THE VIRTUAL FORCE FEEDBACK FOR TORQUE ESTIMATION AND CONTROL IN A VEHICLE STEER BY WIRE (SBW) SYSTEM

SHEIKH MUHAMMAD HAFIZ FAHAMI BIN ZAINAL

UNIVERSITI TEKNOLOGI MALAYSIA

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SHEIKH MUHAMMAD HAFIZ FAHAMI BIN ZAINAL

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To my family, especially for my parents Sharifah Faridunishah binti Abdul Kadir and Zainal bin Jusan for the supporting and encouragement to complete this thesis.

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ABSTRACT

This study presents the method to generates and control a force feedback with torque control for a driver steering feel in a vehicle steer by wire (SBW) system. The control algorithm of force feedback was developed by simulation and validated through experimental to investigated the steering and control performance. This is done by constructed a steering wheel rig hardware in the loop (HIL) and interfaced to Matlab XPC target software. Two method are proposed to generate and control a force feedback whereby the current measurement is a main element used to estimates the steering torque . For the first control algorithm, the torque at the front axle system and self aligning are used to generate a force feedback and the PID controller with fuzzy system (PID+Fuzzy) are used to control a feedback torque. Meanwhile, the reference model was used to improves the centering steering wheel position. For a second control algorithm, the torque map and torque of steering wheel and front axle system are used to generate the force feedback. Meanwhile, the LQR control with gain scheduling (LQR+GS) are used to control the torque. Furthermore, the compensation torque is used to improves the steering feel and to stabilize the system by varying a compensation gains. The results demonstrate shown, that the torque control using a LQR+GS method is improves against a torque map and 90% similar to Electric Power Steering (EPS) system. This is because there are multiple gains varying that able to improve a steering control performance. On the others hand, the hyperbolic tangent and linear equation proposed improves a vehicle maneuverability at low and high speed.

ABSTRAK

Kajian ini mencadangkan kaedah untuk menjana dan mengawal maklum balas tork untuk kawalan tork stereng pemandu dalam mengemudi kenderaan melalui wayar (SBW) sistem. Sebuah algoritma kawalan maklum balas daya dibangunkan melalui simulasi dan disahkan untuk disiasat stereng dan kawalan prestasi oleh stereng ujian pelantar - perkakasan dalam gelung (HIL) menggunakan Matlab XPC perisian sasaran. Dua kaedah yang dicadangkan untuk menjana dan mengawal maklum balas kuasa di mana kaedah ukuran semasa digunakan untuk anggaran tork yang bersesuaian. Untuk algoritma kawalan pertama, tork pada sistem gandar dan tork depan antara tayar dan permukaan jalan digunakan untuk menjana maklum balas tork dan kawalan PID dengan sistem Fuzzy (PID + Fuzzy) digunakan untuk mengawal maklum balas tork tersebut. Selain itu, model rujukan digunakan untuk meningkatkan kedudukan stereng berpusat dengan mengubah pekali kemudi stereng. Untuk algoritma kawalan kedua, peta tork dan tork stereng dan sistem gandar depan digunakan untuk menjana maklum balas tork. Manakala, kawalan LQR dengan keuntungan penjadualan (LQR+GS) digunakan untuk mengawal maklum balas tork. Tambahan pula, tork pampasan digunakan untuk meningkatkan rasa kemudi stereng dan untuk menstabilkan sistem dengan mengubah pekali kawalan. Perbandingan keputusan simulasi dan eksperimen menunjukkan peningkatan maklum balas tork dan kawalan menggunakan kaedah (LQR+GS terhadap peta tork dan 90 % dan menghampiri prestasi Electric Power Steering (EPS) sistem. Selain daripada itu, tangen hiperbolik dan persamaan linear yang dicadangkan memperbaiki cara pemanduan kenderaan pada kelajuan rendah dan tinggi.

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LIST OF ABBREVIATIONS

PID	–	Proportional - Integral - Derivative
PI	–	Proportional - Integral
PD	–	Proportional - Derivative
SMC	–	Sliding Mode Controller
SMLC	–	Sliding Mode Learning Controller
ADRC	–	Active Disturbance Rejection Control
ECU	–	Electronic Controller Unit
EPS	–	Electric Power Steering
LQR	–	Linear Quadratic Regulator
VSR	–	Variable Steering Ratio
SBW	–	Steer by Wire
PC	–	Personal Computer
RMS	–	Root Mean Square
DC	–	Direct Current
PCI	–	Peripheral Component Interconnect
XPC	–	Action Replay Saved Code
KF	–	Kalman Filter
HIL	–	Hardware in the Loop
VS	–	Very Soft
MS	–	Medium Soft
SF	–	Stiff
C.O.G	–	Center of Gravity
ABS	–	Anti lock Braking System
ESC	–	Electronic Stability Control
HPAS	–	Hydraulic Power Assist Steering
DOF	–	Degree of Freedom
CAD	–	Computational Aided Design
AFS	–	Active Front Steering

CNF	–	Composite Nonlinear Feedback
GPS	–	Global Position System
GPI	–	General Proportional Integral
ESO	–	Extended State Observer
NLF	–	Nonlinear Feedback
TD	–	Tracking Differentiator
ODE	–	Ordinary Differential Equations
	–	

LIST OF SYMBOLS

δ_f	–	Front Tire Angle
δ_{sw}	–	Steering Wheel Angle
δ_{m1}	–	Steering Wheel Motor Angle
δ_{m2}	–	Front Axle Motor Angle
β	–	Vehicle Body Slip Angle
r	–	Yaw Rate
b_{m1}	–	Steering wheel motor damping
J_{m1}	–	Motor inertia of steering wheel motor
k_{sm}	–	Steering Wheel motor constant
$k_{s1,s2}$	–	Lumped torque sensor stiffness
i_{a1}	–	Current steering Wheel motor
δ_{m1}	–	Angular displacement Steering Motor
V_{s1}	–	Voltage Steering wheel Motor
R_1	–	Resistance Steering wheel Motor
L_1	–	Inductance Steering wheel Motor
R_2	–	Resistance Front axle motor
L_2	–	Inductance Front axle motor
b_{m2}	–	Front axle motor damping
J_{m2}	–	Motor inertia Front axle motor
k_{fm}	–	Front axle motor constant
i_{a2}	–	Current Front axle motor
δ_{m2}	–	Angular displacement Front axle motor
V_{s2}	–	Voltage Front axle Motor
M_{rackf}	–	Rack Lumped Mass
y_{rack}	–	Rack lateral displacement
k_{lf}	–	Tie rod compliance
B_{rackf}	–	Rack damping coefficient
r_p	–	Pinion Gear radius

r_L	–	Offset king ping axis
B_{kpf}	–	King ping damping coefficient
I_f	–	Lumped front wheel inertia
I_s	–	Vehicle Moment Inertia
C_f	–	Front Cornering Stiffness
C_r	–	Rear Cornering Stiffness
L_f	–	Length front center tire to C.O.G Vehicle
L_r	–	Length rear center tire to C.O.G Vehicle(m)
F_{yf}	–	Front Tire Lateral Force
F_{yr}	–	Rear Tire Lateral Force
α_f	–	Front Tire Slip Angle
α_r	–	Rear Tire Slip Angle
m	–	Mass of vehicle
δ_{swnew}	–	New target Steering Wheel Angle
F_{yf}	–	Vehicle Lateral Force
α_f	–	Front Tire Slip Angle
t_p	–	Pneumatic trail
t_m	–	Mechanical trail
β	–	Vehicle Body Slip Angle
r	–	Yaw Rate
τ_a	–	Self Aligning Torque
V	–	Vehicle Speed
k_{lne}	–	Adjustable gain ratio
k_s	–	Steering Stiffness
C_s	–	Steering viscous coefficient
I_s	–	Steering moment inertia
$N5$	–	Negative Very Large
$N4$	–	Negative Large
$N3$	–	Negative Very Medium
$N2$	–	Negative Medium
$N1$	–	Negative Normal
S	–	Small
$P1$	–	Positive Normal
$P2$	–	Positive Medium
$P3$	–	Positive Very Medium

