DESIGN AND DEVELOPMENT OF DRIVE SIMULATOR FOR VEHICLE DYNAMIC STUDY

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"I hereby declare that this report is the result of my own work except for quotes as cited in the references"

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Date: 18 MAY 2009

To Mr. Mochamad Safarudin, family and friends,

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The credits of this project goes to Ir.Mochamad Safarudin for providing me a chance to launch a project and acted as my main supervisor who has been guiding the progress in developing this driving simulator. Besides that, many thanks to my coursemates that had been helpful in assisting my project. Also, a thanks to Dr. Khisbullah Hudha for spending some time in evaluating the progress of the project during the 1st half and also the outcome of the project. Finally, I would like to express my gratitude to Amrik Singh for sharing experimental result obtained from Dr. Khisbullah Hudha for simple model validation.

ABSTRACT

This report presents the project in developing a drive simulator for vehicle dynamics study purposes. The project involves the development of virtual reality drive simulator and the modeling of 8 Degree of Freedom vehicle model. This project will enable researchers to conduct experiments and testing similar to actual ones. The result generated by this program is easy to be comprehended by all level of society. This project will project will take into account the tire model analysis and animation in virtual reality. The drive simulator will be constructed based on Vehicle System Dynamic study. The tire model chosen for this study is mainly based on “tire and Vehicle Dynamics” by Hans. B. Pacejka. Using Pacejka’s tire model, the forces will be obtained to complete the simulation of the drive simulator. The simulation will be performed in Simulink and MATLAB. The visualization will be done by Virtual Reality Modeling Language. In virtual reality, a 3D graphic separated into child and parent. The system will be running based on coordinate system in VRML. The definition of the coordinate system in VRML is different from the one used in MATLAB or Simulink. The input to this program is through a steering wheel to computer which will give an actual simulation of a real driver in virtual reality.

ABSTRAK

Laporan ini akan mempersembahkan projek dalam mereka bentuk sebuah pemanduan simulasi untuk kajian dinamik kenderaan bermotor. Projek ini merangkumi pembinaan alam maya untuk pemanduan simulasi dan pemodelan kenderaan dengan 8 Darjah Kebebasan. Pada akhir projek ini, dengan menggunakan alam maya simulasi, para pengkaji tidak perlu membahayakan nyawa untuk mengkaji sifat dinamik kenderaan melalui eksperimen yang sebenar kerana simulasi ini dapat memberikan keputusan yang hampir sama. Keputusan yang dihasilkan oleh program ini adalah mudah difahami oleh masyarakat umum. Projek ini akan merangkumi aspek pemodelan tayar analisis serta animasi di dalam alam maya. Pemanduan simulasi akan dibina berasaskan kajian "*Vehicle System Dynamic*". Model tayar yang dipilih untuk kajian ini adalah berdasarkan "*Tire and Vehicle Dynamics*" oleh Hans B. Pacejka. Dengan menggunakan model Pacejka, daya-daya yang terhasil pada tayar boleh didapati untuk melengkapkan simulasi program. Simulasi akan dijalankan di dalam Simulink dan MATLAB. Gambaran akan dihasilkan oleh *Virtual Reality Modeling Language*. Dalam alam maya, sebuah 3D grafik dibahagikan kepada "*child*" dan "*parent*". Melalui kategori ini, sistem akan berjalan berdasarkan sistem koordinat yang ada di dalam VRML. Definisi sistem koordinat dalam VRML adalah berbeza dengan sistem koordinat di dalam Simulink dan MATLAB. Cara masukan ke dalam program ini adalah melalui stering roda yang dihubungkan ke computer di mana ia akan memberikan simulasi yang sebenar oleh pemandu yang sebenar di dalam alam maya.

