



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**DESIGN AND DEVELOPMENT OF 3-DOF MOTION PLATFORM  
FOR VEHICLE SIMULATOR**

This report submitted in accordance with requirement of the UniversitiTeknikal  
Malaysia Melaka (UTeM) for the Bachelor Degree of Mechanical Engineering  
(Automotive) with Honours.

By

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## **DEDICATION**

To my beloved parents and family members who always fully support me in my life

## **ACKNOWLEDGEMENT**

I would like to use this chance to thank a lot of people who helping and teaching me while going through this Final Year Project or PSM study.

First of all, I am indeed grateful to my host university which is University Teknikal Malaysia Melaka (UTeM) for giving me this opportunity to carry out a two semester or one year final year project which will surely improve my self at many aspect such as knowledge, thinking and communication before entering the real working environment. I am sure that all the knowledge that I gain from the study will help me in accomplish my tasks for in the future engineering world. I am looking forward to further study in my beloved university.

Secondly, I would like to say thank you to my PSM supervisor and my hero Mr. Fauzi bin Ahmad for his patience, guidance and kindness. He provided many useful ideas, suggestions and examples to me on how to carry out my tasks or works effectively. Besides that, he also had the hard work to teach and guide me on a lot of MATLAB/Simulink software knowledge and skills. Furthermore, he will keep encourage me with word of caring and kindness to reduce my pressure at the time not even facing the tasks of PSM study but also others subject tasks. For me, he is the one of the caring and greatest lecturers that I have ever met in my study life.

Lastly, I would like to thank all the university staff and all my course mates who are also under going their PSM study for their cooperation and contributions. We always share information among each other in order to make things done. We are able to communicate well with each other and discussed together happily.

**THANK YOU! I LOVE YOU ALL!**

## **ABSTRACT**

The objectives of doing this report is to record down and summarize out what I have been done during my PSM study and also the valuable knowledge and mechanical skills that I have learnt throughout my daily tasks performed. This report starts with background study for my PSM title which is design and developing of 3-DOF motion platform for vehicle simulator. For the introduction part I will stated out the problem statement and the reason that affect me to study this title. Besides, inside this part of my reports I also include other detail of this study such as scope and objective of this study, project planning and methodology, Gantt chart and methodology flow chart. It is follow by the chapter 2 which stated out the literature review about the study of the vehicle simulator. This chapter include the fundamental of some mechanical knowledge in motion platform such as slider crank and stepper motor. Besides, this chapter also conclude some research method and research result that other researcher had done at the past. Next is the chapter 3, 4 and which showing the mechanisms that I using in this study such as vehicle model and slider crank mechanism. Throughout all simulation activities, I have gained the simulation result for the modeling of 7-DOF vehicle ride model in MATLAB/Simulink software and verified the model with CarSimEd software by comparing the result taken by both softwares. All this are show in chapter 3 and chapter 4 in this report. Other than that, at chapter 5 and 6 the development of 3-DOF motion platform had been done by simulate the platform model while verified with the 7-DOF full vehicle ride model. Finally, I have come out with conclusion which sum up my overall sharing about the study for PSM. Throughout this study, I have the opportunity improve my knowledge for simulation software and engineering mechanisms.