$P4$	–	Positive Large
$P4$	–	Positive Large
$P5$	–	Positive Very Large
VS	–	Very Soft
MS	–	Medium Soft
SF	–	Very Stiff
$\tau_{totalfeedback}$	–	total feedback torque
δ_{shaft}	–	Column Shaft Angle
V_{s3}	–	Voltage Assist Motor - Electric Power Steering
R_3	–	Resistance Assist Motor - Electric Power Steering
L_3	–	Inductance Assist Motor - Electric Power Steering
I_{m3}	–	Steering Wheel Inertia - Electric Power Steering
δ_{m3}	–	Assist Motor Angle - Electric Power Steering
K_{eps}	–	Lumped torque stiffness - Electric Power Steering
K_{b3}	–	Assist motor constant - Electric Power Steering
B_{shaft}	–	Steering shaft damping coefficient - Electric Power Steering
K_{shaft}	–	Steering shaft stiffness - Electric Power Steering
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CHAPTER 1

INTRODUCTION

1.1 The overview of Steer by Wire (SBW) system

Since the last decade, the aspects of automotive engineering safety features such as vehicle traction control, anti-lock braking (ABS) system, and electronic stability control (ESC) have been used by implementing the benefit of using electronic control system. The advantages of applying the electronic technology have been proven to enhance the vehicle dynamic performance and safety [1–8]. However, despite these major advancements, the implementation of electronic control in the steering system is quite rare. The Hydraulic Power Assisted Steering (HPAS) system was first introduced in 1950 followed by Electric Power Steering (EPS) system that has become a standard parts in a modern steering system. The EPS has eliminated the needs of valves, hoses and pump which allows a simpler packaging [9–11] and leads to a more reliable system [12–16]. Moreover, since the torque assist is used only when required, the reduced driver steering effort feature does not significantly degrade the fuel efficiency [17, 18].

The next generation of advanced steering system is the steer by wire (SBW) system [19, 20] as shown in Figure.1.1. The SBW system allows the elimination of mechanical column shaft through the installation of several sensors and actuators [21–28] controlled by the Electronic Controller Unit (ECU) to improve the vehicle maneuverability and stability [29–33]. Through the ability to eliminate the mechanical column shaft completely, an SBW system offers simplifications of the interior car design [34–38] and allows better compartments design with better ergonomics and comfort [39, 40]. The elimination of mechanical column shaft also reduces noise, vibration and the risk of impact force to the driver in a frontal accident [41, 42]. Furthermore, the steering wheel can be modularly and easily located for either right or left hand drivers, as it allows better space utilization especially for engine

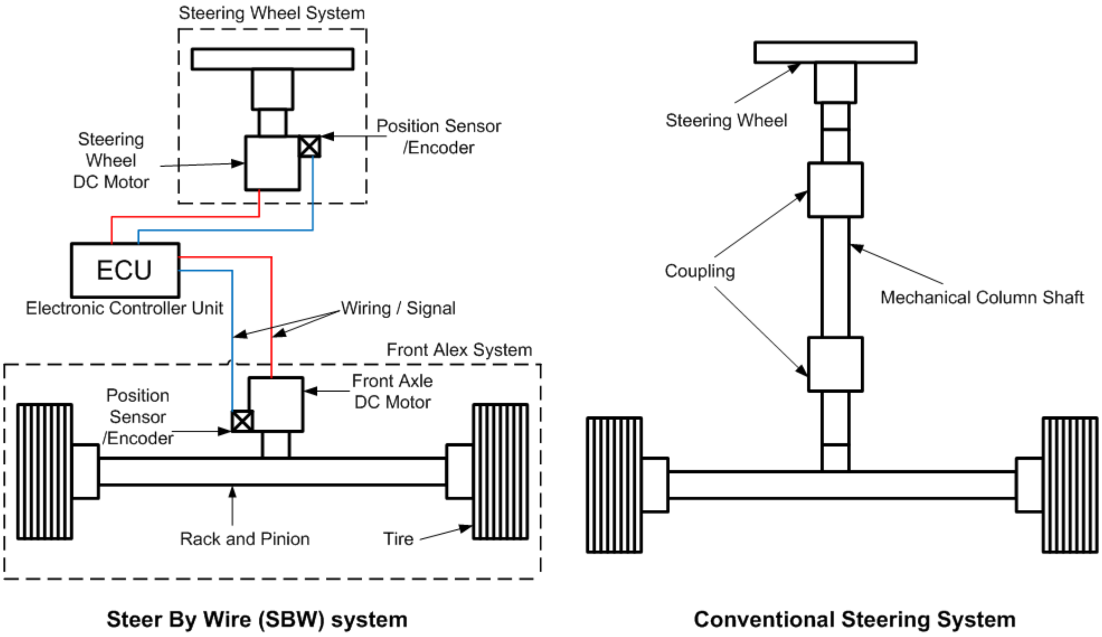

Figure 1.1: Different between Steer by Wire (SBW) and Conventional steering system

compartment. The most significant benefit of SBW system is the ease of integration with the active steering control and suspension system [43,44] which allows significant enhancement of vehicle stability, rollover and maneuverability [45–56]. Furthermore, the transmission delay between steering wheel and front tires potential to be controlled [57]. There are several main characteristics of steering function requirements in a SBW system:

Wheel Synchronization

Wheel Synchronization, also knowns as directional control, is the basic requirement in vehicle steering function of SBW systems. that requires the front tires to follow the driver input command without bias and time delay [58–61].

Variable Steering Ratio (VSR)

The steering ratio is the ratio between the steering wheel angle and front tire angle. In a conventional steering system, the steering ratio is almost constant or fixed ratio. A variable steering ratio (VSR) provides significant improvement of the vehicle maneuver at various speeds and act as function of the steering wheel angle, vehicle speed, and other parameters.

Steering Wheel Returnability

A steering wheel should return automatically to the center position once the driver released their hand off the steering wheel [62, 63]. The return rates of steering wheel centering position may vary depending on the vehicle parameters [64].

Steering Feel

In a conventional steering system, the driver directly senses the steering feel when driving. The steering feel is generated from the mechanical contact between the front tire and road surfaces that is transmitted to the driver through the mechanical column shaft. Thus, the driver is able to sense the variations of feel depending on road conditions. The steering feel becomes important to the driver during driving, not only to maintain vehicle directional control but also to the vehicle stability [65]. In an SBW system that has no mechanical column shaft, ot is required to emulate a force feedback similar to a conventional steering system which can be enhanced to the variable steering feel.

1.2 Background of Research

The sense of steering feel is one of the most important elements required by the driver during manoeuvre. The sensing element is needed to ensure that a driver has a higher awareness level when driving to provide safety. In a conventional steering system with a mechanical column shaft, a driver is able to directly control the vehicle direction by turning the steering wheel. In reverse, the driver will directly sense the feel of resistance torque in the steering wheel in accordance to the variations of the road condition. In an SBW system, the mechanical column shaft is eliminated. One major issue in eliminating the mechanical column shaft, is that the phase relationship between the steering wheel angle and the steering torque sensed by driver is significantly changed. Without the mechanical steering column shaft, the system naturally has no sensing ability of steering feel and may have a destabilizing effect on the system [35]. In order to provide the steering feel, a force feedback with torque control has to be generated and controlled through electric motor for the steering wheel system. The artificial steering feel in the SBW at least should be able to emulate the feel in the conventional steering system in addition to provide an advanced steering function.

1.3 Problem Statement

In a conventional steering system, the driver directly senses the steering feel during maneuver. This is due to the force feedback generated from the contact between the tire and road surface directly transmited through a mechanical column shaft to the driver. However, since the mechanical column shaft is eliminated in the SBW system, it is necessary to generate a force feedback with torque control for the driver steering feel. This allows the driver to sense stiffness and softness on the steering wheel in order to ensure that the driver has more confidence level when driving. Furthermore, the force feedback is used to make the steering wheel return to center position when drivers release their hand from the steering wheel.

