"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

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

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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."

Signature :

Name : YEW KHENG LOON

DATE : 7/5/2009

To my lovely family

To my supporting supervisor and friends

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ABSTRAK

Sistem pengemudian secara dawai membekalkan banyak kelebihannya dari segi kefungsian. Antaranya adalah penambahbaikan kelakuan dalam pemanduan kenderaan. Kajian ini menjelaskan penambahbaikan dalam pemanduan menggunakan pengemudian secara dawai. Dengan menggunalan 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 diapilikasi 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.

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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
$\hat{C}_{\alpha_f}$	=	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 factional 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 Cesiel 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.

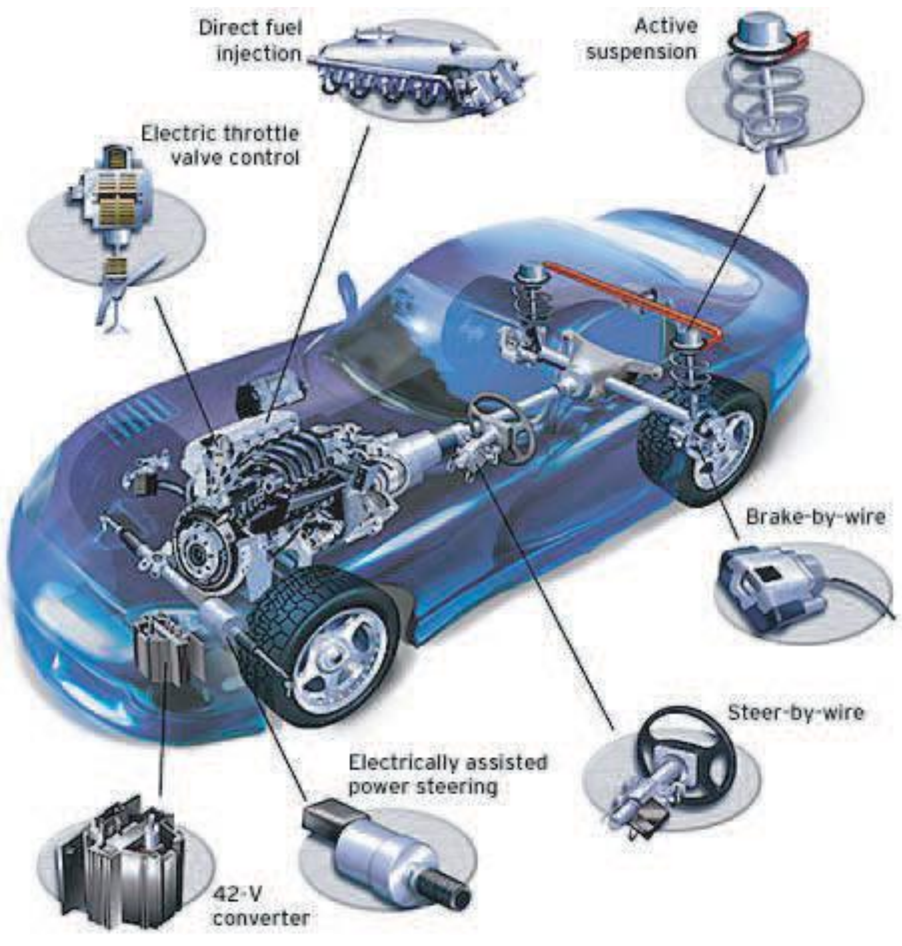

Figure 1.1 : Automotive applications for by-wire technology. (Source: Motorola)

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.

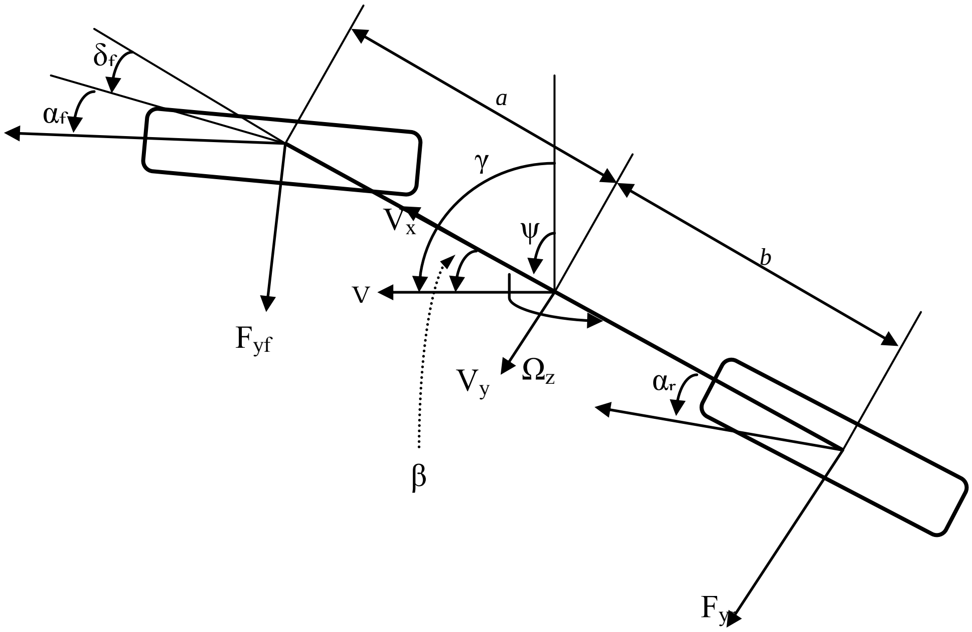

Figure 2.1: Single track vehicle mathematical model

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,

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

$$\dot{\Omega}_z = \left(\frac{bC_{\alpha r} - aC_{\alpha f}}{I_zV}\right)V_y + \left(\frac{-b^2C_{\alpha r} - a^2C_{\alpha f}}{I_zV}\right)\mathrm{r} + \left(\frac{aC_{\alpha f}}{I_z}\right)\delta_f$$

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

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

$$F_{yf} = \frac{W.V^2.b}{g.R.L}$$

$$= \frac{2W_f.V^2}{g.R}$$

$$F_{yr} = \frac{W.V^2.a}{g.R.L}$$

$$= \frac{2W_f.V^2}{g.R}$$

$$\alpha_f = \frac{F_{yf}}{2C_{\alpha_f}}$$

$$= \frac{W_f.V^2}{C_{\alpha f}g.R}$$