$ | = | Longitudinal Velocity of Car, $m/s$ |
| $\dot{\psi}$ | = | Yaw Rate, $rad/s$ |
| $\delta_f$ | = | Front Steering Angle, $rad$ |
| $\delta_r$ | = | Rear Steering Angle, $rad$ |
| $F_{yr}$ | = | Lateral Force of Rear Tire, $N$ |
| $F_{yf}$ | = | Lateral Force of Front Tire, $N$ |
| $\dot{\psi}$ | = | Yaw Rate, $rad/s$ |
| $F_{xrl}$ | = | Longitudinal Force of Rear Left Tire, $N$ |
| $F_{xfr}$ | = | Longitudinal Force of Front Right Tire, $N$ |
| $F_{xfl}$ | = | Longitudinal Force of Front Left Tire, $N$ |
| $F_{xrr}$ | = | Longitudinal Force of Rear Right Tire, $N$ |
| $F_{yrl}$ | = | Lateral Force of Rear Left Tire, $N$ |
| $F_{yfr}$ | = | Lateral Force of Front Right Tire, $N$ |
| $F_{yrr}$ | = | Lateral Force of Rear Right Tire, $N$ |
| $F_{yfl}$ | = | Lateral Force of Front Left Tire, $N$ |
| $M_\psi$ | = | Moment of the Yaw Motion, $kgms^{-1}$ |
| $I_\psi$ | = | Inertia of Yaw Motion, $rad/s$ |
| $\ddot{\psi}$ | = | Yaw Acceleration, $rad/s^2$ |
| $w$ | = | Track Width of Car, $m$ |
| $\dot{V}_y$ | = | Lateral Acceleration of Car, $ms^{-2}$ |
| $L_r$ | = | Distance of Sprung Mass Centre of Gravity from the Rear Axle, $m$ |
| $L_f$ | = | Distance of Sprung Mass Centre of Gravity from the Front Axle, $m$ |

| | | |
|---|---|---|
| $\alpha_f$ | = | Slip Angle of Front Tire, $rad$ |
| $\alpha_r$ | = | Slip Angle of Rear Tire, $rad$ |
| $e_{\dot{\psi}}$ | = | Yaw Rate Error, $rad/s$ |
| $e_{\beta}$ | = | Vehicle Side Slip Angle Error, $rad$ |
| $K_p$ | = | Proportional Gain of PID controller |
| $K_i$ | = | Integral Gain of PID controller |
| $K_d$ | = | Derivative Gain of PID controller |
| $\dot{\psi}_{des}$ | = | Desired Yaw Rate, $rad/s$ |
| $\dot{\beta}_{des}$ | = | Desired Vehicle Side Slip Angle, $rad$ |

## LIST OF APPENDICES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| DOF | Degree of Freedom |
| 4WS | Four Wheel Steering |
| FYP | Final Year Project |
| LVDT | Linear Variable Differential Transformer |
| LTI | Linear Time Invariant |
| SISO | Single Input and Single Output |
| PID | Proportional Integral Derivative |
| 2WS | Two Wheel Steering |
| UTeM | Universiti Teknikal Malaysia Melaka |

# CHAPTER I

# INTRODUCTION

## 1.1 OVERVIEW

The demand of the improving the vehicle handling of vehicle, stability has been motivating the researcher to go deep in the research vehicle handling by development of driver assistance system such as active braking, active steering and active suspension. Among all of the vehicle subsystem, the steering system has the great effect on the vehicle handling. The four wheel steering as well as the steer by wire is the most recent research that most of the researcher involving in.

Four wheel steering is also known as all wheel steering which the rear wheel can be steered actively during turning maneuvers. The four wheel steering is different with the four wheel drive as in the four wheel drive all the wheels are powered while in the four wheels steering its function is to improve handling and helps the vehicle to make tighter turns. In 1907, a patent was made in Japan for a four wheel steering (4WS) system in which front and rear wheel steering mechanisms were connected by means of a shaft (Irie and Kuroki, 1990).

When comparing 4WS and 2WS, 4WS offers following advantages that are superior cornering stability, the steering responsiveness and precision improvement, rapid lane changing manoevers improvement and reducing the turning radius at low speed (Hiller and Coombes, 2004).

