

VEHICLE HANDLING IMPROVEMENT USING STEER BY WIRE
TECHNOLOGY

“I hereby declare that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechanical Engineering (Automotive)”

YEW KHENG LOON

This report is submitted to the Faculty of Mechanical Engineering as a part of
supervision of proposed Bachelor of Mechanical Engineering (Automotive)

Signature

:



Supervisor's name

:

En. Ir. Mochamad Safarudin

Date

:

7-5-2009

VEHICLE HANDLING IMPROVEMENT USING STEER BY WIRE
TECHNOLOGY

YEW KHENG LOON

This report is submitted to the Faculty of Mechanical Engineering as a part of
stipulation of bestowal Bachelor of Mechanical Engineering (Automotive)

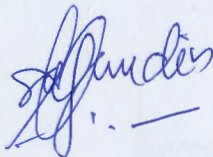
Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

MAY 2008

“I hereby declare that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechanical Engineering (Automotive)”

Signature

:



Supervisor's name

:

En. Ir. Mochamad Safarudin

Date

:

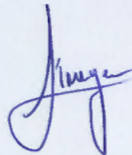
7-5-2009

"I hereby declared that this report is a result of my own work except for the excerpts that have been cited clearly in the references."

To my lovely family
To my supporting supervisor and friends

Signature

:



Name

:

YEW KHENG LOON

DATE

:

7/5/2009

To my lovely family
To my supporting supervisor and friends

ACKNOWLEDGEMENTS

This Projek Sarjana Muda has emerged out of a great deal of research and simulation about Steer-by-wire technology, and I am gratefully acknowledge the following contributors to this project. They have played a vital role in helping me solve obstacles and give me a more thought provoking ways to done this project.

Ir. Mochamad Safarudin, Lecturer of Automotive Department and also my supervisor, Universiti Teknikal Malaysia Melaka, have been a constant source of advice. He has generously shared with me his knowledge and continues to encourage me to work individually with his guidance.

I also acknowledge my fellow friends, Choong Kei Shing and Amrik Singh, that have provide me clarity and technical support. Their support has smoothened and enhanced my overall progress.

Finally I wish to thank my parents for their patience support throughout all my years in university. Their moral support provides me the energy to continue during difficult times.

ABSTRAK

Sistem pengemudian secara dawai membekalkan banyak kelebihannya dari segi kefungsiannya. Antaranya adalah penambahbaikan kelakuan dalam pemanduan kenderaan. Kajian ini menjelaskan penambahbaikan dalam pemanduan menggunakan pengemudian secara dawai. Dengan menggunakan model kenderaan satu belah yang berupa basikal sebagai analisis, kajian ini menunjukkan penambahbaikan dalam pemanduan kenderaan menggunakan pengemudian secara dawai. Di samping itu, satu sistem kawalan akan dibina supaya ciri-ciri pemanduan asas kenderaan dapat dikawal mengikut kehendak pemandu. Sistem kawalan ini berfungsi dengan menghadkan pengemudian pemandu semasa menghampiri had pemanduan. Sistem kawalan balas akan diaplikasikan ke dalam pengemudian secara dawai untuk penambahbaikan pemanduan kenderaan. Ciri-ciri pemanduan asas kenderaan akan dimodifikasi dengan mengawal ketegangan tayar hadapan kenderaan.

ABSTRACT

Steer by Wire systems provide many benefits in terms of functionality. Among them is improvement in vehicle handling behavior. This paper describes handling improvement using steer by wire. By using single track vehicle model, this paper shows the handling improvement of vehicle using steer by wire. In addition, a control system is also developed to alter the vehicle handling behavior. Feedback control system will be applied to the steer by wire to improve handling. Vehicle's fundamental handling characteristics are altered by changing front tire cornering stiffness.

