MODELLING AND CONTROL OF SEMI ACTIVE SUSPENSION SYSTEM INCORPORATING MAGNETORHEOLOGICAL DAMPER FOR GENERIC VEHICLE

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requirements for the award of the degree of
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All praises to Allah the Almighty

To my parents, Sulaiman Mamat and Zainuyah Abbas,

my wife Siti Zubaidah, my daughter Siti Aisyah Humaira and my son Safwan Sadiq

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ABSTRACT

This study presents the simulation and experimental works for Magnetorheological (MR) semi active suspension system in generic vehicles. In simulation study, a seven degree of freedom (7-DOF) vehicle model was developed using MATLAB-Simulink and verified using TruckSim. A semi active controller with road friendliness oriented was developed to reduce vehicle tire force; besides, ride comfort becomes the secondary objective of the proposed controller. The proposed semi active controllers which are Tire Force Control (TFC), Aided Tire Force Control (ATFC) and ground Semi Active Damping Force Estimator (gSADE) and simulation results were compared with existing controller known as Groundhook (GRD) and passive suspension system. Then, these controllers were applied experimentally using generic quarter vehicle model. The overall results showed gSADE is the most effective controller in reducing vehicle tire force and improving ride comfort. Both reduction of gSADE vehicle tire force and ride comfort compared with passive system are similar about 14.2%. In the simulation study, ideal and real cases (using MR damper model) were conducted. In the ideal case, two bump profiles were used to test the effectiveness of the controller and the results showed gSADE recorded the highest improvement of the tire force followed by ATFC, TFC, GRD and passive system. The maximum improvement of gSADE control compared with passive system is about 21% in reduction of tire force and 22% in improving ride comfort. A similar test was conducted using MR damper model, and the overall result showed gSADE recorded almost similar improvement of the tire force compared with TFC. The maximum reduction of vehicle tire force and improvement of ride comfort using gSADE control compared with passive are 15% and 30%, respectively.

ABSTRAK

Kajian ini membentangkan kerja simulasi dan eksperimen bagi Magnetreologi (MR) suspensi separa sistem aktif dalam kenderaan umum. Dalam kajian simulasi, sebuah kenderaan dengan tujuh darjah kebebasan (7-DK) dibangunkan dengan menggunakan MATLAB-Simulink dan disahkan menggunakan TruckSim. Kawalan separa aktif dengan berorientasikan mesra jalanraya dibangunkan untuk mengurangkan daya tayar kenderaan; selain itu, keselesaan perjalanan dijadikan objektif sekunder. Pengawal separa aktif yang dicadangkan ialah *Tire Force Control* (TFC), *Aided Tire Force Control* (ATFC) dan *ground Semi Active Damping Force Estimator* (gSADE) dan hasil simulasi dibandingkan dengan pengawal sedia ada yang dikenali sebagai *Groundhook* (GRD) dan sistem suspensi pasif. Kemudian semua pengawal tersebut digunakan dalam eksperimen menggunakan model kenderaan suku-umum berskala. Keputusan keseluruhan menunjukkan pengawal gSADE paling berkesan dalam mengurangkan daya tayar kenderaan dan meningkatkan keselesaan tunggangan. Kedua-dua pengurangan kawalan gSADE iaitu daya tayar kenderaan dan keselesaan tunggangan berbanding dengan sistem pasif adalah sama iaitu 14.2%. Dalam kajian simulasi, kes ideal dan sebenar (menggunakan model peredam MR) telah dijalankan. Dalam kes ideal, dua profil bonggol telah digunakan untuk menguji keberkesanan pengawal dan keputusan menunjukkan gSADE telah mencatat peningkatan terhadap pengurangan daya tayar yang paling tinggi diikuti oleh ATFC, TFC, GRD dan sistem pasif. Peningkatan maksima kawalan gSADE berbanding dengan sistem pasif adalah kira-kira 21% dalam pengurangan daya tayar dan 22% peningkatan keselesaan tunggangan. Ujian yang sama telah dijalankan dengan menggunakan model peredam MR, dan keputusan keseluruhan menunjukkan gSADE mencatat peningkatan terhadap pengurangan daya tayar yang hampir sama dengan TFC. Pengurangan maksima daya tayar kenderaan dan peningkatan keselesaan tunggangan menggunakan kawalan gSADE berbanding pasif adalah masing-masing 15% dan 30%.