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LIST OF SYMBOLS

a	=	distance of c.g. from front axle (m)
b	=	distance of c.g. from rear axle (m)
c	=	track width (m)
h_{cg}	=	c.g. height (m)
h_{rcf}	=	front roll center distance below sprung mass c.g. (m)
h_{rcr}	=	rear roll center distance below sprung mass c.g. (m)
J_x	=	roll inertia (kg m^2)
J_z	=	yaw intertia (kg.m^2)
J_{xz}	=	product of roll and yaw inertia ($kg^2.m^4$)
m / m_s	=	vehicle sprung mass (kg)
u/v	=	longitudinal / lateral velocities of c.g. in body fixed coordinates (m/s)
φ	=	roll angle (rad)
ψ	=	yaw angle (rad)
ω	=	roll rate / yaw rate of c.g. in body fixed coordinate (rad/s)
w_f	=	front curb weight (kg)
w_r	=	rear curb weight (kg)
L	=	Length of Wheelbase (m)
k_φ	=	roll stiffness coefficient (Nm/rad)
b_φ	=	roll damping coefficient (Nms/rad)
r	=	effective radius of wheel (m)
I_w	=	wheel moment of inertia (kg m^2)
s_x	=	longitudinal displacement (m)
s_y	=	lateral displacement (m)

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CHAPTER 1

INTRODUCTION

1.1 Background Study

This project's study is mainly about vehicle dynamics of a car. The study of the behavior of the vehicle is important to determine the outcome of the vehicle in various motions. The experiments and study has been carried out in real world using actual vehicle. The safety of the driver is compromised while carrying out the experiments.

In recent years, the concern in rollover of a vehicle has caught the eye of traffic administrations. Test are carried out at own risk and compromises the safety of researchers. In developing the active or passive roll control system, a vehicle model that can represent roll behavior is essential to predict the impending rollover as well as accurately applying the actuation force to avoid vehicle rollover, according to Vehicle System Dynamics

.

The need of having a driving simulator is mainly contributing to safety of researchers and also minimizing cost. Accidental damages on vehicles are expensive and dangerous towards the driver himself. Most of the time researchers finds difficulty in getting perfect outcome to help in developing control system that would assist in vehicle control systems.

Due to transient load transfer and extreme maneuvers, a high order model is required to represent the vehicle. High model such as 8 DOF and 14 DOF is able to predict the motions of the vehicle at various conditions. The 8 DOF model considers the basic motion of a vehicle without the flexibility of modeling non-linear spring and dampers as these values are represented simply by equivalent roll stiffness and roll damping coefficients.

Simulation programs such as ADAMS, CARSIM, and MATLAB has been developed to aid the experiments but the result cannot be comprehended by many parties. Only mathematician and physicist can comprehend output data from these engineering programs. At certain level, it is best if the experiment can done by a commoner to boost confidence in making everyone understands the motion of the vehicle.

1.2 Problem Statement

In vehicle dynamics studies, experiments are conducted to analyze the behavior of vehicle while moving. This includes the contribute effect which will directly contribute to the yaw and roll motion. In addition to that, the longitudinal and lateral motions are included since the vehicle is a moving body and it may negotiate bends.

In completing this study, the vehicle will be studied base on 8 Degree of Freedom and by putting the equation of motion in MATLAB and Simulink, it is expected to create a virtual reality for a test drive experience and experiment purposes instead of using a real vehicle. The drive simulator will simulate an almost actual condition of driving experience.

The main reason for Virtual Reality driving simulator development is to provide a clear graphical view of vehicle behavior on extreme maneuvering. It is fairly difficult to imagine the behavior in terms of only graph expression and values obtained.

1.3 Project Objectives

The main purpose of this project is to develop a drive simulator using Virtual Reality Builder in MATLAB. The project will begin with the study of 8 Degree of Freedom i.e. the equation of motion for roll, yaw, lateral, longitudinal and spin. From the equation of motion, calculations are done by Simulink and will give rise to motions in Virtual Reality. Finally, the main purpose of this project can be achieved by achieving the following sub-objectives:

1. To understand the equations of motion required for 8 Degree of Freedom in a moving vehicle.
2. To master the use of Simulink, Virtual Reality Builder, and MATLAB functions.
3. To develop a virtual reality environment for the drive simulator.

1.4 Project Scope

This study focuses on the drive simulation in virtual reality which will be developed in PSM II. The drive simulator will simulate the vehicle behavior base on the input of the driver himself. Also, to ease the vehicle dynamic study, this drive simulator will be able to do certain experiments. In other words, it must be able to serve as a tool for yaw, roll, longitudinal, and lateral study.

In short the project scope is listed as follow:

1. Development of 8 Degree of Freedom model vehicle simulator using Simulink.
2. Perform simulation of vehicle in Simulink.

