UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE DEVELOPMENT OF ACTIVE FRONT WHEEL STEERING SYSTEM

MOHD HAFIDZ B ZAKARIA

MSc. IN MECHANICAL ENGINEERING

2014

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

DECLARATION

I declare that this thesis entitled, *"The development of active front wheel steering system"* 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 for any degree.

Signature	: ………………………………………….
Name	: Mohd Hafidz b Zakaria
Date	: ………………………………………….

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 Master of Science in Mechanical Engineering.

Signature	: ………………………………….
Supervisor Name	: Engr. Dr. Noreffendy b Tamaldin
Date	: ………………………………….

DEDICATION

Dedicated to my beloved parents, wife, brothers and sisters.

ABSTRACT

This study deals with the use of Active Front Wheel Steering (AFWS) system in reducing the unwanted yaw motion cause by the side wind disturbance. The core of this study is the development of a control structure for AFWS system in a nine degree of freedoms full vehicle model, which consists of handling, ride and tyre model as to study the vehicle dynamic behavior in lateral axis. Validation with the CarSimEd software was conducted to identify the behaviour of the full car model when the steering input is given. Through a double lane change test, the results show that the developed full vehicle model and CarSimEd data are having a good agreement with acceptable error. Then, the control structure for the Active Front Wheel Steering system then developed on the validated full vehicle model to reduce the unwanted yaw motions after the side wind force is applied to the body of the vehicle. The proposed control structure for the AFWS system consists of two control loops, which named as the inner loop and outer loop controller. It consists of a serial feedback control which is operated based on the response of vehicle lateral position and yaw rate. Lastly, the controller is tested on the Hardware-in-the-loop simulation (HiLS) which will examine the effectiveness of the whole AFWS system. A collaboration between software and hardware in HiLS shows that the system can reduce the effect of the side wind disturbance in terms of lateral displacement error, body slip angle, yaw and yaw rate responses.

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ABSTRAK

Kajian ini adalah berkenaan dengan penggunaan sistem Steering Tayar Hadapan Aktif (AFWS) yang bertujuan menghapuskan kesan olengan yang disebabkan oleh gangguan angin lintang. Asas kajian ini adalah dengan membangunkan satu sistem kawalan bagi AFWS di dalam model penuh kenderaan, yang terdiri daripada model pengendalian, tunggangan dan tayar untuk mengkaji tindak balas kenderaan pada arah sisi. Model disahkan dengan perisian CarSimEd untuk mengenal pasti tindak balas model tersebut terhadap input daripada pemandu. Melalui ujian memotong di barisan berkembar, keputusan telah menunjukkan bahawa model kenderaan yang dibangunkan mempunyai hasil yang hampir sama dengan data dari perisian CarSimEd dan ralat yang berlaku boleh diabaikan. Kemudian, struktur kawalan untuk sistem AFWS telah dibangunkan pada model kenderaan yang telah disahkan tadi. Ia bertujuan untuk mengurangkan kesan olengan yang tidak diingini selepas angin lintang dikenakan pada sisi badan kenderaan. Struktur kawalan yang dicadangkan untuk sistem AFWS terdiri daripada dua pusingan kawalan yang dinamakan sebagai gegelung dalaman dan gegelung luaran. Kedua-dua gegelung tersebut berfungsi berdasarkan maklumat daripada kedudukan kenderaan pada arah sisi dan kadar olengan kenderaan. Akhir sekali, struktur kawalan tersebut diuji pada simulasi yang bersambung antara perisian dan perkakasan untuk meneliti keberkesanan sistem AFWS secara keseluruhan. Kerjasama antara perisian dan perkakasan dalam simulasi tersebut telah menunjukkan bahawa sistem AFWS boleh mengurangkan kesan gangguan angin lintang dan ia dapat dilihat berdasarkan hasil kajian yang telah diperolehi.

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TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

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LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

3D	-	Three-dimensional
ABS	-	Antilock braking system
AFWS	-	Active front wheel steering system
DAQ	-	Data acquisition
DC	-	Direct current
DoF	-	Degree of freedom
EPS	-	Electronic power steering
HiLS	-	Hardware-in-the-loop simulation
SIMO	-	Single input multiple output
PCI	-	Peripheral component interconnect
PID	-	Proportional, integral, and derivative
SISO	-	Single input single output
F_w	-	Side wind force
L_w	-	Distance side wind force to body centre of gravity
a	-	Distance between front of vehicle and *C.G.* of sprung mass
b	-	Distance between rear of vehicle and C.G. of sprung mass