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LIST OF SYMBOLS

A	-	Surface area [m^2]
A_{fSADE}	-	fSADE gain
A_{SADE}	-	SADE gain
a	-	Length of vehicle from the center of gravity to the front end
B	-	Sampling interval
b	-	Length of vehicle from the center of gravity to the rear end
c	-	Length of the vehicle from the center of gravity to the right end
c_0	-	Viscous damping
c_{0a}	-	Modified Bouc-Wen damping constant
c_{0b}	-	Modified Bouc-Wen damping constant
c_1	-	Damping coefficient
c_{1a}	-	Modified Bouc-Wen damping constant
c_{1b}	-	Modified Bouc-Wen damping constant
c_{ADD}	-	Acceleration Driven Damper damping coefficient
$c_{d,ij}$	-	Damping coefficient at; *i* for front or rear and *j* for left or right
c_{grd}	-	Groundhook damping coefficient
c_{gSADE}	-	gSADE damping coefficient
c_{mg}	-	Modified Groundhook damping coefficient
c_{ms}	-	Modified Skyhook damping coefficient
c_s	-	Damping coefficient
c_{SADE}	-	SADE damping coefficient
c_{sky}	-	Skyhook damping coefficient

c_{s_fuzzy}	-	fSADE damping coefficient
c_{TFC}	-	Tire Force Control damping coefficient
d	-	Length of the vehicle from the center of gravity to the left end
F	-	Force [N]
F_{ADD}	-	Acceleration Driven Damper damping force
F_{ATFC}	-	Aided Tire Force Control damping force
F_{BM}	-	Bingham model force
F_{BW}	-	Bouc-Wen model force
F_{dg}	-	Modified Groundhook damping force
F_{dh}	-	Modified Hybrid Skyhook-Groundhook damping force
F_{ds}	-	Modified Skyhook damping force
F_{dt}	-	Damper tire force
F_{fSADE}	-	fSADE damping force
F_{GFM}	-	Gamota-Filisko model force
F_{GRD}	-	Groundhook damping force
F_{gSADE}	-	gSADE damping force
F_{hybrid}	-	Hybrid Skyhook-Groundhook damping force
F_L	-	Vertical load
F_{MBW}	-	Modified Bouc-Wen model force
$F_{S,FL}$	-	Sprung front left force
$F_{S,FR}$	-	Sprung front right force
$F_{S,ij}$	-	Suspension sprung force at; *i* for front or rear and *j* for left or right
$F_{S,RL}$	-	Sprung rear left force
$F_{S,RR}$	-	Sprung rear right force
F_{SADE}	-	SADE damping force
F_{sd}	-	Suspension damper force

$F_{sd,ij}$	-	Suspension damper force at; *i* for front or rear and *j* for left or right
F_{SKY}	-	Skyhook damping force
F_{ss}	-	Suspension spring force
$F_{ss,ij}$	-	Suspension spring force at; *i* for front or rear and *j* for left or right
$F_{t.ij}$	-	Dynamic tire force at; *i* for front or rear and *j* for left or right
F_{TFC}	-	Tire Force Control damping force
$F_{ts,ij}$	-	Vehicle tire stiffness at; *i* for front or rear and *j* for left or right
F_v	-	Force from the MR damper characteristic at specific relative velocity
$F_{v,\max}$	-	Maximum force at 5 V
$F_{v,\min}$	-	Minimum force at 0 V
f	-	Semi active suspension damping force
f_0	-	Force due to presence of accumulator
f_a	-	Active suspension damping force
f_c	-	Coulomb friction force
G	-	Aided Tire Force Control gain
G_d	-	Road roughness in term of power spectrum density
g	-	Gravity acceleration [m/s^2]
g_{gSADE}	-	gSADE gain
h	-	Distance between fixed and moving plate [m]
h_s	-	The centre of gravity of sprung mass
I	-	Desired current [Amp]
I_i	-	Current from 0 to 2 Amp
$I_{\max}$	-	Maximum current ,2 Amp
$I_{\min}$	-	Minimum current 2, Amp
J_x	-	Moment of inertia about *x*-axis
J_y	-	Moment of inertia about *y*-axis