3. Development of virtual reality driving environment using Virtual Reality Builder and Autodesk 3D Max.
4. Connect Simulink and Virtual Reality Builder and develop a drive simulator that can be driven by a human driver.
5. Test virtual reality simulation.

1.5 Project Outline

This report on "The development of 8 Degree of Freedom simulation using Simulink and MATLAB" is divided into 5 chapters. Chapter 1 introduces the audience to the general background of this research, the problem statement, project objectives, as well as the project scope. Also, it offers an overall view of the project outline.

Chapter 2 is a compilation of required information and literature reviews gathered from electronic media, published journals, and books.

Chapter 3 explains about the methodology used in the study of 8 Degree of Freedom in a driven vehicle and development of drive simulator. The methodology consists of 2 main stages; detail study of equation of motion through journals and books and simulating the equations obtained.

Chapter 4 will present the results of the simulation and also the outcome of the project. This chapter will also be discussing on the validity of the simulation by brief comparison to experimental results and also assumptions made. The details on Virtual Reality's connection with Simulink will also be discussed later in this chapter.

Finally, chapter 5 will present the conclusion and suggestion in upgrading the project for a better performance and more user friendly.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Vehicle Dynamics

The vehicle dynamics study is a complicated analytical study and experiment of vehicle behavior in various motion situations. The study involved is about the basic physical principal of physics that will predict the effect of forces and moments towards the vehicle.

Analysis done in vehicle dynamics is through the basic dynamic analysis before deriving higher order of models. In certain analysis, the vehicle is analyzed statically.

2.2 Equation of Motion

To create a drive simulator, it is essential to create a Simulink model for the vehicle analysis. Referring to the journal "Vehicle System Dynamics" by Shim, T. and Ghike, C. (2006), the equations of motions derived by the writer will be put into Simulink.

From this journal, the equation of motions for longitudinal, lateral, yaw and pitch are obtained. The equations are as follow:

$$m_t(\dot{u} - \omega_z v) = \sum F_{xgij} + (m_{uf}a - m_{ur}b)\omega_z^2 - 2h_{rc}m\omega_z\omega_x \text{ (longitudinal)}$$

$$m_t(\dot{v} + \omega_z u) = \sum F_{ygij} + (m_{ur}b - m_{uf}a)\dot{\omega}_z + h_{rc}m\dot{\omega}_x \text{ (lateral)}$$

$$J_z\dot{\omega}_z + J_{xz}\dot{\omega}_x = (F_{yglf} + F_{ygrf})a - (F_{yglr} + F_{ygrr})b + \frac{(F_{xgrf} - F_{xglf})c_f}{2} + \frac{(F_{xgrr} - F_{xglr})c_r}{2} + (m_{ur}b - m_{uf}a)(\dot{v} + \omega_z u)$$

$$(J_x + mh_{rc}^2)\dot{\omega}_x + J_{xz}\dot{\omega}_z = mgh_{rc}\phi - (k_{\phi f} - k_{\phi r})\phi - (b_{\phi f} - b_{\phi r})\dot{\phi} + h_{rc}m(\dot{v} + \omega_z u)$$

(Source: Shim, T. and Ghike, C., (2006))

The longitudinal equation of motion is derived from the diagram in Figure 2.1 and Figure 2.2. The free body diagram is drawn as shown in Figure 2.1 and Figure 2.2. From the diagram in Figure 2.1 and Figure 2.2, we use the equation summation of force at *x*-axis.