TABLE OF CONTENT

CHAPTER	CONTENT	PAGE
	ACKNOWLEDGEMENTS	
	ABSTRAK	
	ABSTRACT	
	TABLE OF CONTENT	
	LIST OF TABLE	
	LIST OF FIGURE	
	LIST OF SYMBOL	
1	INTRODUCTION	1
	1.1 RESEARCH BACKGROUND	1
	1.2 PROBLEM STATEMENT	3
	1.3 OBJECTIVES	4
	1.4 SCOPE	4
2	LITERATURE REVIEW	5
	2.1 Single Track Vehicle Model	5
	2.2 The Fundamental Handling Characteristic: Understeer, Oversteer And Neutral Steer	8
	2.3 Tire Model	12
	2.3.1 Pacejka Tire Model	13
	2.3.1.1 Lateral Force, F_y	13
	2.3.1.2 Aligning Torque, M_z	14
	2.3.1.3 Braking Effort, F_x	14

2.4	Steer By Wire	15
2.4.1	Steering System Model	18
2.5	Virtual Reality	19
2.6	Steer-By-Wire Handling Improvement	19
2.6.1	Cornering Stiffness Handling Modification	19
2.6.2	Proportional Integral Derivative Controller	20
2.6.2.1	PID Tuning	23
3	METHODOLOGY	25
3.1	Flowchart	25
3.1.1	Literature Review	27
3.1.2	Mathematical Model of Single Track Vehicle Model and Tire Model	27
3.1.3	Development of Simulink Model for Tire Model and Single Track Vehicle Model	27
3.1.4	Parameters Assignments	28
3.1.5	Simulation of Models	29
3.1.6	Models Validation	29
3.1.7	Development of Simulink Model of Tire Model and Single Track Vehicle Model for Steer by Wire	30
3.1.8	Tire Cornering Stiffness Modification	31
3.1.9	Manoeuvre Simulation	31
3.1.10	Steer By Wire Handling Improvement Analysis	31
3.1.11	Virtual Reality Steer By Wire	32
3.1.12	Result And Discussion	35
3.2	Software Requirement	36
3.2.1	Matlab	36

	3.2.2	Simulink	36
	3.2.3	3ds Max 2008	37
4		RESULT AND DISCUSSION	38
	4.1	Single Track Vehicle Model	38
	4.2	Steering System Model	41
	4.3	Cornering Stiffness Modification	43
5		CONCLUSION AND RECOMMENDATION	47
	5.1	Conclusion	47
	5.2	Recommendation	48
		REFERENCE	50
		BIBLIOGRAPHY	51
		APPENDICES	52

LIST OF TABLE

NO	TABLE	PAGE
2.1	Values of coefficients a_1 to a_8 for a car tire (Source: E.Bakker, L. Nyborg, and H.B. Pacejka, (1987))	15
3.1	Single track vehicle parameters	28
3.2	Steering system parameters	30
4.1	Experimental car parameters	38

LIST OF FIGURE

NO	FIGURE	PAGE
1.1	Automotive applications for by-wire technology (Source: Motorola)	2
2.1	Single track vehicle mathematical model	6
2.2	Oversteer and understeer behaviour	11
2.3	Neutral steer ($\alpha_f = \alpha_r$)	11
2.4	Understeer ($\alpha_f > \alpha_r$)	11
2.5	Oversteer ($\alpha_f < \alpha_r$)	12
2.6	SAE tire axis terminology (Source: Gim G. and Choi Y., (Nov. 2001))	12
2.7	Characteristic of Magic Formula for fitting tire test data (Source: Pacejka, H.B and Besselink, I.J.M. (1997))	15
2.8	Conventional steering system	16
2.9	Steer-by-wire system	16
2.10	Steer-by-wire steering system model	18
2.11	Steering system model	19
2.12	Graph PV against time, for three values of Kp (Ki and Kd held constant)	22
2.13	Graph PV against time, for three values of Ki (Kp and Kd held constant)	22
2.14	Graph PV against time, for three values of Kd (Kp and Ki held constant)	23