k	-	ISO road roughness classification
k_0	-	Linear spring stiffness
k_1	-	Spring stiffness
k_s	-	Suspension spring stiffness
$k_{s,ij}$	-	Spring stiffness at; *i* for front or rear and *j* for left or right
k_t	-	Tire stiffness
L	-	Length of road profile
m_1	-	Sprung mass
m_2	-	Unsprung mass
m_s	-	Sprung mass
$m_{u,FL}$	-	Unsprung mass at front left
$m_{u,FR}$	-	Unsprung mass at front right
$m_{u,RL}$	-	Unsprung mass at rear left
$m_{u,RR}$	-	Unsprung mass at rear right
$m_{u,ij}$	-	Unsprung mass at; *i* for front or rear and *j* for left or right
n	-	Bouc-Wen and modified Bouc-Wen hysteresis parameter
$n_{\max}$	-	Maximum theoretical sampling spatial frequency
n_s	-	Spatial frequency
n_0	-	0.1 cycle/meter
n_i	-	Generic spatial frequency
T	-	Time [s]
v	-	Desired Voltage
v_i	-	Voltage from 0, 1, 2, 3, 4, 5 V
$v_{\max}$	-	Maximum voltage, 5 V
$v_{\min}$	-	Minimum voltage, 0 V
v_p	-	Plate velocity [m/s]
x	-	Abscissa variable
x_0	-	Initial displacement

x_1	-	Sprung mass displacement
$\dot{x}_1$	-	Sprung mass velocity
$\ddot{x}_1$	-	Sprung mass acceleration
x_2	-	Unsprung mass displacement
$\dot{x}_2$	-	Unsprung mass velocity
$\ddot{x}_2$	-	Unsprung mass acceleration
$\dot{x}_{12}$	-	Relative velocity between sprung and unsprung masses
z	-	Modified Bouc-Wen hysteretic component
z_0	-	Road elevation
$\dot{z}_1$	-	Sprung mass velocity
$\ddot{z}_1$	-	Sprung mass acceleration
$\dot{z}_2$	-	Unsprung mass velocity
$\ddot{z}_2$	-	Unsprung mass acceleration
$\dot{z}_{12}$	-	Relative velocity between sprung and unsprung masses
$z_{r,ij}$	-	Road elevation at; *i* for front or rear and *j* for left or right
$\ddot{z}_{S,eff}$	-	Effective values of ride index performance
$\ddot{z}_s$	-	Sprung acceleration
$z_{s,ij}$	-	Sprung vertical displacement at; *i* for front or rear and *j* for left or right
$\dot{z}_{s,ij}$	-	Sprung vertical Velocity at; *i* for front or rear and *j* for left or right
$z_{u,ij}$	-	Unsprung vertical displacement at; *i* for front or rear and *j* for left or right
$\dot{z}_{u,ij}$	-	Unsprung vertical velocity at; *i* for front or rear and *j* for left or right
$\ddot{z}_{u,ij}$	-	Unsprung vertical acceleration at; *i* for front or rear and *j* for left or right
α	-	Bouc-Wen and modified Bouc-Wen hysteresis parameter
α_a	-	Modified Bouc-Wen damping constant