Several researchers have studied several methods to create the force feedback with torque control. Typically, the torque sensor is attached to the rack and pinion system directly measures the torque. However, since the torque sensor is an expensive component and has high maintenance cost, several studies have proposed torque control method using an observer to estimate the force feedback. Unfortunately, the development of an observer requires the exact model of the vehicle steering system, which is difficult. Thus, it is a challenge to generate a robust force feedback method in a torque control system with lower cost and has similar performance as using the force feedback with a torque sensor.

Normally in a vehicle steering system, the driver directly controls the front tire through the mechanical column shaft. Thus, it has a transmission delay to the movement of the front tire due to the column shaft [57]. However, in an SBW system, by applying suitable controller, this delay could be reduced and proportionally improves the vehicle maneuver [66, 67]. When driving at a lower speed, especially during parking maneuvers, drivers require a large turn on the steering wheel to turn the front tire angle. Thus, it increases the drivers burden when they turn the steering wheel. By adapting the concept of variable steering ratio (VSR), it could reduce driver burden and improve the vehicle maneuver. Therefore, this thesis proposes a control algorithm to generate a force feedback with torque control for a driver steering feel in a vehicle SBW system. The potential elements to generate and improve the steering feel are taken into account. Furthermore, the suitable controllers for the wheel synchronization are analyzed and compared with EPS system for monitoring the delay transmission. Moreover, the mathematical concept for VSR function is proposed to improve vehicle maneuver and reduce the driver burden on the steering wheel, especially during parking maneuvers.

1.4 Research Objectives

The primary objectives of this studies are described the following:

1. To develop the force feedback for torque estimation control algorithm, variable steering ratio and wheel synchronization in a vehicle SBW system.
2. To study, analyze and investigate the performance of the proposed control algorithm and compare with a conventional steering system.
3. To validate the effectiveness of the proposed control algorithm using HIL methodology.

1.5 Limitation and Scope of Study

The limitation and scope of research covers the following activities:

- The focus is given on generate a force feedback with torque control.
- A current measurement technique is used to estimate the torque at steering wheel and front axle motor.
- The steering wheel rig is designed and constructed to verify the effectiveness of the propose force feedback with torque control algorithm.

1.6 Significance of Study

The driver steering feel is generated by a force feedback whereby it is an important role for driver steering feel during manoeuvres. It does not only maintain the steering directional control but also provides more confidence level for drivers during manoeuvre. Therefore, in an SBW system, it is necessary to generate the force feedback with torque control that is able to counteract an external disturbance for a driver steering feel.

Most of existing researches have proposed to generate a force feedback using a torque sensor. In an SBW system, it is necessary to reduce a number of torque sensors used as the cost of SBW system itself is already expensive. Moreover, only a few studies focused on controlling the torque at various speeds with disturbance. Furthermore, most of the researches used a complex mathematical model to generate a force feedback whereby it has increased the potential on increase the number of faults happening due to the high processing and a limited ECU capacity.

The finding of this studies will contribute to the development of a force feedback system with torque control using current measurement method for a driver steering feel in SBW systems. For the automotive manufacturers, the use of the current measurement will reduce the complexity to generate the force feedback as well as reducing the cost and for assembly and a testing process. For the researches, this study will help them recover the critical area and gains knowledge to improve the control technique. Therefore, this study is deemed significant to generate the force feedback for SBW system with the following reasons:

- *Current Sensor*
  The method of direct current measurement is used to generate a force feedback control with torque estimation instead of using a torque sensor.
- *Torque control*
  An appropriate torque control algorithm is used to adequately control the steering torque response at various speed with a disturbance that will improve the driver steering feel.
- *Complex mathematical model*
  A complex mathematical model will be simplified to reduce a number of complexities and provides a diverse control algorithm.

1.7 Methodology

The flow of the research methodology conducted in this thesis is shown in Figure 1.2.

The methodology begins by studying the previous works related to the models of the SBW system and the control algorithms of each characteristics function. The SBW system model consisted of a steering wheel and front axle system. Meanwhile, the characteristic function is wheel synchronization, variable steering ratio and a force feedback with torque control. Furthermore, the single track linear vehicle model is investigated and repeated to get an in-depth understanding on the topic.

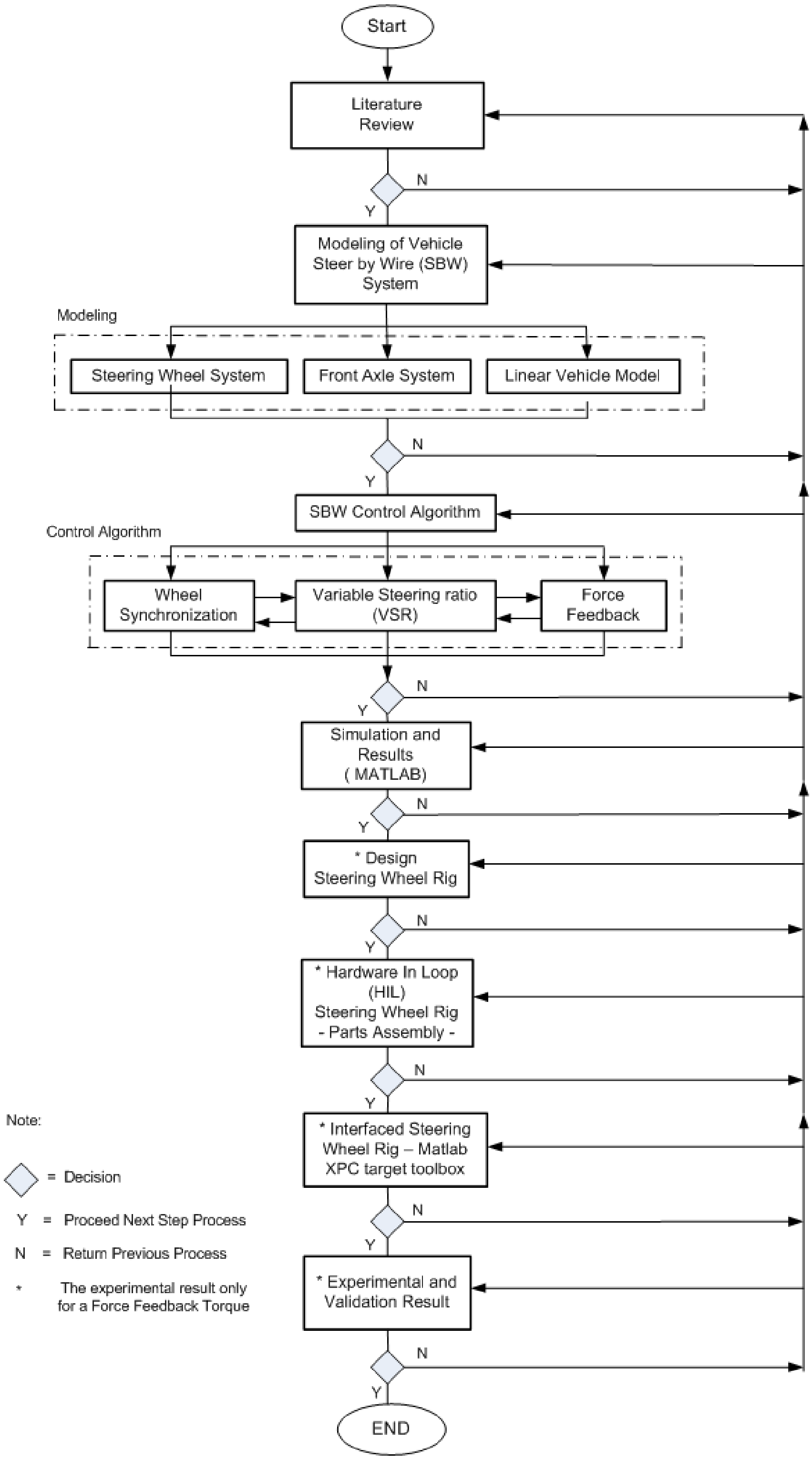

Figure 1.2: Flow Chart - Research Methodology

Then, the SBW system subsystem is modeled whereby it is composed of steering wheel system, front axle system and single track linear vehicle model. The steering wheel system contains the steering wheel motor, while the front axle system is related to the front axle motor, rack pinion system and steering linkage system. Furthermore, the single tracks linear vehicle model is modeled based on two degree of freedom (DOF) which is a yaw rate and body slip angle. On the other hand, the stability characteristic of each subsystem is defined using pole- zero map function to investigate the stability response. This is done using Matlab tools software.