## ABSTRAK

Tujuan saya menulis laporan ini adalah untuk mencatat dan meringkaskan apa yang telah dilakukan oleh saya selama penelitian Projek Sarjana Muda 1 saya dan juga pengetahuan serta kemahiran mekanik yang telah saya pelajari dalam semua tugas-tugas seharian saya dilakukan. Laporan ini bermula dengan kajian latar belakang untuk judul PSM saya yang bertajuk desain dan pembinaan platform dalam 3 gerakan untuk simulator kenderaan. Untuk bahagian pengenalan saya akan menyatakan keluar kenyataan masalah dan sebab-sebab yang mempengaruhi saya untuk belajar judul ini. Selain itu, dalam sebahagian laporan saya, saya juga termasuk detail lain untuk kajian tersebut seperti ruang lingkup dan tujuan kajian, perancangan projek dan metodologi, carta Gantt dan diagram alir metodologi. Hal ini diikuti dengan bab 2 yang menyatakan tentang kajian ilmiah dalam kajian simulator kenderaan. Bab ini meliputi pengetahuan asas mekanik pada platform gerakan seperti slider crank dan stepper motor. Selain itu, bab ini juga menyimpulkan beberapa kaedah kajian dan hasil kajian yang penyelidik lain telah dilakukan dalam masa yang lalu. Selepas itu, bab 3 dan 4 menunjukkan mekanisme yang saya gunakan dalam kajian ini seperti model kenderaan dan mekanisme slider crank. Sepanjang semua aktiviti simulasi, saya telah mendapatkan hasil simulasi untuk pemodelan model kenderaan 7 gerakan pada MATLAB / Simulink dan disahkan dengan perisian CarSimEd dengan membandingkan keputusan yang diambil oleh kedua-dua perisian. Semua ini akan ditunjuk dalam bab 3 dan bab 4 dalam laporan ini. Selain itu, simulasi untuk platform telah dicapai dan dibukti dalam bab 5 dan 6. Akhirnya, saya telah dapat membuat kesimpulan sebagai tujuan perkongsian saya dalam bab 7 secara keseluruhan tentang kajian untuk PSM. Sepanjang kajian ini, saya diberi peluang untuk meningkatkan pengetahuan saya dalam perisian simulasi dan mekanisme kejuruteraan.

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## LIST OF SYMBOLS

|                 |  |
|-----------------|--|
| $F_{fl}$        | = suspension force at front-left corner                                  |
| $F_{fr}$        | = suspension force at front-right corner                                 |
| $F_{rl}$        | = suspension force at rear-left corner                                   |
| $F_{rr}$        | = suspension force at rear-right corner                                  |
| $m_s$           | = sprung mass weight   |
| $\ddot{z}_s$    | = sprung mass acceleration at body centre of gravity                     |
| $F_{sfl}$       | = front left suspension spring force                                     |
| $F_{sfr}$       | = front right suspension spring force                                    |
| $F_{srl}$       | = rear left suspension spring force                                      |
| $F_{srr}$       | = rear right suspension spring force                                     |
| $F_{dfl}$       | = front left suspension damping force                                    |
| $F_{dfr}$       | = front right suspension damping force                                   |
| $F_{drl}$       | = rear left suspension damping force                                     |
| $F_{drr}$       | = rear right suspension damping force                                    |
| $K_{sfl}$       | = front left suspension spring stiffness                                 |
| $K_{sfr}$       | = front right suspension spring stiffness                                |
| $K_{srl}$       | = rear left suspension spring stiffness                                  |
| $K_{srr}$       | = rear right suspension spring stiffness                                 |
| $C_{sfl}$       | = front left suspension damping constant                                 |
| $C_{sfr}$       | = front right suspension damping constant                                |
| $C_{srl}$       | = rear left suspension damping constant                                  |
| $C_{srr}$       | = rear right suspension damping constant                                 |
| $Z_{ufl}$       | = front left unsprung mass vertical displacement                         |
| $Z_{ufr}$       | = front right unsprung mass vertical displacement                        |
| $Z_{url}$       | = rear left unsprung mass vertical displacement                          |
| $Z_{urr}$       | = rear right unsprung mass vertical displacement                         |
| $\dot{Z}_{ufl}$ | = front left unsprung mass velocity                                      |
| $\dot{Z}_{ufr}$ | = front right unsprung mass velocity                                     |
| $\dot{Z}_{url}$ | = rear left unsprung mass velocity                                       |
| $\dot{Z}_{urr}$ | = rear right unsprung mass velocity                                      |
| $a$             | = distance between vehicle front to the centre of gravity of sprung mass |
| $b$             | = distance between vehicle rear to the centre of gravity of sprung mass  |