3.1	Single track vehicle model	28
3.2	Double lane change according to ISO 3888	29
3.3	PID controller	31
3.4	Tire in exploded view	32
3.5	Rack and pinion resemble with tires and actuator	33
3.6	Steering assemble with actuator	33
3.7	Isometric view of simplify steer by wire	34
3.8	Interface simulink	34
3.9	VRsink block parameters	35
3.10	3ds Max 2008	37
4.1	Validation of vehicle model with double lane change test	38
4.2	Double lane change steering angle	39
4.3	Graph of yaw rate for double lane change validation	39
4.4	Validation of vehicle model with step steer test	40
4.5	Graph of yaw rate for step steer validation	40
4.6	Graph of desired steering input	41
4.7	Graph of actual steering input	42
4.8	Graph of steering input	42
4.9	Cornering stiffness modification model	43
4.10	Graph of yaw rate for cornering stiffness modification	44
4.11	Graph of lateral acceleration for cornering stiffness modification	45
4.12	Graph of sideslip angle for cornering stiffness modification	46

LIST OF SYMBOL

F	=	Force
F_{xf}	=	Force at x-axis for front tire
F_{yr}	=	Cornering force of rear tire
F_{yf}	=	Cornering force of front tire
a	=	Distance from front axle to center of gravity
b	=	Distance from rear axle to center of gravity
δ_f	=	Front steering angle
α_f	=	Front slip angle of tire
α_r	=	Rear slip angle of tire
α_{sat}	=	Saturated steering angle
ψ	=	Yaw angle
β	=	Sideslip angle
V	=	Velocity
V_x	=	Velocity at x-axis
V_y	=	Velocity at y-axis
V_{char}	=	Characteristic speed
V_{crit}	=	Critical speed
\dot{v}_x	=	Longitudinal acceleration
\dot{v}_y	=	Lateral acceleration
Ω_z	=	Yaw acceleration
$\dot{\Omega}_z$	=	Yaw rate
m	=	Mass
a	=	Acceleration
a_y	=	Lateral acceleration
M	=	Moment
Σ	=	Total

I_z	=	Inertia at z-axis
C_{α_f}	=	Front cornering stiffness
C_{α_r}	=	Rear cornering stiffness
\hat{C}_{α_f}	=	New front cornering stiffness
$\delta_f(t)$	=	Steer angle of the front wheel as a function of time
L	=	Wheel base
R	=	Turning radius
W	=	Weight
W_f	=	Front weight
W_r	=	Rear weight
g	=	Acceleration due to gravity
K_{us}	=	Coefficient of understeer gradient
B	=	Stiffness factor
C	=	Shape factor
D	=	Peak factor
E	=	Curvature factor
S_v	=	Vertical shifts
S_h	=	Horizontal shifts
η	=	Desired fractional change in original front cornering stiffness
δ_d	=	Desired steering angle
J_s	=	Moment of inertia of the steering system at road wheel
b_s	=	Damping of the steering system at the road wheel
r_s	=	Steering ratio
r_p	=	Torque magnification factor
K_m	=	Motor constant
I_m	=	Motor current
r_g	=	Motor efficiency
η	=	Gearhead ratio

CHAPTER 1

INTRODUCTION

1.1 Research Background

The design of automotive steering system has not changed much since the invention of steering wheel. Conventional automotive steering system mechanism is which the driver's rotates the steering wheel according to driver's input and the steering input will be transmitted through a shaft to the rack and pinion to generate steering motion at the front wheels. Hydraulic power steering assist is introduced first in the 1950s to improve steering performance. This type of power assist unit uses hydraulic pressure supplied by a motor-driven pump to amplify driver steering torque. The technical advantage of power assist unit is to ease driver steering effort and provide more safety factor by allowing the driver to swerve or change direction easily to avoid an accident.

Power assist unit technologies in recent years have introduced electric power steering to replace the existing hydraulic power steering assist. Electric power steering is more efficient than conventional power steering because the electric power steering motor only provide assist when the steering wheel is turned, while the hydraulic pump must run constantly. In addition, electric power steering eliminates the usage of hydraulic power steering fluid which posed environmental hazard if leaked or disposed incorrectly.