After the SBW subsystem is modeled, the control algorithm of each steering function is proposed. For wheel synchronization, two methods are proposed which is using a PID and LQR controllers. Both controllers then are compared to analyze a better steering response. Meanwhile, for VSR function to improve a vehicle manoeuvre at low and high speed, two methods are proposed, which is the hyperbolic tangent and linear equation. Both method are based on the steering wheel angle and vehicle speed function. Meanwhile, for the force feedback with torque estimation control, two methods are proposed. The first method is based on the PID with Fuzzy (PID+Fuzzy) system and the second method is based on LQR with a gain scheduling (LQR+GS). The potential elements to generate a force feedback are taken into account for both methods to provide a realistic driver steering feel with appropriate torque control technique applied. Then, the effectiveness of the proposed control algorithm is simulated using Matlab tools software and the results are compared with EPS system and torque map for force feedback response. The analyses with justification for each proposed control methods are defined.

To validate the proposed control algorithm for the force feedback with torque estimation control, the real time hardware in the loop (HIL) control environment is conducted. The steering wheel rig is designed using 3D dimensional - Computational Aided Design (CAD) software, which is Solidworks, to design each part of the steering wheel rig. After the design is finalized, the steering wheel rig is constructed in accordance to the design with suitable sensors and actuators installed. The steering wheel rig then is interfaced using Matlab - XPC target toolbox software to validate the proposed force feedback control algorithm. Again, the experiment result is analyzed with justifications and the values of root mean square(RMS) are used to compare with EPS system.

1.8 Thesis Contribution

The outcome of this study can be summarized into two major contributions and two minor contributions in a vehicle steer by wire (SBW) system which is a force feedback with torque estimation control and a variable steering ratio.

1.8.1 The Force feedback for torque estimation and control algorithm

A Force Feedback using PID + Fuzzy system

The force feedback is based on the element from the torque of front axle motor and the estimation of self aligning torque. The torque of front axle motor is measured using direct current measurement technique. Meanwhile, the self aligning torque is estimated based on the vehicle dynamics response which is yaw rate and body slip angle. By using these elements, it is able to generate a force feedback for realistic driver steering feel. Meanwhile, the reference model is used to improve the centering steering wheel position based on steering stiffness parameter. In order to control the torque and able to counteract external disturbances, PID controllers with fuzzy system are used. The fuzzy system consisted of steering wheel angle and vehicle speed. The control algorithm is validated using hardware in the loop (HIL) methodology using Matlab software tools and the responses are compared with Electric Power Steering(EPS) system.

A Force Feedback using LQR + Gain Scheduling

The methods using current measurement are followed in a second force feedback and torque estimation. The torque of steering wheel and front axle motor are taken into account to create the force feedback. Moreover, the torque map is adapted to improve the force feedback response. The compensation torque consists of damping and inertia factor are added to have a more realistic driver steering feel and to stabilize the system. Meanwhile, the LQR with gain scheduling is used to control the torque. The gains of LQR controller are changed using gain scheduling technique which is based on the condition of steering wheel angle and vehicle speed function. Again, the control algorithms are validated using HIL methodology through Matlab software tools and the responses are compared with the EPS system.

1.8.2 The Variable Steering Ratio (VSR)

Variable steering ratio using hyperbolic tangent

The main function of VSR is to improve vehicle maneuver at lower and high speed maneuver. The hyperbolic tangent concept achieves the VSR function only at low speed maneuver. While, at medium and high speed it acts as fixed steering ratio. The concept is based on vehicle speed parameter with the gain of the hyperbolic function fixed.

Variable steering ratio using linear equation

For an approach using a linear equation, it achieves the function of VSR whereby it improves vehicle maneuver at low and high speeds. The concept is based on the steering wheel angle and vehicle speed parameter. The gain can be designed for a better response. The gain is increased at high speed to increase a steering ratio and is decreased to reduce a steering ratio at low speed. These improve vehicle stability at high speed and reduce driver burden at low speed especially during parking.

1.9 Thesis Outline

This thesis is organized as follows:

- Chapter 1 is the introduction. Then, it follows up with a problem statement, research objectives, scopes of the study, methodology of research, contributions and the overall outline of the thesis.
- Chapter 2 explains the detail and work from previous literature review that involved the wheel synchronization, variable steering ratio and the force feedback and torque estimation control algorithm for the SBW system
- Chapter 3 explains and models the SBW subsystem which consists of steering wheel system, front axle system and single track linear vehicle model. The stability of each subsystem is defined and discussed.
- Chapter 4 proposes and discusses the control algorithm of wheel synchronization, variables steering ratio and the force feedback with torque control for the SBW system. The simulation results of each control algorithm are compared with the EPS system.

- Chapter 5 explains the designed and constructed steering wheel rig to validate the effectiveness of the proposed force feedback control algorithm. This is done by interfacing using Matlab - XPC target software. The experimental result is analyzed discussed and compared to EPS system.
- Chapter 6 describes the conclusion of the overall thesis which consists of literature review, control algorithm, simulation and experiment results. The final decisions of each control algorithm are defined and discussed. Further works are also discussed in this chapter.

1.10 Published Works, Patent and Awards

The following related research works that have been published in this thesis:

S.M.H. Fahami, H Zamuri and S.A. Mazlan *Development of Estimation Force Feedback Torque Control Algorithm for Driver Steering Feel in Vehicle Steer by Wire System : Hardware in the Loop*, International Journal of Vehicular Technology, vol 2015, Article ID 314597, 17 pages, 2015.

S.M.H. Fahami, H Zamuri, S.A. Mazlan and Sarah Atifah Saruchi *The Variable Steering Ratio for Vehicle Steer by Wire System Using Hyperbolic Tangent Method*, Journal of Applied Mechanics and Materials, Vol.575, pp.781-784, June 2014

S.M.H. Fahami, H Zamuri, S.A. Mazlan and N. Zulkarnain *The Design of Vehicle Active Front Steering Based on Steer by Wire System*, Journal of Advanced Science Letters, Vol.19, pp.61-65. Jan.2013.

S.M.H. Fahami, H Zamuri, S.A. Mazlan and Zakaria, M.A. *Modeling and Simulation of Vehicle Steer by Wire System*, IEEE Symposium Science Humanities and Engineering Research(SHUSER), Malaysia, DOI: 10.1109/SHUSER 2012.6268992 pp.765-770, 2012.

Sarah Atifah Saruchi, H Zamuri,S.A. Mazlan, S.M.H. Fahami and N. Zulkarnain *Wheel Synchronization Control in Steer-by-Wire Using Composite Nonlinear Feedback*, Journal of Applied Mechanics and Materials,Vol.575,pp.762-765,September 2014

Sheikh Muhammad Hafiz Fahami, Hairi Zamzuri, Saiful Amri Mazlan, Wira Jazair "A Method for Controlling Vehicle Steer by Wire system " Patent No: P12014700692, September 2014.

Bronze Medal "The Virtual Force Feedback Torque Control for Vehicle Steer by Wire (SBW) system in Industrial Arts and Technology Exhibition (INATEX) 2013 on Sustainable Commercialization Through Innovative Research and Development 2013

Bronze Medal "The Force Feedback Mechanism for Vehicle Steer by Wire System in Malaysia Technologcy Expo (MTE) 2013 The Leading International Invention and Innovation Expo.