$\theta$  = pitch angle at body centre of gravity  
 $\varphi$  = roll angle at body centre of gravity  
 $Z_s$  = sprung mass vertical displacement at body centre of gravity  
 $Z_{sfl}$  = front left sprung mass vertical displacement  
 $Z_{sfr}$  = front right sprung mass vertical displacement  
 $Z_{srl}$  = rear left sprung mass vertical displacement  
 $Z_{srr}$  = rear right sprung mass vertical displacement  
 $\dot{\theta}$  = pitch rate at the body centre of gravity  
 $\dot{Z}_s$  = sprung mass vertical velocity at body centre of gravity  
 $K_{sf}$  = front suspension spring stiffness  
 $K_{sr}$  = rear suspension spring stiffness  
 $C_{sf}$  = front suspension damping constant  
 $C_{sr}$  = rear suspension damping constant  
 $\ddot{\theta}$  = pitch acceleration at the body centre of gravity  
 $\ddot{\varphi}$  = roll acceleration at the body centre of gravity  
 $I_{yy}$  = pitch axis moment of inertia  
 $I_{yy}$  = pitch axis moment of inertia  
 $w$  = track width of sprung mass  
 $\ddot{Z}_{ufl}$  = front left unsprung mass vertical acceleration  
 $\ddot{Z}_{ufr}$  = front right unsprung mass vertical acceleration  
 $\ddot{Z}_{url}$  = rear left unsprung mass vertical acceleration  
 $\ddot{Z}_{urr}$  = rear right unsprung mass vertical acceleration  
 $Z_{rfl}$  = front left road profile at each tires  
 $Z_{rfr}$  = front right road profile at each tires  
 $Z_{rrl}$  = rear left road profile at each tires  
 $Z_{rrr}$  = rear right road profile at each tires  
 $F_p$  = force acting on the slider crank  
 $v_p$  = velocity of the slider  
 $F_c$  = force acting perpendicular to the crank  
 $v_c$  = velocity of the crank  
 $K_p$  = Proportional gain  
 $K_i$  = Integral gain  
 $K_d$  = Derivative gain

# CHAPTER 1

## INTRODUCTION

### 1.1 Overview

Driving simulators are often used in educational and research purposes. Driving simulators' capability in producing a virtual driving environment resembling real driving condition can be used to train novice drivers before they are exposed to the real world. (Kasim, 2004). Besides, driving simulators are important in data collection for road safety research, human factor study, vehicle system development and also traffic control device development. These allow designers, engineers as well as ergonomists to bypass the design and development process of detailed mock-ups of the automobile interiors for human factor and vehicle performance studies.

A driving simulators range in complexity, capability and can be classified into 3 major groups that are high, medium and low-level driving simulator. The National Advanced Driving Simulator NADS in IOWA, USA and the Toyota Driving simulator in Japan which started its operation on Nov 2007 are all the examples of high level simulator. These high level simulators have sophisticated systems such as a dome with 360 degree projection screen for virtual environment generation. They are also equipped with a full vehicle cab and a large motion platform which can mimic the driving conditions. On the opposite, low level simulators can be relatively simple which only require personal computer or graphical work station, monitor and a simple cab and driving controls. Between these two extremes is the mid-level driving simulator. Mid-level driving simulators can have adequate fidelity, validity and realism; yet affordable compared to the high-level driving simulator. With proper configuration and harmonization of the visual, motion and cues, they can perform a wide range of driving scenarios and tasks.

The goal of this study is to explore the possibility of development of vehicle driving simulator with low cost but high performance. The main work of this study includes modeling and validation of the 3-DOF motion platform. The research begins with the analytical studies on MATLAB/ Simulink software and following by modeling of 7-DOF full

vehicle ride model, modeling a kinematics slider crank which will combine with modeling of stepper motor that act as an actuator for the slide crank. Besides that, the research also includes the study of PID controller and finally designing a control system for the motion platform.



Figure 1: Classification of driving simulators



a. Toyota driving simulator



b. 5DT driving simulator



c. National Advance Driving Simulator



d. Honda driving simulator

Figure 2: Examples of driving simulator



## 1.2 Problem Statement

Road safety has always been a major concern for the Malaysian Government. The rapid increases in motor vehicle ownership in combination with the relatively young age of the populations and wide mix of vehicle types in the recent years have resulted in a significant increase of road safety problems. According to Malaysia Institute of Road Safety research (MIROS).