Active four wheel operate with the front wheel do the most of the steering whereby the turning of the rear wheel is limited to the half around 5 to 6 degree turning during the opposite direction turn (Knowles, 2002). When vehicle is in high speed and need to move sideways, both of the front and the rear wheels will turn in the same direction (Cao et al., 2010) which the wheels are called positive-phase steering, where a quick side movement can be made. When the vehicle speed is about 96 km/h and the steering wheel is turn at 100 °, the rear wheel will turn about 1 ° in the same direction of the front wheels yet if at this speed the steering wheel is turned 500 ° then the rear wheel will turn 1 ° opposite direction to the front wheels. When it is in low speed and need to turn a sharp turn, the rear wheels will turn in the opposite direction with about 5 °- 6 ° of the front wheels (Knowles, 2002). Figure 1.1 and Figure 1.2 shows that the configuration of the wheel of a four wheel steering when it is in high speed and when it is in low speed.

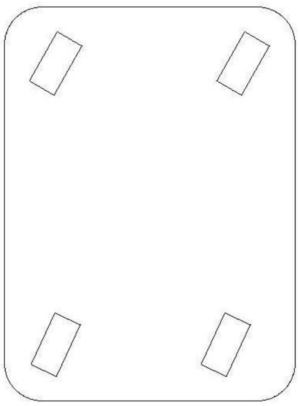

Figure 1.1: The configuration of the wheel during high speed turning

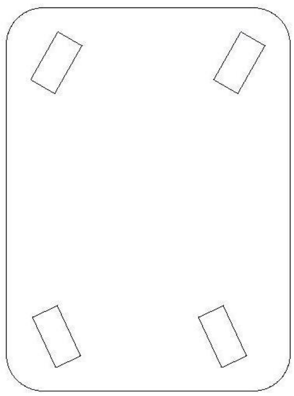

Figure 1.2: The configuration of wheel during low speed turning

## 1.2 PROBLEM STATEMENTS

When a two wheel steering vehicle undergoes sharp corner and lane change during high speed, the turning radius of steering perform less than supposed steering turning radius, this occur because of the slide forces that act on the vehicle pushing the front of the vehicle into the corner and rotates the vehicle to the corner due to the slip angle which will eventually lead to understeer. Another possibility will occur is that when the vehicle undergoes a sharp corner with high speed, the turning radius of the vehicle perform more than suppose steering turning radius whereby it is due to the unbalance occur because of the shifting of the centre of gravity which will lead to oversteer (O'Hara, 2005).

One of the methods to reduce the possibility for the vehicle to understeer and oversteer is by using active four wheel steering as proposed in this project. With the adaption of four wheel steering system, the turning radius could be reduced and the yaw rate error and vehicle side slip angle error will be reduced as well as increasing the grip of tire on the road since both of the tire is pointed in the same direction, with this it can prevent the unbalance occur due to the slide forces or shifting of the center of gravity which will lead to understeer and oversteer (Gilles, 2004).

## 1.3 OBJECTIVES

The objectives of this project are:

1. To develop vehicle dynamics model.
2. To develop active four wheel steering control strategy.

## 1.4 SCOPES

The scopes of this project are as follow:

1. Development of the mathematical model and Matlab/SIMULINK to represent dynamic behavior of the vehicle in longitudinal direction.
2. Validation of vehicle model with validated vehicle dynamics software.
3. Development of active four wheel steering for vehicle handling improvement.

## 1.5 THESIS OUTLINES

In Chapter I, overview of the project is done where the introduction of the 4WS vehicle and the operation of the 4WS vehicle are briefly explained in this chapter. The advantages and disadvantages of the 4WS vehicle as well as the operation of the 4WS during high speed or slow speed are also explained in this chapter. Objective, scope and problems statement are defined in this chapter.

In Chapter II, study on the literature review on the current research on journal paper was done. Information such as types of degree of freedom used in the vehicle modeling, type of controller used in the 4WS vehicle, simulation software that been used for simulation of the vehicle model, validation method for the vehicle model, type of test for the 4WS car, types of tire model that been used for the study for the 4WS car is covered in this chapter.

In Chapter III, the research method that used for this project is fully explained in this chapter. Development of 2 DOF bicycle model mathematical model, derivation of 2 DOF bicycle model, development of the Matlab/SIMULINK model and the validation process of the 2 DOF bicycle model with double lane change test and step steer test with 120 km/h as well as finding the parameters for the Matlab/SIMULINK in CarSim are covered in this chapter. The method of tuning for the both controller such as PID controller and fuzzy logic controller are also covered in this chapter.

In Chapter IV, the simulation is done for 2 DOF bicycle model using double lane change test and step steer test. The results in this chapter consist of effect of yaw