t	-	Track width
δ_f	-	Front tyre angle from horizontal axis
a_x	-	Longitudinal acceleration
a_y	-	Lateral acceleration
β	-	Side slip angle
v_x	-	Lateral velocity
v_y	-	Longitudinal velocity
r	-	Yaw motion
G	-	Body centre of gravity
F_{xfl}	-	Longitudinal force for front left corner
F_{xfr}	-	Longitudinal force for front right corner
F_{xrl}	-	Longitudinal force for rear left corner
F_{xrr}	-	Longitudinal force for rear right corner
F_{yfl}	-	Lateral force for front left corner
F_{yfr}	-	Lateral force for front right corner
F_{yrl}	-	Lateral force for rear left corner
F_{yrr}	-	Lateral force for rear right corner
F_z	-	Vertical force
α_{fl}	-	Tyre slip angle for front left tyre
α_{fr}	-	Tyre slip angle for front right tyre
α_{rl}	-	Tyre slip angle for rear left tyre
α_{rr}	-	Tyre slip angle for rear right tyre

s	-	Tyre slip rates
$\ddot{\phi}$	-	Roll motion
$\ddot{\theta}$	-	Pitch motion
g	-	Gravitational acceleration
k_{φ}	-	Stiffness constant for roll
β_{φ}	-	Damping constant for roll
k_{θ}	-	Stiffness constant for pitch
β_{θ}	-	Damping constant for pitch
I_x	-	Moments of inertia of the sprung mass around *x*-axes
I_y	-	Moments of inertia of the sprung mass around *y*-axes
C_1, C_2, C_3 and C_4	-	Specific tyre constant parameters
σ	-	Composite slip
ap	-	Tyre contact patch
T_w	-	Tread width
T_p	-	Tyre pressure
F_{ZT} and K_{α}	-	Tyre contact patch constants
K_s	-	Lateral stiffness
K_c	-	Longitudinal coefficients
A_0, A_1, A_2 and CS/FZ	-	Stiffness constants
v	-	Nominal coefficient of friction
Γ	-	Tyre camber angle
K_{μ}	-	Coefficient of friction

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LIST OF PUBLICATIONS

JOURNAL

Hudha, K., Zakaria, M.H. and Tamaldin, N. (2011). Hardware in the loop simulation of active front wheel steering control for yaw disturbance rejection. *International Journal of Vehicle Safety 2011 - Vol. 5, No.4 pp. 356 – 373*

PROCEEDING

Zakaria, M.H. and Hudha, K. (2010). Yaw disturbance rejection control using active front wheel steering system. *Proceeding of International Conference on Sustainable Mobility (ICSM 2010)* Nov, 29 – Dec, 3 2010 at Kuala Lumpur, Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Preface

Vehicle stability is a never-ending issue in automotive research since the development in technology creates potential for another advance stability system to be explored. Another factor contributes to the improvement of the system is the needs for a better ride and handling characteristic; from a simple to a complex system which has the ability to control multiple subsystems simultaneously referred to the steering system, braking system and suspension system. These are the major systems in a vehicle that highly influences to the level of stability other than tyre effect and road profile. The systems are designed to enhance the stability and able to reduce the effect of the external distraction such as sudden braking, road irregularity and side wind gust.

Recently, electronic stability control takes action through integration of braking system and throttle input. The combination is quite successful in terms of reducing lateral motion of a vehicle during a high speed cornering and also when the car is on a slippery road. However, there is another potential subsystem that can provide other advantages for the purpose of increasing the vehicle stability namely steering assist system. There are few reasons why steering assist system is needed besides the current stability control system such as direct yaw moment control which control braking system individually on each tyre. Ackerman et al. (1999) had compared the contribution from steering and braking to yaw moment and he stated that only one-fourth of the longitudinal tyre force produced from braking is developed from tyre to achieve the same amount of the yaw moment. For disturbance such as side wind force, the braking assist system is unable to reject and leave it to the steering system to overcome the disturbance and maintain the original direction of travel.

1.2 Problem Statement

The main problem in the current driver assistance technology is the lack of a system that is able to encounter the effect from side wind gust. The lacking of the system will result to the uncomfortable handling characteristic where the driver has to encounter manually the yaw motion caused by the disturbance to make the vehicle stay on the original direction. The major distraction for the driver is when a massive speed of side wind burst and the tyre starts to skid, which will cause to an accident.

Besides, there are other examples that will result to the same unwanted yaw motion such as slippery road and emergency braking. This critical situation needs a quick response from the driver. The driver need to counteract the steering wheel in order to compensate the immediate disturbance torque. Since the disturbance is suddenly occurred, there is always a tendency for the driver to overreact or may take a second of reaction time that may lead to worst situation (Ackermann, 1997).

Another question is whether the reaction is right or not. This is all about the driver's experience. We cannot assume that all the drivers have the same experience like as a professional racing driver who is already trained to handle the critical situation and should have no problem to encounter any tyre skidding that might occur while manoeuvring a vehicle. So this is why the active steering control is needed to perform the steering correction in order to reduce the unwanted effect from the critical situation.