In Malaysia the number of road accidents per 1000 population is gradually increase from 10.8 to 12.8 cases (18.5%) in year 2000 until 2006. (Wong et al., 2004) Based on statistics, there are fourteen factors of road accident occurred, where the common factors are speeding (32.8%), careless driving (28.2%) and careless overtaking (15.1%). Other factors are tailgating (driving too closely behind another vehicle) (3.8%) and road condition (3%). It showed that the driver's behaviour is the main cause of road accidents, contributing to 76.1% of all the causes of road accidents. (Ahmad, et al., 2009). Many action had been taken by government to overcome this problem such as road maintenance, building new roads, reactive action and proactive action. Consider from many aspects, the best way to reduce such problem is still the development of the driving simulator. Therefore, this project is proposed to design a vehicle simulator which will help these people improve their driving skill before driving on the real road.

Overalls, the vehicle simulator have a motion platform which is the combination of slider crank, stepper motor and parallel platform. Each corner of platform is supported by a slider crank leg and all totally is four legs. Stepper motor is use as an actuator to actuate each slider crank so that the platform can move at 3-DOF motion that is pitch motion, roll motion and vertical motion. Finally, design a control system for the motion platform.

For further development, the motion platform will be combining with a robotic arm to create a platform that will help human in removing of explosive items such as boom. This is because there is a need of high balancing ability while handling with such dangerous things.

### **1.3 Background of the Study**

Vehicle simulation can be defined as the representation of vehicle and system dynamics characteristics with varying degrees of realism for research, design, training or entertainment purpose. (Ho Bang, 2007). Development of system modeling and simulation module is an important issue for effective operation including simulator subsystem. In addition, we have to implement a dynamics modeling which have robustness in the presence of uncertainty. Generally, there are differences between real systems and mathematical modeling. Robust stability in the presence of uncertainty is an important issue in control system analysis and has attracted considerable interests. And the so-called performance such as tracking of the reference input and satisfying of specification is another significant problem. Deriving a dynamic system modeling satisfying these objectives are very difficult because of the tradeoffs between complexity and performance of simulation in procedure of real implementation.

### **1.4 Project Objective**

The main objective of this study is to design and development of 3-DOF motion platform for vehicle dynamic simulator by using CAD software or MATLAB/Simulink software. 3-DOF means the motion platform will have pitch motion, roll motion and vertical motion. Besides, fabricate and to evaluate the motion platform performance is also the primary objective of this study.

### **1.5 Project Scope**

- 7-DOF full vehicle ride model derivation and modeling in MATLAB/ Simulink software.
- Verification of the 7-DOF full vehicle ride model with Carsimed software.
- Modeling of 3-DOF motion platform.
- Modeling and verification of dynamics and kinematics slider crank.
- Modeling and verification of stepper motor.
- Design the inner force tracking control of slider crank and motor.
- Motion platform control.

## 1.6 Research Planning

| Semester | Activity   |
|----------|--|
| PSM1     | <ul style="list-style-type: none"><li>• Searching for information on title</li><li>• Doing literature review about the title</li><li>• Study methodology to solve the problem</li><li>• Decide the behaviour of the slider crank</li><li>• Derive the equation of motion for slider crank, stepper motor and 7-DOF full vehicle model, 3-DOF motion platform</li><li>• PSM1 report preparation</li><li>• Submission of report</li></ul>  |
| PSM2     | <ul style="list-style-type: none"><li>• Modeling of slider crank in Matlab simulink</li><li>• Modeling of stepper motor in Matlab simulink</li><li>• Modeling of 7-DOF full vehicle ride model</li><li>• Validation of 7-DOF full vehicle ride model with carsimed software</li><li>• Modeling of 3-DOF motion platform</li><li>• Design control system for motion platform</li><li>• Analysis and validation of the motion platform</li><li>• Conclusion of PSM</li><li>• PSM 2 report preparation</li><li>• Submission of report</li></ul> |

## 1.7 Methodology

The motion platform for driving simulator is a mechatronic equipment that is capable of giving the realistic feeling of a actual vehicle to the drivers. This is a research that involves multidisciplinary engineering skills. It is divided into 3 major parts which is the control system design and simulation, motion platform mechanism design and fabrication, and finally the integration of both control and actual model. In the stage of control design and simulation, all the system should be modelled first such as vehicle model and motion platform so that the control strategy can be design.