REFERENCES

1. Fahami, S. M. H., Zamzuri, H. and Mazlan, S. A. Development of Estimation Force Feedback Torque Control Algorithm for Driver Steering Feel in Vehicle Steer by Wire System: Hardware in the Loop. *International Journal of Vehicular Technology*, 2015. 2015(Article ID 314597): 17pages.
2. Sarah, A. S., Zamzuri, H., Mazlan, S. A., Fahami, S. M. H. and Zulkarnain, N. Wheel Synchronization Control in Steer-by-Wire Using Composite Nonlinear Feedback. *Journal of Applied Mechanics and Materials*, 2014. 575: pp.762–765.
3. Philip, K. and Eckrich, M. Active Steering - The BMW Approach Toward Modern Steering Technology. *SAE Technical Paper Series*, 2004-01-1105.
4. Se-Wook.OH, Chae, H. C., Yun, S. C. and Han, C. S. The Design of a Controller for the Steer by Wire System. *JSME International Journal Series*, 2004. Vol.47(3): pp.896–905.
5. Shoji, A., Hiroshi, K. and Takeuchi, S. Development of SBW system with force Feedback using a disturbance observer. *Steering & Suspension Technology Symposium:Steering, SAE Technical Paper Series 2004 World Congress, Detroit, Michigan*, 2004. 01-1100.
6. Yixin, Y. Vehicle Steer by Wire System Control. *SAE Technical Paper*, 2006. 01-1175.
7. S.Kimura, M.Segawa, T.Kada and S.Nakano. Research on Steering Wheel Control Strategy as Man Machine interfaced for steer by wires system. *Koyo Engineering Journal English Edition*, 2005. 166E: pp.29–33.
8. Segawa.M, Kada.T.S and Nakona. A study of reactive torque control for steer by wire system. *In Proceedings of the International Symposium on Advanced Vehicle Control (AVEC), Hiroshime, Japan*, 2002: pp.653–658.
9. Sven, Johannes and Sasol. Modelling and Control of a Steer-By-Wire Vehicle. *Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility*, 2007: pp.114–142.
10. Li.Qiang and He.Ren. Modeling and simulation study of the steer by wire

system using bond graph. *IEEE International Conference on Vehicular Electronics and Safety, Xian, China*, 2005: 7–11.

11. Hai.W, Man, Z., Kong, H. and Shen, W. Terminal sliding mode control for steer-by-wire system in electric vehicles. *7th IEEE Conference on Industrial Electronics and Applications (ICIEA), Holiday Inn, Singapore*, 2012: 919–924.

12. T.Kaufmann, S.Milsap, B.Murray and J.Petrowski. Development Experience with Steer by Wire. *SAE Technical Paper Series*, 2001-01-2479.

13. Abhjit, B., R.Wagner, J., Darren M.Dawson, D. B. and Setlur, P. An On Adjustable Steer by Wire Haptic Interface Tracking Controller for Ground Vehicles. *IEEE Transaction Vehicular Technology*, 2009. 58: pp.546–554.

14. Haggag, S., Alstrom, D., Cetinkunt, S. and Egelja, A. Modeling, control, and validation of an electro-hydraulic steer-by-wire system for articulated vehicle applications. *Mechatronics, IEEE/ASME Transactions*, 2005. 10(6): pp.688 – 692.

15. Peter, D. and Gerhard, R. Electric Power Steering - The First Step on the Way to Steer by Wire. *SAE Technical Paper Series*, 1999-01-0401.

16. Rath, M., Kelly, M., Kober, K. and Gulati, A. Optimum Design of a Steer by Wire System using Systematic System Engineering Approach. *SAE Technical Paper Series*, 2008-01-1452.

17. Kumar, E. and Kamble, D. D. N. An Overview of Active Front Steering System. *International Journal of Scientific Engineering Research*, 2012. Vol.3, Issue 6.

18. Zhang, L., Wang, L. and Liao, C. Reliability Research for Steer-by-Wire System of Electric Vehicle. *Power and Energy Engineering Conference, APPEEC 2009. Asia-Pacific, Wuhan, China*, 2009: pp.1–4.

19. Arasan, S. T., Midhun, V. and V. Subburaj, a. P. J. Design of Controller for Fundamental Steer-by-wire system. *SAE Technical Paper*, 2003-28-0013.

20. Yu, Q., Zaimin, Z., Xinjian, W. and Xinbo, C. Research on Steer-by-wire principle and the realization of Steer-by-wire system. *International Conference on Electric Information and Control Engineering (ICEICE),Wuhan, China*, 2011. 2: pp.5269–5272.

21. Qiu, Y., Chen, X. and Wang, X. Simulation and realization of Steer-by-Wire system. *Second International Conference on Mechanic Automation and Control Engineering (MACE), Beijing, China*, 2011: pp.6076–6078.

22. Bertoluzzo, M., Buja, G., Menis, R. and Sulligoi, G. Approach to steer-by-wire system design. *IEEE International Conference on Industrial Technology,(ICIT), Hong Kong, China*, 2005: pp.443–447.

23. Bertoluzzo, M., Buja, G. and Menis, R. Control schemes for steer-by-wire systems. *Industrial Electronics Magazine, IEEE*, 2007. 1(1): pp.20–27.

24. Verschuren, R. and Duringhof, H. Design of a Steer-by-Wire Prototype. *SAE Technical Paper*, 2006-01-1497.

25. Heitzer, D. and Seewald, A. Development of a Fault Tolerant Steer-By-Wire Steering System. *SAE Technical Paper*, 2004-21-0046.

26. S.Feick, M.Pandit, Zimmer, M. and Uhler, R. Steer-by-Wire as a Mechatronic Implementation. *SAE Technical Paper*, 2000-01-0823.

27. Pimentel, J. An Architecture for a Safety-Critical Steer-by-Wire System. *SAE Technical Paper*, 2004-01-0714.

28. D., W. Steer-by-wire system based on FlexRay protocol. *Applied Electronics, AE 2009*, 2009: pp.269–272.

29. Daher, N. and Ivantysynova, M. A Steer-by-Wire System that Enables Remote and Autonomous Operation. *SAE Technical Paper*, 2014. 01(2404).

30. Ukaew, A. Model Based System Design of Conceptual Drive-by-Wire ECU Functions for Electric Vehicle Conversion. *SAE Int.J.Passeng.Cars Electron. Electr.Syst.*, 2013-01-0426.

31. Guvenc, B. and Guvenc, L. Robust steer-by-wire control based on the model regulator. *Proceedings of the 2002 International Conference on Control Applications, Glasgow, UK*, 2002. 1: pp.435 – 440.

32. Zanten, A. Evolution of electronic control system for improving the vehicle dynamic behaviour. *In Proceedings of the International Symposium on Advanced Vehicle Control (AVEC)*, 2002.

33. Wang, H., Kong, H., Man, Z., Tuan, D. M., Cao, Z. and Shen, W. Sliding Mode Control for Steer-by-Wire Systems With AC Motors in Road Vehicles. *IEEE Transactions on Industrial Electronics*, 2013. 61(3): pp.1596–1611.

34. Fahami, S. M. H., Zamzuri, H., Mazlan, S. A. and Zakaria, M. A. Modeling and Simulation of Vehicle Steer by Wire System. *IEEE Symposium Science Humanities and Engineering Research (SHUSER), Kuala Lumpur, Malaysia*, 2012: pp.765–770.

35. Sanket, A., Bolourchi, F., Demerly, J. and Millsap, S. A Control System

Methodology for Steer by Wire Systems. *SAE Technical Paper Series*, 2004-01-1106.

36. Y.Shengbing. Study on Control Strategy of Steer by Wire System. *Wuhan University of Technology*, 2008.

37. Jang, S.-H., Park, T.-J. and Han, C.-S. A control of vehicle using steer-by-wire system with hardware-in-the-loop-simulation system. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Kobe, Japan*, 2003. 1: pp.389–394.

38. Oncu, S., Guvenc, L., Ersolmaz, S., Ozturk, N., S. Kilic and M., S. Steer-by-Wire Control of a Light Commercial Vehicle Using a Hardware-in-the-Loop Test Setup. *SAE Technical Paper*, 2007-01-4198.

39. Harter, W., Pfeiffer, W., Dominke, P., Ruck, G. and Blessing, P. Future Electrical Steering Systems : Realizations with Safety Requirements. *SAE Technical Paper Series*, 2006-01-0822.