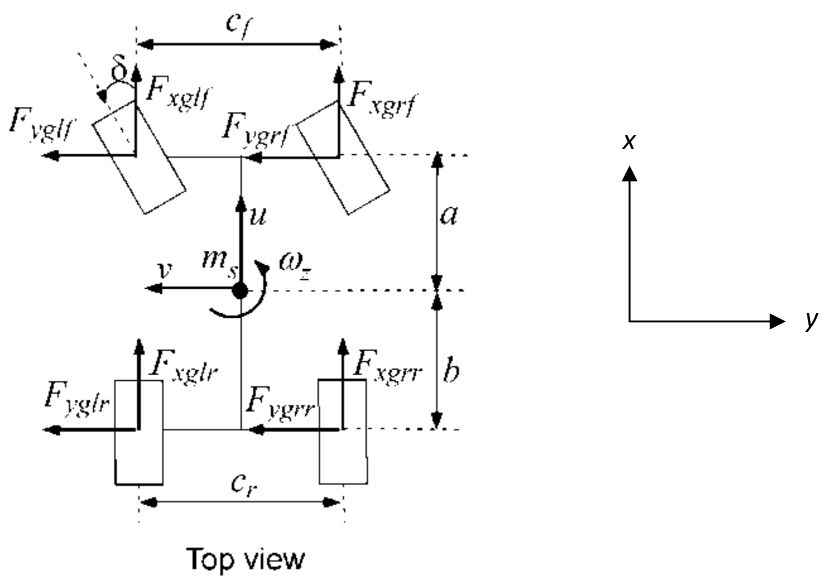

Figure 2.1: Top view of vehicle free body diagram

(Source: Shim, T. and Ghike, C., (2006))

The forces F_{xgf} and F_{ygf} are obtained by resolving longitudinal and cornering forces at tire contact patch since the tire forces are generated in a wheel-fixed coordinate system. Sample of the equations are as follow:

$$F_{xgrf} = F_{xtrf}\cos\delta - F_{ytrf}\sin\delta$$

$$F_{ygrf} = F_{ytrf}\cos\delta + F_{xtrf}\sin\delta$$

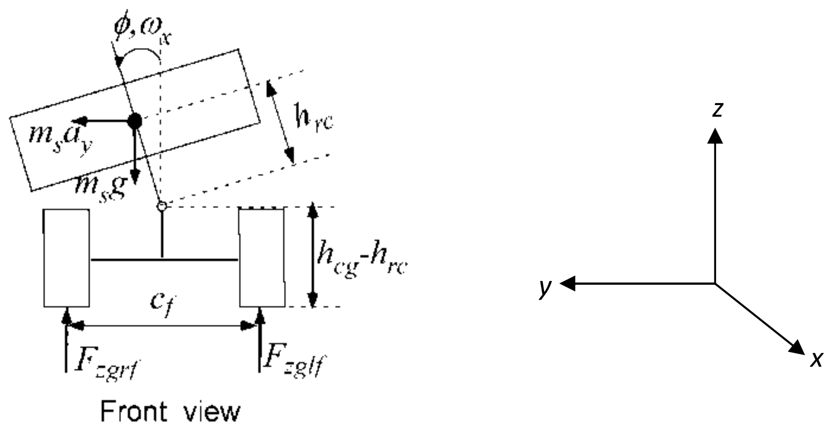

Figure 2.2: Front view of vehicle free body diagram

(Source: Shim, T. and Ghike, C., (2006))

$$\sum F_x = 0$$

$$\therefore m_t(\dot{u} - \omega_z v) = \sum F_{xgij} + (m_{uf}a - m_{ur}b)\omega_z^2 - 2h_{rc}m\omega_z\omega_x$$

To determine the equation for lateral motion, the same method is used, except that we are considering the *y*-axis instead. Thus,

$$\sum F_y = 0$$

$$\therefore m_t(\dot{v} + \omega_z u) = \sum F_{ygij} + (m_{ur}b - m_{uf}a)\dot{\omega}_z + h_{rc}m\dot{\omega}_x$$

The subscript *ij* represents the either rf, lf, rr or lr.

The height of roll center and height of center gravity is shown in Figure 2.3.

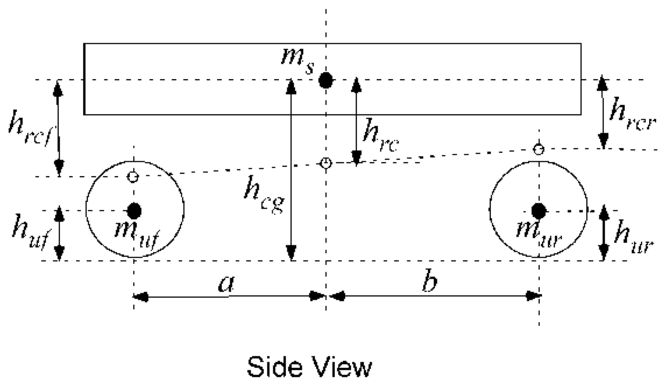

Figure 2.3: Side view of vehicle

(Source: Shim, T. and Ghike, C., (2006))