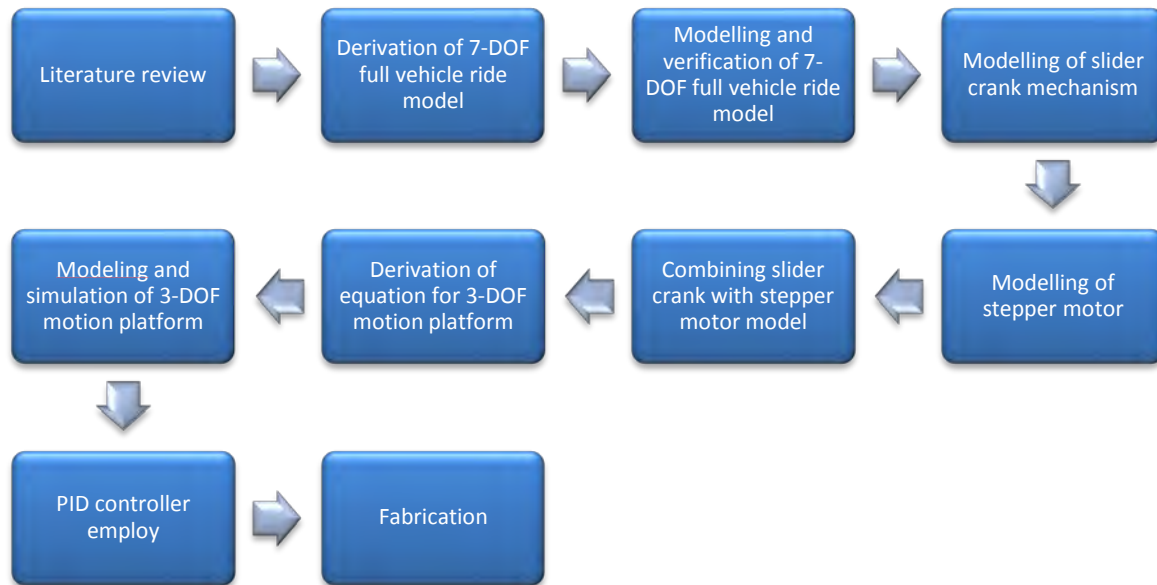
First of all, the study begins with the literature review on the 7-DOF full vehicle ride model analysis. Then, the derivation equation of the 7-DOF full vehicle ride model is modeling in MATLAB/Simulink software. After that the full vehicle model is verified with vehicle dynamic simulation software namely as CarSimEd under the same input parameters as an model validation.

The second step of the study will be following with the derivation equation of the slider crank mechanism. The derivation equation wills then modeling in the same MATLAB/Simulink software too and verified it. After that, the studies proceed with the modeling and verification of the stepper motor. Stepper motor will be use as the actuator to actuate the slider crank that located at the four corner of the motion platform. Therefore, both modeling will be combining after each of their verification.

Until this stage, the studies can be considered half complete. The next step will be the modeling of the 3-DOF motion platform. To derive the equation of the motion platform, the unsprung mass equation inside the 7-DOF full vehicle model is neglected. Therefore, the vertical motion of the unsprung mass will also be neglected. These resulting the motion platform only have three degree of freedom that is body pitch motion, roll motion and vertical motion. Then, the motion platform equation is also modeling in MATLAB/Simulink software and verified. Finally, a proportional-integral-derivative (PID) control is employed to achieve stable and accurate displacements of the motion platform. After that, the final step will be the fabrication of the motion platform.

## 1.8 Methodology Flow Chart

The methodology flow chart will show the flow method that I will used in this study and explained the method step by step form literature review until fabrication.



