ACTIVE STEERING SYSTEM BASED ON NONLINEAR CONTROL SYSTEM

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To Universiti Teknikal Malaysia Melaka for supporting my study,

To my dearest mother for her encouragement and blessing,

To my beloved wife for her support,

To my family for their love…

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ABSTRACT

The objective of this project is to improve the performance of steering control of a vehicle. This can be achieved by designing a nonlinear active steering control system which will compensate disturbances such as road conditions and crosswind. The model of the system is derived and simulated based on the single track car model which has been established as a basis of any car steering system. A nonlinear active steering controller is then be designed by using the Sliding Mode Control (SMC) strategy whereby yaw rate and side slip angle are used as the control parameters. The proposed controller is applied to the nonlinear system, simulated and tuned using Matlab/Simulink platform. Yaw rate, side slip angle, control inputs and sigmas are considered as the parameters that contribute to the performance of the proposed controller. Performance of the developed controller is then being compared to the performance of Linear Quadratic Regulator (LQR) and pole placement controller to verify its robustness and stability.

ABSTRAK

Tesis ini bertujuan untuk meningkatkan keupayaan kawalan stereng kenderaan. Ini dapat direalisasikan dengan mereka sebuah sistem kawalan yang tidak linear yang dapat menahan gangguan dari luar seperti keadaan jalan yang tidak menentu dan angin lintang. Model sistem ini telah diterbitkan dan disimulasikan berdasarkan kepada model sistem trek kereta sesiri yang merupakan model asas bagi semua sistem stereng kereta. Sebuah pengawal stereng tidak linear yang aktif kemudiannya direka dengan menggunakan strategi 'Sliding Mode Control (SMC) dimana kadar putaran dan sudut gelinciran tepi akan digunakan sebagai parameter kawalan. Sistem kawalan yang telah direka akan diaplikasikan ke sistem yang tidak linear di atas disimulasikan dan diuji dengan menggunakan Matlab/Simulink sebagai platform. Kadar putaran, sudut gelinciran tepi, input kawalan dan sigma dikenalpasti sebagai parameter-parameter yang menyumbang kepada keupayaan sistem kawalan yang dicadangkan. Semua parameter ini akan disbandingkan dengan keupayaan 'Linear Quadratic Regulator (LQR)' dan pengawal penempatan kutub untuk memastikan kelasakan dan kestabilannya.

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LIST OF SYMBOLS

α_F	-	Slide slip angle at front tire
α_R	-	Slide slip angle at rear tire
β_F	-	Front chassis side slip angle
β_R	-	Rear chassis side slip angle
c_F	-	Front cornering stiffness
c_R	-	Rear cornering stiffness
δ_F	-	Front steering angle
δ_R	-	Rear steering angle
F_{ytF}	-	Lateral force at front tire
F_{ytR}	-	Lateral force at rear tire
ℓ_F	-	Distance between center of gravity (CG) and front axle
ℓ_R	-	Distance between center of gravity (CG) and rear axle
F_{yF}	-	Dominant component in chassis coordinates for front tire
F_{yR}	-	Dominant component in chassis coordinates for rear tire
F_X	-	Longitudinal force component
J	-	Car body moment of inertia
m	-	Mass of the car body

v	-	Velocity of the car
M_{ZD}	-	Disturbance
μ	-	Coefficient of road friction
$\sigma(t)$	-	Sliding surface for a single track model
Hf	-	Friction force between ground and the wheel
ρ	-	Sliding gain for a single track model
δ	-	Boundary layer thickness for a single track model
β	-	Side slip angle
r	-	Yaw rate
S	-	Generalized sliding surface

LIST OF ABBREVIATIONS

DOF	-	Degree of Freedom
ZOH	-	Zero Order Hold
LQR	-	Linear Quadratic Regulator
VSC	-	Variable Structure Control
SMC	-	Sliding Mode Control
MRAC	-	Model Reference Adaptive Control
PP	-	Pole Placement

CHAPTER 1

INTRODUCTION

1.1 Introduction

Automatic steering of vehicles is of increasing interest as part of an integrated system of automated highway or drive assistance. The design of active steering control is appeared as robustness problem. A vehicle will face a large variation of its speed and mass of the wind speed and of the contact between the tire and the road surface. Numerous control laws have been designed for automatic steering control. Recently, there are a lot of researches in the area of vehicle stability in sequence to the increasing of vehicle capabilities. This includes the active suspension system and active steering system.