α_b	-	Modified Bouc-Wen damping constant
α_{ms}	-	Modified Skyhook to passive combined ratio
β	-	Bouc-Wen and modified Bouc-Wen hysteresis parameter
β_{mg}	-	Modified Groundhook to passive combined ratio
φ_i	-	Random phase angle
$\ddot{\varphi}$	-	Roll acceleration
γ	-	Bouc-Wen and modified Bouc-Wen hysteresis parameter
η	-	Modified Bouc-Wen constant
μ	-	Hybrid Skyhook-Groundhook combined ratio
μ_{ATFC}	-	Aided Tire Force Control combined ratio
μ_m	-	Modified Hybrid Skyhook-Groundhook combined ratio
δ	-	Bouc-Wen and modified Bouc-Wen hysteresis parameter
$\ddot{\theta}$	-	Pitch acceleration

LIST OF ABBREVIATIONS

ADD	-	Acceleration Driven Damper
ATFC	-	Aided Tire Force Control
CDC	-	Continuous Damping Control
ConF	-	Control Forces
CPU	-	Computer Processing Unit
DAQ	-	Data Acquisition System
DLC	-	Dynamic Load Coefficient
DLSF	-	Dynamic Load Stress Factor
DOF	-	Degree-of-Freedom
ER	-	Electrorheological
FLO	-	Fuzzy Logical Controller
fSADE	-	Fuzzy Semi Active Damping Force Estimator
GRD	-	Groundhook
gSADE	-	Ground Semi Active Damping Force Estimator
H∞	-	H-Infinity
HGV	-	Heavy Goods Vehicles
HSAS-FC	-	Hybrid Stability Augmentation System-Force Control
ISO	-	International Organization for Standardization
MHSG	-	Hybrid Skyhook-Groundhook
MR	-	Magnetorheological
MRD	-	Magnetorheological Damper
PSD	-	Power Spectrum Density
PWM	-	Pulse Width Modulation
RMS	-	Root-Mean-Square
SADE	-	Semi Active Damping Force Estimator
SKY	-	Skyhook
TFC	-	Tire Force Control

USB	-	Universal Serial Bus

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CHAPTER 1

INTRODUCTION

1.1 Background of Problem

A vehicle that transports goods needs high vehicle stability, ride comfort and road friendliness. Some of this vehicle is regularly driven on different terrains, and thus the stability of the vehicle needs to be studied to improve the vehicle ride quality and road friendliness. Generally, suspension is one of the important systems that can be improved to achieve good ride comfort and road friendliness (Woodrooffe, 1995).

A vehicle suspension system is a mechanism that separates the vehicle body (sprung mass) from vehicle wheels (unsprung mass). Ride, handling and safety are criteria that always been considered in designing a vehicle suspension. There are three types of common suspension being used in the automotive industry namely passive, semi active and active suspensions. Many automotive researchers have studied the benefits of passive suspension system intensively compared to active and semi active suspension. Active suspension control systems rely entirely on external power to supply forces to operate the actuators. Although an active suspension provides better performance than semi active suspensions, it has major drawbacks such as the need for a large external power source, increased complexity and cost and decreased reliability. Therefore, research on semi active suspension control systems has grown extensively because a semi active suspension offers both the reliability of a passive system and the versatility of an active control system; its performance lies between active and passive suspension system (Hedrick and Yi, 1991; Yi *et al*.,1992).

In recent years, magnetorheological (MR) fluids have attracted researchers' interest due to their wide range of use as vibration dampers for vehicle suspension systems (Bakar *et al*., 2011). Their damping capabilities can be adjusted very quickly by applying suitable electric or magnetic fields (Stanway *et al*., 1996; Bakar *et al*., 2011). MR fluid dampers enable vibration control of semi active suspension systems with reaction times in the range of milliseconds; in addition, it requires low power consumption. Due to their rather simple mechanical design which involves only few moving parts thus ensure high technical reliability and exhibit almost no wear (Butz and Stryk, 2002). These fluids can vary their viscosity by varying the magnetic field across the fluid. The fluid contains iron particles which are aligned by magnetic field (Spencer *et al*., 1997) and this alignment makes the oil stiffer and rigid. The fluid responds very quickly and the alignment can be done within 6.1 ms (millisecond) (Symans and Constantinou, 1999). The MR damper is seen as a safe damper, because of its action when power loss occurs; after semi active suspension loss its power it will reverts to a passive damper.