According to Brian Daugherty, Douglas Cesieli and Michael C. Gaunt (2006), Steer-by-wire steering system is the same with the conventional automotive steering system except the mechanical linkages between the steering wheel and the front wheels are removed. The mechanical linkages are replaced with electronic sensors, controllers and actuators. By having more redundancy more sensors, controllers and actuators, the steer-by-wire can sustain higher fault-tolerant. However, by having more electronic component attach in the car, steer-by-wire suffer serious drawback of electrical power consumption. The present power supply commonly used in automotive is 12V, while all by-wire technologies needed 42V to operate at optimum performance.

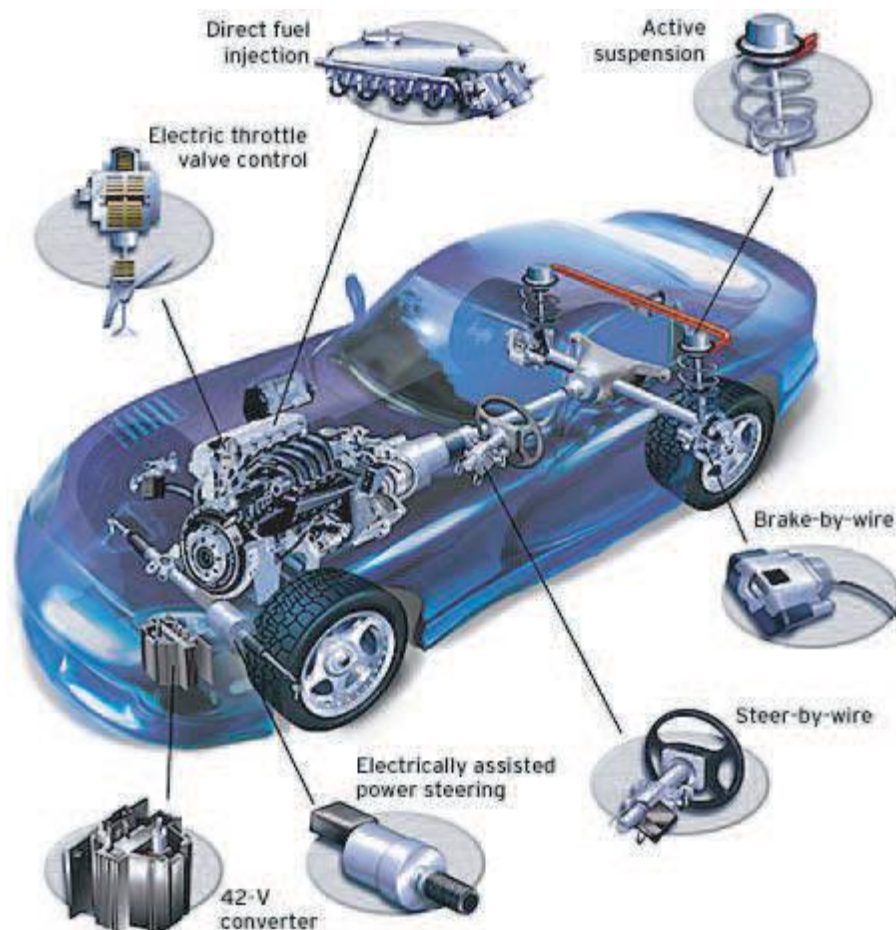


Figure 1.1 : Automotive applications for by-wire technology. (Source: Motorola)

Steer-by-wire offer many advantages, first of all by eliminating the connecting shaft, the risk of the steering column entering the cockpit is decrease in the event of a frontal crash. Furthermore the absence of a steering column simplifies

the design of car interiors. The steering wheel can be assembled easily into the dashboard for either left-hand or right-hand drive without the need of considering the steering column restriction. In addition, engine compartment will have more space utilization and able to design a bigger engine. Moreover, by removing the mechanical linkage, noise, vibration and harshness from the road will no longer be felt directly by the driver thru the steering wheel.