In order to help the driver to maintain a safe drive and comfort, it is important that a good stability control system included into a vehicle. However, it is well known that a driver is slow to react when the vehicle becomes unstable. This is where the automatic driver assistance system takes place whereby; whenever a driver loses some degree of control, the system will detect and stabilize the vehicle immediately hence enables the driver to regain the control of the vehicle.

The vehicle suspension system has become one of the key elements of a new car. This contributes to the enhancement of car safety system which also includes the active steering control system. There are several controller techniques proposed to achieve a good vehicle stability system (Ackermann et all, 1995). The techniques are used to overcome several basic problems associated with vehicle handling which prevents vehicle stabilization and the movement of the vehicle towards the desired path (Nur, 2006).

The most common factors that influence the vehicle stability are vehicle handling and ride characteristics. The combination of these two factors with the mechanics of the road-tire interaction contributes to this problem. Therefore, the suitable control system will consider how to overcome the problems stated above.

There is one good example of car skidding. A sudden movement of the steering could make a car skid dangerously and these could lead to a worse situation. Unexpected child crossing a road may cost a driver to an evasive action. A new driver can easily overreact and accidentally roll the car. This is where the active steering control could do the corrective action. Normally the skidding situation occurs when a vehicle is driven at high speed at a normal road condition. It is impossible to happen at low speed. In addition, extreme braking action may also cause this mayhem. Therefore, since the driver’s action is not quick enough at the beginning of skidding or rollover, may lead to more dangerous situations. Here is where an automatic feedback system is useful to assist the driver to avoid it. Another is automatic driving along a lane reference where in both cases, robustness of the control system which considers the uncertainties of the road conditions are crucial. Addition factors can be considered as well such as vehicle mass, velocity and acceleration, slip-angle and yaw angle.

1.2 Project Overview

According to Ackermann (2002), there are already driver assistant systems that use braking method at each wheel. They are cheap due to the reason where they used the hardware of the existing ABS braking system with an additional yaw rate sensor and do not need a new actuator. However, there are several reasons why active steering system is considered as a good alternative.

Firstly, torque is needed to compensate yaw disturbance torques (torque is tire force times lever arm). Secondly, the difference of friction coefficient on the left and right sides (μ-split braking) may be the cause of the disturbance torque. A steering torque can compensate the braking torque and enable a straight short braking path. Lastly, energy conservation, reduction of tire wear and brakes and smooth operation around zero correction are the other reasons why an active steering should a good alternative.

In practical situations, active steering is the only feasible way for continuous operation and better comfort under continuous disturbances. Braking systems are not capable of reacting to an emergency situation sufficiently and safely. It cannot immediately compensate small errors and late during intervention of emergency situation when the vehicle is close to skidding or rolling.

The vehicle dynamics are subjected to various uncertainties due to modelling inaccuracies (You et all, 2004). Hence, robust performance capabilities against uncertainties have long been there in the stage for robust controller application due to the limitation of the conventional linear control.

The main objective is to rectify and clarify the automatic control of passenger cars for general lane-following manoeuvres. The 2-DOF controller is based on H_∞ loop-shaping methodology where it provides good lane-keeping and lane-change abilities on both curved and straight road segments. Furthermore, it offers a computationally efficient algorithm and does not require explicit knowledge of the vehicle uncertainty. However, the test results demonstrate the higher the speed of the vehicle the more unstable it will be.

1.3 Objective

There are three main objectives of this study:

1. To develop and establish a single-track car model.
2. To design a controller that based on the robust control strategy (Sliding Mode Control (SMC)). This will overcome uncertainties and disturbances of a road handling.
3. To evaluate and analyzed the performance of the system in time domain related to such as overshoot, rise time and settling time due to step response based on proposed controller.

The main objective on this research is emphasized more on the performance for disturbance rejection to prevent a car skidding due to the disturbances. Thus, various parameters such as tire slip angle and yaw will be observed to verify the performance of the proposed controller. Hence, the performance of the proposed controller will be compared to Linear Quadratic Regulator (LQR).