Semi active suspension serves the same purpose as passive suspension; the only difference is semi active suspension damping forces can be controlled. The idea of semi active suspension has been introduced by Karnopp *et al*. (1974) and the controller initially proposed is Skyhook (SKY) control for ride control. Novak and Valasek, (1996) have proposed modified skyhook known as Groundhook (GRD) control with the purpose of reducing vehicle tire force. Most of the important and basic issue to be studied in a semi active suspension system is ride comfort and mostly in passenger vehicle. One of the widely used comforts oriented controller which has been successfully applied in semi active suspension is Skyhook control. Other numerous approaches have also been developed such as optimal control (Savaresi *et al*., 2005), clipped optimal control (Canale *et al*., 2006; Giorgetti *et al*., 2006) and H∞ control (Du *et al*., 2005).

For heavy vehicle, aiming to reduce vehicle tire force is challenging. Cole and Cebon, (1989), and Cole *et al*. (2000) did extensive work on semi active suspension for heavy vehicle, both theoretical and experimental. Groundhook control was also investigated by Valasek *et al*. (1997) and shown the reduction of heavy vehicle tire force (Novak and Valasek, 1996; Savaresi *et al*., 2005). In theory, semi active suspension with GRD controller can control tire velocity by installing fictitious damper on the vehicle ground; and it shows that the proposed controller is able to reduced vehicle tire force.

1.2 Statement of Problem

The designer of heavy goods vehicles (HGVs), today are more aware of the needs to design suspension system that satisfies an additional criterion, namely road friendliness that reduces road damage caused by heavy goods vehicles. The forces of interaction between the tires and the road surface induce stresses on the pavement, which ultimately will lead to road failure (Tsampardoukas *et al*., 2008; Yarmohamadi and Berbyuk, 2012). For passenger vehicles the contact forces between tires and road are too small to cause significant pavement damage (Valasek *et al*., 1998). The high cost of maintenance of highways and road networks, because of premature road failure due to heavy traffic has caused global concern. Fluctuating component of tire-road force is the main contributor to road damage along with other environmental factors (Pable *et al*., 2007). For HGVs the contact forces between tires and road are considerable and hence for these vehicles, suspension parameters need to be selected to reduce road damage.

Ride comfort and road friendliness of a vehicle performances are dependent on the road that the vehicle travels. Ride comfort is proportional to the absolute acceleration of the vehicle body, road friendliness is linked to the vehicle unsprung performances (Chen *et al.*, 2010); and stability of the vehicles is related to the tire-ground (Eslaminasab, 2008).

The aim of this research is to propose a semi active suspension control for generic vehicle, incorporating with magnetorheological damper by developing a new control algorithm and investigate the effectiveness of the proposed control structure in term of road friendliness and ride comfort. Furthermore, to develop understanding the effect of the semi active damper performance response time due to different control strategies through analytical and simulation methods. On the other hand, the technology of MR damper in semi active suspension has not yet been adopted for heavy vehicle (Eslaminasab, 2008).

1.3 Objective of the Study

The primary objective of this study is to propose a new control algorithm for generic vehicle to improve road friendliness and ride comfort. The supporting objective of this study are:

1. To develop seven degree of freedom (7-DOF) vehicle ride model and verify the passive vehicle model that was developed in MATLAB-Simulink with multi-body vehicle simulation software.
2. To investigate the effectiveness of the propose controller which known as Tire Force Control (TFC), Aided Tire Force Control (ATFC) and Ground Semi Active Damping Force Estimator (gSADE). The investigation in term of road friendliness and ride comfort in ideal and practical (application of MR damper model) cases.
3. To develop semi active suspension experimental test rig to validate the performance of the propose controller. The semi active suspension test rig is based on generic quarter vehicle model using MR damper.