40. Chaaban, R. N. B. B., K. and Saudrais, S. Model-based development of an embedded steering-by-wire system. *8th International Symposium on Mechatronics and its Applications (ISMA),American University of Sharjah Sharjah, UAE*, 2012: 1–6.

41. Langenwalter, J. Embedded automotive system development process - steer-by-wire system. *Proceedings Design, Automation and Test in Europe, Munich, German*, 2005. 1: 538–539.

42. Chen. Xinbo, Y., Li.Nie and Duonian, Q. The independent steer-by-wire system of the omni-directional EV and its Fault-Response-System. *International Conference on Electric Information and Control Engineering (ICEICE), Wuhan, China*, 2011: 5507–5509.

43. Samin, P. M., Jamaluddin, H., Rahman, R. A., Hudha, K. and Abu Bakar, S. A. Semi-Active Suspension Control to Improve Ride and Handling with Magnetorheological(MR)Damper. *International Journal of Engineering Systems Modelling and Simulation*, 2011. Vol.3(3): pp.99–111.

44. yan, Y. L. and li, Y. P. Motor motion control of automobile Steer-by-Wire system in electric vehicles. *IEEE Vehicle Power and Propulsion Conference, Michigan, USA*, 2009: pp.1502–1505.

45. Bing, Z., Oh, P. and Lenart, B. Active Steering Control with Front Wheel Steering. *Proceeding of the 2004 American Control Conference, Boston, American*, 2004. 2: pp.1475–1480.

46. Seda, P. O. Modeling and Simulation of Active front Steering System. *Academic Journal Scientific Research and Essays*, 2012. 7(41): pp.3479–3486.

47. Fahami, S. M. H., Zamzuri, H., Mazlan, S. A. and Noraishikin. The Active Front Steering System based on Vehicle Steer by Wire system. *Journal of Advance Science Letter*, 2013. 19(1): pp.61–65.

48. Wei, Y., Fu, R., Guo, Y. and Zhu, Y. Simulation and Optimization of Angle Characteristics Model for Steer by Wire system. *Seventh International Conference on Fuzzy System and Knowledge Discovery, Shandong, China*, 2010.

49. Hosaka, M. and Murakami, T. Yaw rate control of electric vehicle using steer-by-wire system. *The 8th IEEE International Workshop on Advanced Motion Control, Kawasaki, Japan*, 2004: pp.31 – 34.

50. Cesiel, D., C.Gaunt, M. and Daugherty, B. Development of a Steer-by-Wire System for the GM Sequel. *SAE Technical Paper*, 2006-01-1173.

51. Hac, A., Doman, D. and Oppenheimer, M. Unified Control of Brake- and Steer-by-Wire Systems Using Optimal Control Allocation Methods. *SAE Technical Paper*, 2006-01-0924.

52. Park, Y. and Jung, I. Semi-Active Steering Wheel for Steer-By-Wire System. *SAE Technical Paper*, 2001-01-3306.

53. Janbakhsh, A. A. and Kazemi, R. A new approach to enhance vehicle maneuverability performance using SBW system. *Proceeding of ISIE 2009 IEEE International Symposium on Industrial Electronics, Seoul, Korea*, 2009.

54. Janbakhsh, A. A. and Kazemi, R. A New approach for simultaneous vehicle handling and path tracking improvement through SBW system. *Proceeding of International Conference ASME, Phoenix, Arizona, USA*, 2010.

55. M.B., B., S.P., S. and M., R. Investigations on vehicle rollover prevention using steer-by-wire system. *International Conference on Control Communication and Computing (ICCC),Thiruvananthapuram, India*, 2013: pp.378–383.

56. Fankema, S. and Mllerb, S. A new model to compute the desired steering torque for steer-by-wire vehicles and driving simulators. *Journal of Mechanical Science and Technology*, 2014: pp.251–271.

57. KUBOTA, Y. Nissan to install electronic ”steer-by-wire” in Infiniti cars,

2012. URL http://www.reuters.com/article/2012/10/17/us-nissan-technology-idUSBRE89G03A20121017.

58. Wang, H., Man, Z., Kong, H. and Shen, W. Terminal sliding mode control for steer-by-wire system in electric vehicles. *7th IEEE Conference on Industrial Electronics and Applications (ICIEA), Holiday Inn Singapore Orchard City Centre Singapore.*, 2012: pp.919–924.

59. Chen, H., Yu, Q., Zhu, L. and Chen, G. Study on Steering by WireController Based on Improved H Algorithm. *International Journal of Computer Science,*, 2013. 10(2: pp.375–380.

60. Jang, S. H., Park, T. J. and Han, C. S. A control of vehicle using steer-by-wire system with hardware-in-the-loop-simulation system. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Kobe, Japan*, 2003. 1: pp.389–394.

61. Y, Y. and T, M. Adaptive Control for Virtual Steering Characteristics on Electric Vehicle Using Steer-by-Wire System. *IEEE Transactions on Industrial Electronics*, 2009. 56(5): pp.1585–1594.

62. Hong, T. and Park, K. A New Steering Wheel Returnability Control Strategy for On-Center Handling Performance. *SAE Technical Paper Series*, 2011-28-0079.

63. Jang, B., Yi, K., Jung, C., Lee, J., Cha, Y. J., Park, J. and Park, J. Correlation of Subjective and Objective Measures of On-Center Handling. *SAE Technical Paper Series*, 2014-01-0128.

64. Heathershaw, A. Developments in On-Centre Steering Evaluation and Testing. *SAE Technical Paper Series*, 2006-01-0796.

65. A, O., Messaoudene, K. and Mammar, S. Dynamic model of steer-by-wire system for driver handwheel feedback. *10th IEEE International Conference on Networking, Sensing and Control (ICNSC),Evry University, France*, 2013: pp.780–785.

66. Nissan, M. C. Nissan Pioneer First - Ever Independent Control Steering Technology, 2012. URL http://www.nissan-global.com/EN/NEWS/2012/_STORY/121017-02-e.html.

67. Downtown, N. Nissan's Steer-by-Wire Technology Due for 2013 Infiniti Production, 2013. URL http://www.nissandowntown.ca/about_us/news_and_events/nissans_steerbywire_technology_due_for_2013_infiniti_production.

68. Hiroki, O. and Murakami, T. A stability Control by Active Angle Control of Front Wheel in a Vehicle System. *IEEE Transaction on Industrial Electronics*, 2008. 55(3): pp.1277–1285.

69. Reza, K., Mousavinejad, I., Rafat, M. and Khaknejad, M. B. Yaw Moment Control of the Passenger Car via Steer by Wire System. *Proceedings of the International Mechanical Engineering Congress Exposition ASME 2011, Colorado, USA*, 2011. (62474): pp.1–9.

70. Yih, P. and Gerdes, J. Modification of vehicle handling characteristics via steer by wire. *IEEE Transaction on Control System Technology*, 2005. 13(6): pp.965–976.

71. Manh, T. D., Man, Z., Zhang, C., Wang, H. and Tay, F. S. Robust Sliding Mode-Based Learning Control for Steer-by-Wire Systems in Modern Vehicles. *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY*, 2014. 63: pp.580–590.

72. Z.Man, S.Khoo, X.Yu and J.Jin. A new sliding mode-based learning control scheme. *Industrial Electronics and Applications (ICIEA), 6th IEEE Conference, Beijing, China*, 2011: pp.1906191.

73. Emre, A., Adli, M., Barkana, D. E. and HalukKucuk. Compliant Control of Steer-by-Wire Systems. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics Suntec Convention and Exhibition Center, Singapore*, 2009: pp.636–643.

74. A.E.Cetin, M.A.Adli, D.E.Barkana and H.Kucuk. Compliant control of steer by wire system. *In Proceedings IEEE/ASME Int. Conf. Adv.Intell. Mechatronics,Singapore*, 2009: pp.636–643.

75. Zou, F., Song, D. and abd Bin Yuan, Q. L. A New Intelligent Technology of Steering-by-Wire System by Variable Structure Control with Sliding Mode. *JCAI,International Joint Conference on Artificial Intelligence, California, USA*, 2009: pp.857–860.