The proposed controller will be verified using the Lyapunov's second method. Finally the performance will be observed and evaluated using MATLAB software and SIMULINK toolbox with respect to several parameters selected.

1.4 Scope of Project

The works commenced within the duration of this project are limited to the following aspects:

- It is based on the work done are according to the model developed by Ackermann J. et all, (1995).
- Active car steering system is evaluated on straight road due to various disturbance profiles and coefficient of road friction.
- To design a controller for a single track car model using SMC and LQR technique to compensate disturbances.
- To perform a simulation using MATLAB/SIMULINK to observe the effectiveness and robustness of the controller.
- To compare the performance of the proposed SMC with LQR.

1.5 Research Methodology

The proposal will commence with the literature study in sequence to the learning and mastering the simulation tools ready made in MATLAB.

Hence, the information needed for the active steering control which gathers the definition, basic concept and other related data are collected and then discussed with the supervisor. With the information gathered, various parameters for the active steering control system will be identified thus recognizing the suitable control strategy(s) needed to be applied. The present controllers available on the market are also identified.

Then, the mathematical model of the controller is developed and this will contribute to the design stage later. At the design stage, a new controller or an enhanced type will be developed. Soon after the design of the required controller is finished, it will be compared to the existed controller in terms of several crucial conditions such as wind, and wet road. In the end, the comparison above is realized using simulation program (MATLAB) to prove its validity.

The methodology of this research is shown in the flow chart in Figure 5 below:-

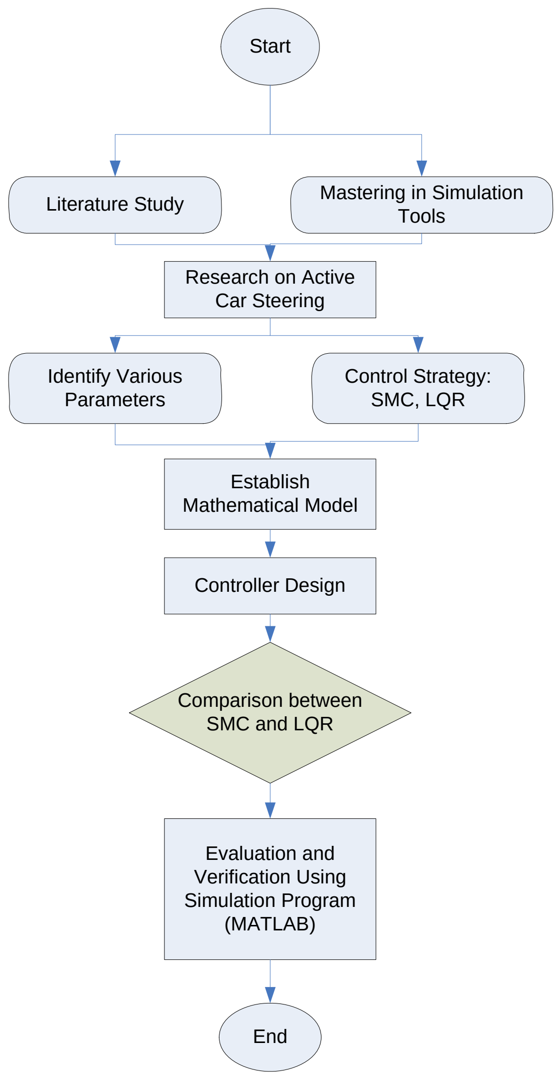

Figure 1.1 Research methodology flow chart

1.6 Literature Review

Various control strategies have been proposed by researchers to improve the vehicle stability according to several parameter variations of the vehicle. These control strategies are grouped into different approaches and techniques. Thus, several reports will be briefly discussed and presented.

According to W.Sienal (1997), whenever a controller is inserted into a vehicle system, it may worsen the condition of the road handling since most approaches assumed linearized models in the design and do not consider nonlinearity in the tire characteristics. These approaches may yield good results as long as the vehicle remains within the linear region of the tire characteristics. Therefore the condition may worsen the driving situation drastically compared to conventional vehicle, as soon as it enters the nonlinear region of the tire characteristics. It is an important factor to consider the stability of the vehicle when designing a controller.