1.4 Scope of the Study

The scopes of this study are defined as the followings:

1. Simulation study is performed on light-heavy duty truck ride (7-DOF) model where the parameters are selected from light-heavy duty truck model. The vehicle model is validated by comparing the simulation results from

MATLAB-Simulink model with vehicle simulation software namely TruckSim.

2. The quarter vehicle test rig was validated by comparing between MATLAB-Simulink and experiment results. The quarter vehicle model in MATLAB-Simulink was used to tune the controller parameters and then these parameters were applied in the experimental study.
3. The investigations of the proposed and existing controllers were only performed in vehicle ride motion; all the vehicle responses were recorded and used to analyzed the capability of the controllers in attenuating vehicle motion. The proposed controllers were compared with passive suspension and established semi active controller namely Groundhook (GRD).
4. Semi active suspension using magnetorheological damper model which based on Bouc-Wen model were used, where the rheological fluid properties control the variable damping force, in simulation study using light-heavy duty truck model.
5. The LORD® Ltd. damper, MR damper (MRD 1005-3) were used in the scaled quarter vehicle test rig. The MR damper was controlled by the current generator where the amount of current was decided by the controllers.

1.5 Research Methodology

Related past research has been reviewed to find out what other researchers have done and suitable method to develop semi active suspension system was selected. Based on vehicle ride model, related equation of motion was extracted to construct passive vehicle model in MATLAB-Simulink and validate that model with TruckSim vehicle dynamic software. Similar parameter was selected for both vehicle model, and then related vehicle responses were compared.

After MATLAB-Simulink model was accepted, then the semi active suspension model was developed. There are four aspects considered in developing the vehicle semi active system; these are vehicle model, control algorithm, current or voltage generator and MR damper model.

The first aspect is the validated vehicle model; similar vehicle model that was developed in MATLAB-Simulink were used in developing semi active suspension system. The second part is control algorithm; there are numerous control algorithms for semi active suspension but only several controllers are suitable for heavy vehicle. Most control algorithms improved vehicle ride only and ignore tire forces; in this study, the vehicle performances in term of dynamic tire forces and vehicle ride comfort were considered. The proposed controller capabilities in controlling vehicle responses will be evaluated by conducting several tests. The propose controller will also be compared with existing semi active suspension controller (Groundhook, GRD) to study its performances.

The third aspect is the implementation of current or voltage generator; this generator will generate the appropriate voltage or current to be supplied to the MR damper model. Voltage generator model was developed using a simple continuous state control and this approach has been similarly adopted by other researchers (Sims *et al*., 1999; Lai and Liao, 2002; Hudha *et al*., 2005; Bakar, 2013).

The last aspect is MR damper model. MR damper response was modeled by modified Bouc-Wen model which was proposed by Spencer *et al*., (1997). MR damper provides semi active force as feedback to the vehicle suspension model and controlled by voltage or current generator. When the magnetic field is applied, the particle chains formed, the fluid reversibly changes between free flowing fluid to semi-solid (Tian *et al*., 2011). Figure 1.1 shows flow of research procedure.