76. Wei, J., Shi, G. and Lin, Y. Design of new variable steering ratio for mechanical active steering system. *IEEE International Conference on Vehicular Electronics and Safety (ICVES),Dongguan, China*, 2013: pp.27–30.

77. Azzalini, M., Gissinger, G., Boussouar, V. and Coutant, P. Computation of a variable steering ratio with a fuzzy logic method. *IEEE Intelligent Vehicle Symposium, Versailles, France*, 2002: pp.259 – 267.

78. Fahami, S. M. H., Zamzuri, H., Mazlan, S. and Saruchi, S. A. The Variable

Steering Ratio for Vehicle Steer by Wire System Using Hyperbolic Tangent Method. *Journal of Applied Mechanics and Materials*, 2014. 575: pp.781–784.

79. Geng, S. F., Feng, P. Q. and Fang, W. L. The Research of Steer by Wire System based on Fuzzy Logic Control. *Journal of Applied Mechanics and Materials*, 2011. 55-57: pp.780–784.

80. Jiang-Yun, Y., Feng, K. and Fang-Yuan, W. Control Strategy for Front Wheel Angle of Steer by Wire based on Variable Steering Ratio. *IEEE 2011 International Conference on Computer Science and Network Technology, Harbin,China*, 2011: pp.852–856.

81. Yuan, W., Fu, R., Guo, Y. and Zhu, Y. Simulation and Optimization of Angle Characteristics Model for Steer by Wire System. *2010 Seventh International Conference on Fuzzy System and Knowledge Discovery,Shandong,China*, 2010: pp.931–935.

82. Yasuo, S., Kawai, T. and Yuzuriha, J. Improvement in Driver-Vehicle System Performance by Varying Steering Gain with Speed and Steering Angle: VGS (Variable Gear-ratio Steering System). *SAE Technical Paper Series 1999-01-0395*, 1999-01-0395. 01.

83. Seda, P. O. Modeling and Simulation of Active Front Steering System. *Academic Journal of Scientific Research and Essays*, 2012. 7(41): pp.3479 – 3486.

84. Feng, T. Vehicle Lateral Control for Driver Assistance and Automated Driving. *Phd thesis University of California, Mechanical Engineering*, 2000.

85. Jenq, H. S. and Chang, I. H. Design of variable transmission of Steering system. *19th Conference on Mechanical Engineering, Tehran, Iran*, 2002: pp.1159 –1166.

86. Kim, C., Jang, J.-H., Oh, S.-K., Lee, J. and Hedrick, J. K. Development of a control algorithm for rack actuating steer by wire system using road information feedback. *Journal of Automobile Engineering*, 2008. 222: pp.1559–1571.

87. Dirk, O., Bunte, T., Heitzer, H.-D. and Eicker, C. How to make Steer by Wire Feel like Power Steering. *Proceedings of 15th IFAC World Congress Barcelona, Spain*, 2002.

88. Hongyu, Z., Zong, C. and Yu, L. J. Road Feel Feedback Design for Vehicle Steer by- Wire via Electric Power Steering. *SAE Technical Paper Series*, 2013-01-2898.

89. Hsiaohsiang, N., Zong, C. and Hu, D. Investigations on Cornering Control Algorithm Design and Road Feeling Optimization for a Steer-by-Wire Vehicle. *Proceedings of the 2009 IEEE International Conference on Mechatronics and Automation,Changchun,China*, 2009: pp.3246–3251.

90. C.Zong, L.Mai, D.Wang and Y.Li. Study on steering effort preference of drivers based on driving simulator. *Chinese Journal of Mechanical*, 2007. 18(8): pp.10011005.

91. Joshua, P., Rossetter, E. J., A.Coe, I. and Gerdes, J. HandWheel Force Feedback for Lane Keeping Assistance: Combined Dynamics and Stability. *ASME Journal of Dynamic Systems, Measurement and Control*, 2006. 128: pp.532–542.

92. Yao.Y.X, Darouch.M and Schaefers.J. Robust H-infinity estimator Design for linear uncertain system. *Journal of Automobile Engineering*, 1994: pp.3568–3569.

93. N.Bajcinca, R.Cortesao, M.Hauschild, J.Bals and G.Hirzinger. Haptic Control for Steer by Wire Systems. *Intelligent Robots and Systems,(IROS 2003). Proceedings IEEE/RSJ International Conference, Las Vegas, USA*, 2003. 2: pp.2004–2009.

94. Zheng, B., Altemare.C and Anwar.S. Fault tolerant steer by wire road wheel control system. *American Control Conference, Proceedings, St.Louis, Missour*, 2005. 3: pp.1619–1624.

95. Ryo, M., Hoshino, H. and Hori, Y. Ergonomic Verification of Reactive Torque Control Based on Driver Sensitivity Characteristics for Active Front Steering. *IEEE Vehicle Power and Propulsion Conference*, 2009: pp.160–164.

96. Ba, H. N. and Ryu, J. H. Direct Current Measurement Based Steer by Wire System for Realistic Driving Feeling. *IEEE International Symposium on Industrial Electronics (ISIE),Seoul, Korea*, 2009: pp.1023–1028.

97. Ruriko, K., Kurata, F. and Yamamoto, M. Experimental Study of Lateral Acceleration Feedback Control with Steer by Wire System. *SAE Technical Paper Series*, 2010. 01(0996).

98. Toshihiro, H., Nishihara, O. and Kumamoto, H. Steering Reactive Torque Presentation Method for a Steer-By-Wire Vehicle -Feedback of a Lateral Acceleration at a Center of Percussion with Respect to Rear Wheels. *Review of Automotive Engineering*, 2008. 29: pp.287–294.

99. Mauroand, D., Stefano, M., Luca, M., M, R., Francesco, T., Michele, M.,

Cristina, I. and Fabio, T. Design of an Adaptive Feedback Based Steering Wheel. *Ergonomics and Health Aspects of Work with Computers*, 2007. 4566: pp.180–188.

100. Pei, S. H. Control Concepts for lateral vehicle Guidance Including HMI Properties. *IEEE International Conference on Systems, Man and Cybernetics, Hague, Netherlands*, 2004. 1: pp.1–6.

101. A.Rodriguez, A., H.Sira-Ramirez and J.A.Garcia-Antonio. A Vehicle Haptic Steering by Wire System Based on High Gain GPI Observers. *Mathematical Problems in Engineering*, 2014: 14 pages.

102. J.Han. From the PID to Active Disturbance Rejection Control. *IEEE Transaction on Industrial Electronics*, 2009. 56(3): pp.900–906.

103. Guangzheng, G., Chen, H., Lou, L. and Nakano, S. Torque Feedback Control for the Hand-Wheel Actuator of SBW Based on Active Disturbance Rejection Controller. *Proceedings of the FISITA 2012 World Automotive Congress, China*, 2012. 198: pp.391–403.

104. Ryouhei, H., Kawaharaa, S., Nakanoa, S. and Kumamotob, H. Resistance torque control for steer-by-wire system to improve humanmachine interface. *Journal of Vehicle System Dynamics*, 2010. 48,No.9: pp.10651075.

105. Shengbing, Y., Chunan, D., Xuewu, J. and Kuiyuan, C. Research on Road Feeling Control Strategy of Steer-by-Wire. *SAE Technical Paper Series*, 2007-01-3652.

106. C.T.Lee and B.Y.Moon. Study on the damping performance characteristics analysis of shock absorber of vehicle by considering fluid force. *Journal of Mechanical Science and Technology*, 2005. Vol.19(-): 520–528.

107. Jianmin, D., Ran, W. and Yongchuan, Y. Research on Control Strategies of Steer-by-Wire System. *International Conference on Computation Technology and Automation (ICICTA), Changsha, China*, 2010. 2: pp.1122–1125.

108. Fukuda, Y. Slip-Angle Estimation for Vehicle Stability Control. *Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility*, 1999. 32(4-5): pp.375–388.