*Figure 3: Methodology flow chart*

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

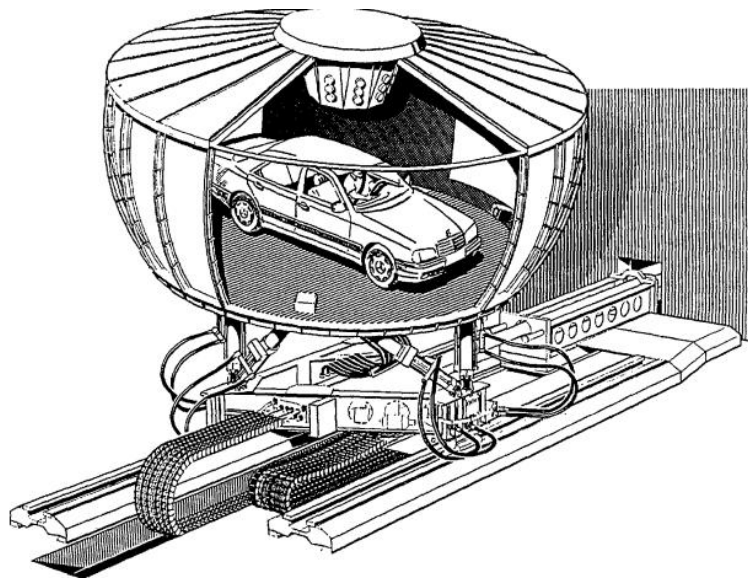
This chapter will discuss the literature review about the background information of the study so that the reader can easily understand the research background. The first parts will provide some of the fundamental ideas and equipment that involves in the development of the vehicle simulator. Besides, it also includes some fundamental knowledge about the parts that use for the study in motion platform such as stepper motor, slider crank. This chapter also conclude some research method and research result that other researcher had done at the past. The research and development on vehicle driving simulator had become more and more popular among the engineering researcher and developer.

##### 2.1.1 Type of Driving Simulator in Used

There are several types of driving simulator that used in our world now that are the Daimler which is Benz driving simulator, National Advanced Driving Simulator owned by the National Highway Traffic safety Administration (NHTSA) and the Toyota Driving Simulator which owned by Toyota Motor Cooperation (TMC) ( Chiew et al.,2008).

##### 2.1.2 The Daimler – Benz Driving Simulator

Driving simulators are developed throughout the world for studies and analysis of human behaviour, vehicle performance as well as road safety research. The Daimler Chrysler has been one of the earliest automobile manufacturers that uses driving simulators in vehicle development process compared to any other car manufacturers. The concept was founded in 1980 and the first driving simulator was constructed in 1983 and put into operation in October 1984. It consists of a projection system that simulates the virtual environment, 6DOF motion system complete with simulator cabin and other individual computational systems. A further improvement was made to the Daimler – Benz driving simulator to further improve motion simulation quality.



*Figure 4: The Daimler*

### **2.1.3 National Advanced Driving Simulator**

Another well-known driving simulator is the National Advanced Driving Simulator (NADS), which was started in 1992 and completed in 2001. It was built at the University of IOWA and owned by the National Highway Traffic safety Administration (NHTSA) which was claimed to be the most advanced driving simulator in the world.



*Figure 5: Advanced Driving Simulator (NADS)*

### 2.1.4 Toyota Driving Simulator

Recently in November 2007, the Toyota Motor Corporation (TMC) announced that it has developed a world-class driving simulator located at Toyota Motor Corporation's Higashifuji Technical Center in Susono City, Shizuoka Prefecture, Japan. The sole purpose of the driving simulation development was to conduct analysis of driving characteristics and development of active safety technology, and to verify the effectiveness of active safety technology.



*Figure 6: Toyota Driving Simulator*

### 2.1.5 Square 3-DOF Motion Platform

In searching the best control structure to be implementing in HILS-LCVDS, a modeling of the motion platform should be done first. In this case, the proposed motion platform design is based on the vehicle configuration. The platform is selected because it is parallel robot manipulator with 4 parallel slider crank mechanism combine with DC motor which is capable of moving in 3-DOF namely rolling, pitching and heave motions. The upper platform connects all 4 parallel links forming a closed loop mechanism. This allows the platform to have good performance in terms of accuracy, rigidity and capable of handling large payload. The motion platform design is shown in Figure 6.