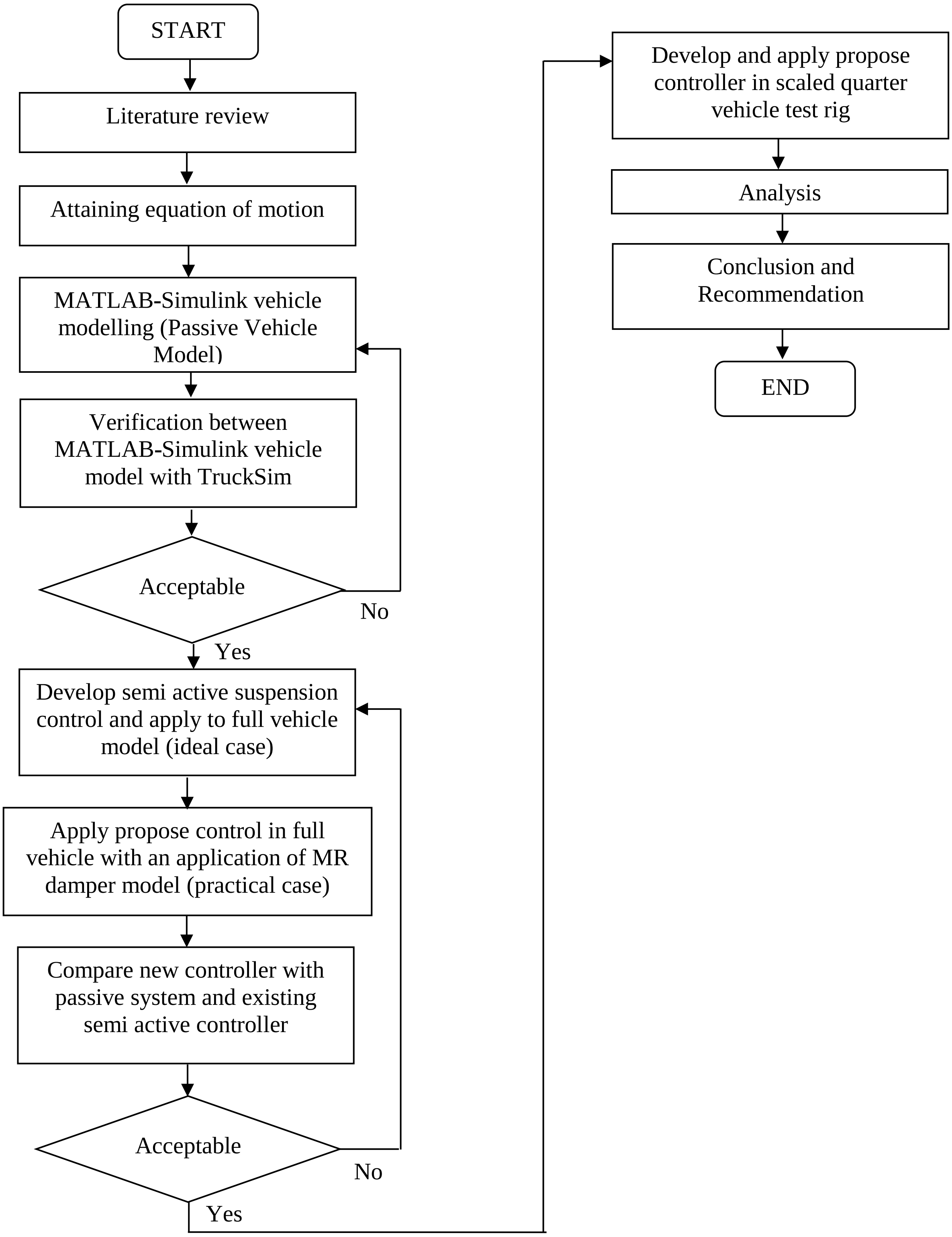

Figure 1.1 Research procedure

1.6 Significant of Research

Based on previous study, road friendliness (road damage) are the important issue need to be considered in designing a heavy vehicle suspension together with vehicle ride comfort. Even though, there are some studies on those criteria but their studies were limited to the simulation and most of the studies considered in improving passenger vehicles rather than heavy vehicles. Most vehicles used passive suspensions; those vehicles are being driven in different terrains and carry goods; so, effective control strategies in semi active suspension need to be develop to reduce road damage and improve vehicle ride comfort.