109. Geng, C., T, U. and Y, H. Body Slip Angle Estimation and Control for Electric Vehicle with In-Wheel Motors. *The 33rd Annual Conference of the IEEE Industrial Electronics Society, Grand Hotel Taipei, Taiwan*, 2007: pp.351–355.

110. Minghui, L., Yongsheng, Z., Liang, C., Wenruo, W., Jianwei, C. and Lei, Z. Design of Body Slip Angle Observer for Vehicle Stability Control. *The 2nd International Conference on Electronic Mechanical Engineering and Information Technology (EMEIT), Liaoning, China*, 2012: pp.2357–2361.

111. S.Sahoo, S.C.Subramanian and Srivastava, S. Design and implementation of a controller for navigating an autonomous ground vehicle. *In Proceedings of the 2nd International Conference on Power, Control and Embedded Systems (ICPCES 12),IEEE, Allahabad, India*, 2012. -(-): 1–6.

112. T.D.Gillespie. Fundamentals of Vehicle Dynamics. *Society of Automotive Engineers*, 1992. -(-): –.

113. Santosh, A., Baviskar, A., R.Wagner, J. and M.Dawson, D. Ground Vehicle Steering system; modeling control and analysis of hydraulic,electric and steer by wire Configure. *International Journal of Vehicle Design*, 2007. Vol.44(1/2): pp.188–208.

114. Yasuo, S., Kawai, T. and Yuzuriha, J. Improvement in Driver-Vehicle System Performance by Varying Steering Gain with Vehicle Soeed and Steering Angle: VGS (Variable Gear Ratio Steering System). *SAE Technical Paper Series*, 1999-01-0395.

115. Yao, J.-Y., Feng, K., Fang, W. and Yuan. Control Strategy for Front Wheel Angle of Steer by Wire Based on Variable Steering Ratio. *International Conference on Computer Science and Network Technology (ICCSNT), Harbin, China*, 2011.

116. Tajima, J., Yuhara, N., Sano, S. and Takimoto, S. Effects of Steering System Characteristics on Control Performance from the Viewpoint of Steer-by-Wire System Design. *SAE Technical Paper*, 1999-01-0821.

117. Klier, W., Reimann, G. and Reinelt, W. Concept and Functionality of the Active Front Steering System. *SAE Technical Paper*, 2004. 2004-21-0073.

118. Zhai, P., Du, H. and Li, Z. Bilateral control of vehicle Steer-by-Wire system with variable gear-ratio. *8th IEEE Conference on Industrial Electronics and Applications (ICIEA), Melbourne, Australia*, 2013: 811–815.

119. Serarslana, B. New approaches to enhance active steering system functionalities: preliminary results. *Journal Vehicle System Dynamics*, 2014. 52(9): pp.1153–1170.

120. Sadale, R., Kolhe, R., Wathore, S., Aghav, J., Warade, S. and Udayagiri, S. Steer-By-Wire Implementation Using Kinect. *Industrial Electronics Magazine, IEEE*, 2012. 174: pp.20–27.

121. Oufroukh, A., Messaoudene, N. and S., M. Dynamic model of steer-by-wire system for driver handwheel feedback. *10th IEEE International Conference on Networking, Sensing and Control(ICNSC), Evry, France*, 2013: 780–785.

122. Groll, M. V., Mueller, S., Meister, T. and Tracht, R. Disturbance compensation with a torque controllable steering system. *Journal Vehicle System Dynamics*, 2007. 44(4): pp.327–338.

123. Ozaki, I. J., F, M. and S., K. Design of steer-by-wire system with bilateral control method using disturbance observer. *IEEE/ASME international conference on Advanced intelligent Mechatronics,Zurich, Switzerland*, 2007: 1–6.

124. Roland, P., A.Naya, M., A.Perez, J. and Cuadrado, J. Geared PM coreless motor Modeling for driver force feedback in steer by wire system. *Journal of Mechatronics*, 2011: pp.1043–1054.

125. Zamzuri, H., Zolotas, A. and Goodall, R. Intelligent control approaches for tilting railway vehicles. *Vehicle System Dynamics*, 2006. 44(S1): pp.834–843.

126. Zhou, Y., shan Liu, M., shuang Hu, L. and da. Zhang, Z. Application of fuzzy five states control system base on phase plane in steer by wire system of loader. *International Conference on Fuzzy Systems and Knowledge Discovery (FSKD),Yantai, China*, 2010. 2: pp.649–653.

127. Man, H. L., ha, S. K., Choi, J. Y. and Yoon, K. S. Improvement of the Steering Feel of an Electric Power Steering by Torque Map Modification. *Journal of Mechanical Science and Technology*, 2005. 19: pp.792–801.

128. Tong, J. P., Han, C. S. and Lee, S. H. Development of the electronic control unit for the rack-actuating steer by wire using the hardware in the loop simulation system. *Journal of Mechatronics*, 2005. 8: pp.899918.

129. Yandong, H., He, L., XiangWang and Zong, C. Research on Torque Ratio Based on the Steering Wheel Torque Characteristic for Steer-by-Wire System. *Journal of Applied Mathematics*, 2014. 2014: pp.1–7.

130. Xiang, W., Zong, C., Xiang, H., Hu, R. and Xie, X. Bilateral Control Method of Torque Driver/Angle Feedback Used for Steer by Wire System. *SAE Technical Paper Series*, 2012. 01(0792): pp.479485.

131. A, L. and S, C. Force Feedback in a stationary driving simulator. *21 st Century IEEE International Conference on System, Man and Cybernatics Intelligent Ssytem, Vancouver, Canada*, 1995. 2: pp.1711–1716.

132. Fankema, S. and Mllerb, S. A new model to compute the desired steering torque for steer-by-wire vehicles and driving simulators. *Journal Vehicle System Dynamics*, 2014. 52: pp.251–271.

133. Chai, Y. W., Abe, Y., Kano, Y. and Abe, M. A study on adaptation of SBW parameters to individual drivers steer characteristics for improved drivervehicle system performance. *Journal Vehicle System Dynamics*, 2007. 44: pp.874–882.

134. Kim, N. and J.Cole, D. A model of driver steering control incorporating the driver's sensing of steering torque. *Journal Vehicle System Dynamics*, 2011. 49(10): pp.1575–1596.

135. Zhang, X., Xin, Z., Guobiao, S. and Yi, L. Steering Feel Study on the Performance of EPS. *IEEE Vehicle Power and Propulsion Conference (VPPC), Harbin, China*, 2008. 2004-21-0073: 1–5.

136. Ba-Hai, N. and Ryu, J.-H. Direct Current Measurement Based Steer by Wire system for realistic Driving Feeling. *IEEE International Symposium on Industrial Electronics (ISIE), Seoul, Korea*, 2009: 1023–1028.

137. Roland, P., A.Naya, M., A.Perez, J. and Cuadrado, J. Geared PM coreless motor Modeling for driver force feedback in steer by wire system. *Journal of Mechatronics*, 2011. 21: pp.1043 1054.

138. Hope.L.L. A fast Gaussian method for a Fourier transform evaluation. *Proceedings of the IEEE*, 2005. 63(9): pp.1353–1354.

139. Delic, S. and Juric, Z. Some improvements of the Gaussian elimination method for solving simultaneous linear equations. *The 36th International Convention on Information Communication Technology Electronics Microelectronics, Croatia*, 2013: pp.96–101.

140. Mangoubi, R., Desai, M. and Sammak, P. Non-Gaussian methods in biomedical imaging. *The 37th IEEE Applied Imagery Pattern Recognition Workshop, AIPR '08, Washington,USA*, 2008: pp.1–6.

141. Yang, Z., Guangyu, Z., Yonghong, S., Wei, W. and Xuerong, G. Test Parameters Optimization Based on Newton-Gaussian Method in Analog Signature Analysis. *Measuring Technology and Mechatronics Automation (ICMTMA), 2013 Fifth International Conference, Hong Kong, China*, 2013: pp.1120 – 1124.

142. Higuchi, A. and Sakaei, H. Objective Evaluation Method of On Center Handling Characterictics. *SAE Technical Paper Series*, 2001. 01(0481).