Another advantage is the variable steering ratio of the steer-by-wire system optimizes the steering response and driver steering wheel feel. In city driving, this ratio should be smaller in order to reduce the hand wheel torque and rotation. Finally, by removing steering column of the vehicle, it significantly decreases the weight of the vehicle and thus reduces fuel consumption. In 2004, BMW 5-Series have manufactured an almost steer-by-wire vehicle. The car has equipped with active steering system and demonstrates handling improvements that a steer-by-wire can achieved.

1.2 Problem Statement

In conventional vehicles, steering angle is the only input from driver that is directly influences the vehicles handling behavior. Conventional steering system utilizes mechanical linkage and the popular rack and pinion for translating the steering angle to the desired vehicle direction. The mechanical linkage will serve as a dangerous component that will thrust into the driver compartment when a front collision happens. Steer-by-wire system removes this mechanical linkage while providing many extra benefits the conventional steering system unable to.

1.3 Objectives

The objectives of this paper are to build a steer-by-wire mathematical model, to build a Simulink model, to apply control strategies to improve handling and to simulate vehicle handling improvement using the control strategies.

1.4 Scope

The scope of this paper are to design a steer-by-wire model for vehicle handling improvement, to develop steer by wire model, built Simulink model, apply control strategy and perform simulation of steer-by-wire equipped with feedback control.

CHAPTER 2

LITERATURE REVIEW

2.1 Single Track Vehicle Model

A vehicle's handling dynamics in the horizontal plane are represented here by the single track vehicle model or bicycle model where left and right wheels can be forces are considered in aggregate and as one wheel in the middle of the vehicle. Due to the two wheels is combined into one wheel, no roll motion along the car's longitudinal axis is considered. Furthermore, there is no suspension kinematics included in the front and rear suspension which consist of linear spring/damper units that connect the unsprung masses, wheels, with the sprung mass, body. The single track vehicle model also known as the bicycle model.

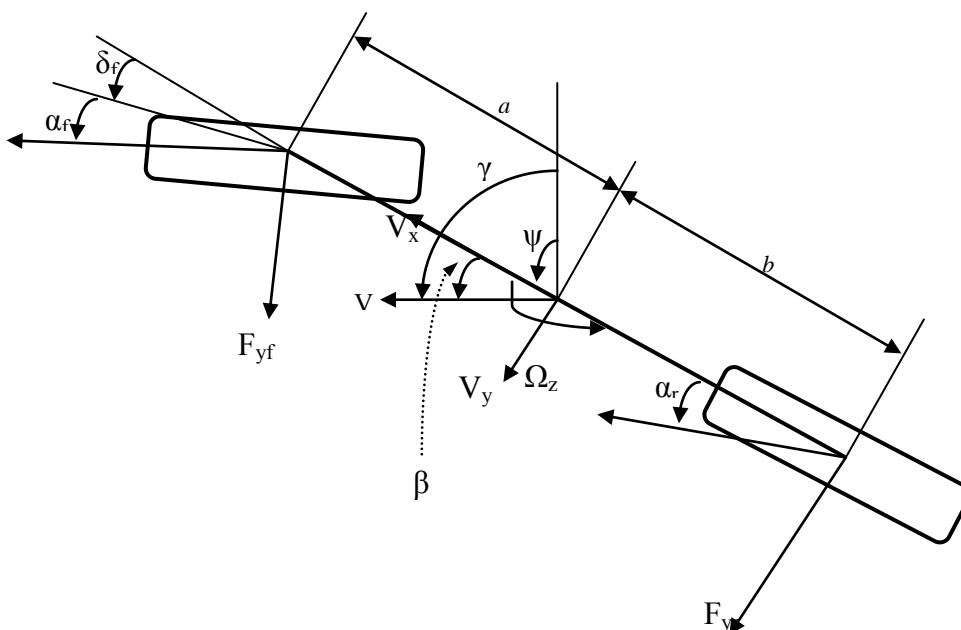


Figure 2.1: Single track vehicle mathematical model

Derivation of the equations of motion for the bicycle model follows from the force and moment balance:

$$\Sigma F = ma$$

$$F_{yf} \cos \delta_f + F_{yr} = ma_y$$

Taking counter clockwise direction as positive

$$\Sigma M = I_z \dot{\Omega}_z$$

$$aF_{yf} \cos \delta - bF_{yr} = I_z \dot{\Omega}_z$$

The total cornering stiffness of the front and rear tires:

$$F_{yf} = -C_{\alpha_f} \alpha_f$$

$$F_{yr} = -C_{\alpha_r} \alpha_r$$

Taking small angle approximations, slip angle can be written as;

$$\alpha_f = \frac{a\Omega_z + V_y}{V_x} - \delta_f$$

$$\alpha_r = \frac{-b\Omega_z + V_y}{V_x}$$

The equation with respect to the axes fixed to the vehicle body are given by,

$$m(\dot{v}_x - V_y \Omega_z) = F_{xf} \cos \delta_f + F_{xr} - F_{yf} \sin \delta_f$$

$$m(\dot{v}_y - V_x \Omega_z) = F_{yr} + F_{yf} \cos \delta_f + F_{xf} \sin \delta_f$$

$$I_z \dot{\Omega}_z = aF_{yf} \cos \delta_f - bF_{yr} + aF_{xf} \sin \delta_f$$

Assuming the steer angle is small and constant longitudinal velocity $V_x = V$, the equation of lateral and yaw motions of a vehicle with steer angle as input,

$$a_y = \left(\frac{-C_{\alpha_f} - C_{\alpha_r}}{mV} \right) V_y + \left(-V + \frac{bC_{\alpha_r} - aC_{\alpha_f}}{mV^2} \right) r + \left(\frac{C_{\alpha_f}}{m} \right) \delta_f$$

$$\dot{\Omega}_z = \left(\frac{bC_{\alpha_r} - aC_{\alpha_f}}{I_z V} \right) V_y + \left(\frac{-b^2 C_{\alpha_r} - a^2 C_{\alpha_f}}{I_z V} \right) r + \left(\frac{aC_{\alpha_f}}{I_z} \right) \delta_f$$

$$\beta = \arctan\left(\frac{V_y}{V}\right)$$

2.2 The Fundamental Handling Characteristics: Understeer, Oversteer, And Neutral Steer

The bicycle model is useful for describing a vehicle's fundamental handling characteristics. One way to approach an explanation of handling characteristics using the bicycle model is to define a term known as the understeer gradient. The prime factors controlling the steady state handling characteristic of a vehicle are the weight distribution of the vehicle and the cornering stiffness of the tires.

$$\delta_f - \alpha_f + \alpha_r = L/R$$

$$\delta_f = \alpha_f - \alpha_r + L/R$$

The cornering force on the front and rear tires F_{yf} and F_{yr} can be determined from the dynamic equilibrium of the vehicle in the lateral direction. For small angles, the cornering forces acting at the front and rear tires are approximately given by

$$\begin{aligned} F_{yf} &= \frac{W_f \cdot V^2 \cdot b}{g \cdot R \cdot L} \\ &= \frac{2W_f \cdot V^2}{g \cdot R} \end{aligned}$$

$$\begin{aligned} F_{yr} &= \frac{W_r \cdot V^2 \cdot a}{g \cdot R \cdot L} \\ &= \frac{2W_r \cdot V^2}{g \cdot R} \end{aligned}$$

$$\begin{aligned} \alpha_f &= \frac{F_{yf}}{2C_{\alpha_f}} \\ &= \frac{W_f \cdot V^2}{C_{\alpha_f} \cdot g \cdot R} \end{aligned}$$