With a new proposed controller, whereby able to reduce road damage; the cost of worldwide road pavement issue can be reduced. While, by improving vehicle ride comfort, vehicle that carrying goods inside it can reduce the probability from being damage; i.e. vehicle that carry machine or anything that sensitive enough from high vibration. Proposed controller also can be applied to the passenger vehicle because the controller able to improve ride comfort.

The proposed control performances will be compared with passive and existing semi active suspension control (Groundhook, GRD) in ideal case study; then the MR damper model will be applied and integrated with the controller as in actual/practical case study. This study is not limited to simulation only but extended to experimental work, where the proposed controller is tested using scaled quarter vehicle rig to test the real time performance of the controller.

1.7 Contribution of Research

The contributions of this research are given as follows:

1. Three new semi active control algorithms were proposed which aim to reduce vehicle tire force; these controllers are TFC, ATFC and gSADE. The TFC was

designed based on unsprung mass acceleration control, so it able to reduce the vehicle tire force during uneven road condition; furthermore, reduce the road damage. The ATFC is designed based on the sprung and unsprung acceleration control, so that the controller is not only perform on the tire force but extended to the vehicle ride comfort. Semi active suspension with gSADE control is almost similar concept as ATFC, but the advantages of this controller is it maximize the function of MR damper by selecting the best current to send as an input to the MR damper.

2. Simulated performance analysis in ideal and actual/practical studies, and these algorithms performance were compared with existed semi active controller which is GRD and passive suspension system. In ideal case, the controllers were act as perfect system, where all require forces can be achieve. In practical studies, the actuator model is applied to the system to give limitation to the controller. The proposed and existing controller were performed using similar analysis.
3. Real-time application of these controllers in scaled quarter vehicle test rig; and also to compare performances of the proposed controllers with GRD control and passive suspension system. The vehicle test rig is interchangeable between passive and semi active system.

1.8 Organization of the Thesis

Chapter 1 is the introduction chapter. This chapter introduces the background of research, problems statement, research methodology, the contribution of research and organization of the thesis was clearly described.

Chapter 2 presents the literature review of related work of semi active suspension. In this chapter, the classification of vehicle suspension, the performance criteria that considered in designing suspension and related vehicle model was defined. This chapter also explained the overview of semi active suspension control which have been done by researchers and engineers; and then the research gap was identified.

Chapter 3 presents the vehicle ride modelling and validation. This chapter describes the vehicle model developed by mathematically. Assumption and limitation on the vehicle modelling are also explained. The vehicle model description in MATLAB-Simulink and TruckSim software explained. The validation is shown by comparing the vehicle responses between MATLAB-Simulink and TruckSim model. Finally, the validation of quarter vehicle model in MATLAB-Simulink is presented by comparing the vehicle responses between MATLAB-Simulink and experiment.

Chapter 4 presents the study of a semi active controller in the suspension system. Three control algorithms were proposed, these controllers known as Tire Force Control (TFC), Aided Tire Force Control (ATFC) and ground Semi Active Damping Force Estimator (gSADE). The performances of semi active suspension system using the quarter vehicle rig with the used of actual MR damper. This chapter describes the development of a scaled quarter vehicle test rig. The components which involved in the experiment, and the development of semi active system in real-time are clearly explained. Finally, the results of vehicle performances are discussed.

Chapter 5 present the semi active suspension control which were applied on the verified full vehicle (7-DOF) model. The performances of the controllers were simulated by two types of road profile as an input, and the vehicle responses was compared with the existing controller which known as Groundhook (GRD) control, and also was compared with a passive suspension system. Related vehicle responses are recorded and discussed.

Chapter 6 presents the application of the MR damper model in the semi active suspension system. MR dampers and voltage generator model are also explained. The performances of the proposed controllers were simulated using verified vehicle model. Similar road profiles as in the ideal case was used to evaluate vehicle performances. Finally, the results of vehicle performances are discussed.

Chapter 7 gives the overall conclusion of the thesis. This chapter also provides several recommendations for future work.

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