J. Ackermann (1994) presented a robust decoupling of car steering dynamics with arbitrary mass distribution. The restrictive mass distribution assumption was abandoned and a generalized decoupling control law for arbitrary mass distribution was derived. The result of this paper provides an interface between the modelling of the steering dynamics of a single car by two masses and the higher level control problems of automatic steering and distance keeping of single mass models in a platoon of cars. However, there are some restrictive assumption in this paper which is the constant velocity, small sideslip and steering angles.

Said, (1996) proposed H_∞ control strategy for the active steering of railway vehicles with independently rotating wheel sets. This research is emphasized on stabilizing the wheel set and to provide a guidance control. The developed controller was able to maintain stability and good performance when parameter variations occur, in particular at the wheel-rail interface. The controller is also robust against uncertainties that are not included in the model such as actuator dynamics. The major task was to try and solve the difficult design conflict between the stability, curving performance and passenger comfort requirements. However, studies from this paper shown that the two wheels on the same axle were allowed to rotate independently from each other. The main drawback was; the independently rotating wheel set (or wheel pair) does not have the natural curving ability of the conventional wheel set, and some form of guidance action becomes necessary.

Doyle et al. (1989) proposed H_∞ control approach to overcome robust stabilization and uncertain plants. You and Jeong et al. (2002) designed linear matrix inequalities based on H_∞ methodology. Previously H∞ loop-shaping design procedure was proposed by McFarlene and Glover (1990). The results showed that this method provides a computationally efficient algorithm and does not require explicit knowledge of the uncertainty.

The combinations of H∞ loop shaping and 2-DOF has been reported by You and Jeong (2004) in order to achieve high performance control system for vehicle handling. It has shown that this algorithm allowed separate processing of the robust stabilization problem and reference signals. The test results the robust control scheme offers a computationally efficient method and does not require explicit knowledge of the vehicle uncertainty. The presented system exhibits the required performances and robustness properties under parameter variations while maintaining passenger comfort. However, the test results demonstrate that higher vehicle speed has a destabilizing effect on the vehicle system.

A model reference adaptive control (MRAC) technique of 2WS cars which is realized by steer-by-wire technology has been reported by T. Fukao et al. (2001). The aim of MRAC is to make the output of varies parameter asymptotically approach the output of a user defined reference model that represents a desired characteristics. The study introduce first-order system whose output is D*, defined as the combination of yaw rate and lateral acceleration. This method can treat the nonlinear relationships between the slip angles and the lateral forces on tires, and the uncertainties on the friction of the road surface.

Moreover, intelligent based techniques such as fuzzy logic, neural network and genetic algorithm have been applied to the active steering system. M.K.Park et al. (1996) presented a fuzzy-rule-based cornering force estimator to avoid using an uncertain highly nonlinear expression, and neural network compensator is additionally utilized for the estimator to correctly find cornering force. The result indicated that the proposed control system is robust against the uncertainty in vehicle dynamic model disturbances such as a side wind gust and road conditions.

K.Huh et al. (1999) proposed a fuzzy logic controller with Hardware-In-the-Loop Simulation (HILS) simulator to evaluate the performance of the system on a slippery road. HILS simulator is composed of hardware (steering wheel) and software (vehicle simulation tool and steering control system). This method used fuzzification, fuzzy inference and defuzzification technique. It can be observed that this controller is able to maintain the steering manoeuvrability on slippery road and quite useful in order to correct the vehicle's route when the vehicle's direction is biased due to side wind or obstacles. However, the proposed steering control system is similar as the ABS braking system.

1.7 Layout of Thesis

This section explains the outline structure of the thesis.

Chapter 2 deals with the mathematical modelling of the system. The formulation of the integrated dynamic model of this system is presented in detail. In the beginning, the state space representations of the chassis and wheel dynamics comprising of DC motors are formulated. The assumptions and limitations that been added to the model will be described accordingly.

Chapter 3 discusses control algorithm design for controlling the system. The analysis regarding the performance of designed controller will be presented.

Chapter 4 discusses the simulation results. The performance of the SMC and LQR controller are evaluated and analysed by simulation using Matlab/Simulink platform.

Chapter 5 will conclude all the topics and suggest recommendations for future works.