DESIGN OF A SIX DEGREE OF FREEDOM MOTION PLATFORM FOR VEHICLE DRIVING SIMULATOR APPLICATION

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To my dearest and loving parents, brother, and all of my friends for their unending love, sacrifices, and moral support

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ABSTRACT

This research presents the design and development of a six degree of freedom (6-DOF) motion platform for vehicle driving simulator application in Universiti Teknologi Malaysia. The development processes include reviews of driving simulator technology and design configurations, development of motion platform mathematical modeling and simulation, control algorithm development and validation of simulation results. The motion platform design is based on Stewart platform design configuration. It was mathematically modeled using inverse kinematics to control the kinematic behaviours of the motion platform. A visualisation tool, SimMechanics was used to validate the motion platform motions cues virtually. A Proportional-Integral-Derivative (PID) control algorithm for motion platform actuators control was developed and tested. The motion platform prototype was constructed and interfaced with simulation model through data acquisition system to perform 6-DOF vehicle motion. The prototype was tested and the kinematic performance of the prototype is validated. The results show that the motion platform can be used for driving simulator application.

ABSTRAK

Penyelidikan ini bertujuan untuk mereka bentuk dan membangunkan satu pelantar gerakan untuk penyelaku pacuan kenderaan yang dapat bergerak dalam enam darjah kebebasan (6-DOF) di Universiti Teknologi Malaysia. Proses pembangunan yang terlibat di dalam penyelidikan ini adalah kajian berkaitan teknologi simulasi memandu, konfigurasi rekaan, pembangunan model matematik dan simulasi pelantar gerakan, pembangunan algoritma kawalan dan pengesahan keputusan simulasi. Rekabentuk pelantar gerakan adalah berdasarkan konfigurasi pelantar *Stewart*. Model matematik pelantar gerakan ini telah dibuat dengan menggunakan kinematik songsang untuk mengawal kelakuan kinematiknya. Alatan gambaran *SimMechanics* telah digunakan untuk mengesahkan pergerakan pelantar gerakan. Pengawal algoritma Terbitan-Kamiran-Berkadaran (PID) untuk pelantar gerakan telah dibangunkan dan diuji. Prototaip pelantar gerakan telah dibina dan diperantaramuka dengan aturcara penghubungan model simulasi untuk bergerak dalam arah 6-DOF. Prototaip telah diuji dan pengesahan prestasi kinematik pelantar gerakan telah dilakukan. Keputusan telah menunjukkan bahawa pelantar gerakan ini boleh digunakan untuk penyelaku pacuan kenderaan.

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LIST OF SYMBOLS/ ABBREVIATION

θ_P	-	Angles between P_1 and P_2 (°)
θ_B	-	Angles between B_1 and B_2 (°)
r_P	-	Upper platform radius (m)
r_B	-	Lower platform radius (m)
P_i	-	Location of actuators connections to upper platform
B_i	-	Location of actuators connections to lower platform
α	-	Roll/ Rotation in X-axis (°)
β	-	Pitch/ Rotation in Y-axis (°)
γ	-	Yaw/ Rotation in Z-axis (°)
x	-	Upper platform position in X-axis (m)
y	-	Upper platform position in Y-axis (m)
z	-	Upper platform position in Z-axis (m)
l_i	-	Leg/ actuator length (m)
${}^{B}d$	-	Position of frame {P}
${}^{P}p_i$	-	Vector describing position P_i with respect to frame {P}
${}^{B}b_i$	-	Vector describing position B_i with respect to frame {B}
${}^{B}q_i$	-	Leg vector with respect to frame {B}
${}^{R}_{P}R$	-	Orientation matrix with respect to frame {B}
X_p	-	Axis perpendicular to line connecting P_1 and P_6
X_B	-	Axis perpendicular to line connecting B_1 and B_6
λ_i	-	Angles between PP_1 and X_p (°)
Λ_i	-	Angles between BB_1 and X_B (°)

R_Y	-	Rotation matrix (Z-axis)
R_P	-	Rotation matrix (Y-axis)
R_R	-	Rotation matrix (X-axis)
{B}	-	Frame {B}/ Lower Platform
{P}	-	Frame {P}/ Upper Platform
CAD	-	Computer-Aided Design
DAQ	-	Data Acquisition System
DOF	-	Degree of Freedom
HYSIM	-	Highway Driving Simulator
IDAQ	-	Input Data Acquisition
IKM	-	Inverse Kinematic Model
iUTMVDM	-	Independent Universiti Teknologi Malaysia Vehicle Dynamic Model
LVDT	-	Linear Variable Differential Transformer
MPGUI	-	Motion Platform Graphic User Interface
NADS	-	National Advanced Driving Simulator
ODAQ	-	Output Data Acquisition
PID	-	Proportional-Integral-Derivative (K_p, K_i, K_d)
POT	-	Potentiometer
PWM	-	Pulse Width Modulation
SimPlatform	-	SimMechanics Motion Platform
SMCM	-	Single Motor Control Model
SPS	-	Spherical-Prismatic-Spherical
TCP/IP	-	Transmission Control Protocol/ Internet Protocol
TMC	-	Toyota Motor Corporation
UPS	-	Universal Joint-Prismatic-Spherical
UTMVDM	-	Universiti Teknologi Malaysia Vehicle Dynamic Model
VTI	-	Swedish National Road and Transport Research Institute

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CHAPTER 1

INTRODUCTION

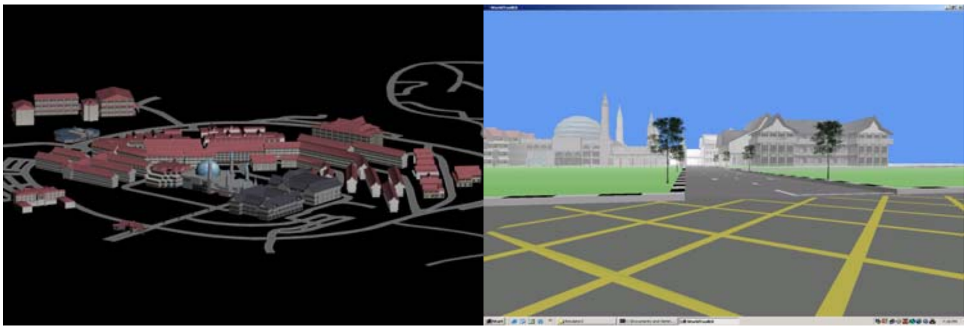
1.1 Preface

Driving simulator has a history of several decades and has been used widely throughout the world. One of the earliest driving simulators dated back in 1970s, when General Motors, Virginia Polytechnic Institute and State University did the pioneering work on human-in-loop driving simulations [1]. The Federal Highway Administration driving simulator (HYSIM) begun operation for human factors work later in 1983 [2]. This is then followed by the development of the VTI driving simulator with extensive motion system by Swedish National Road and Transport Institute in Linkoping on 1984 [3]. Other automobile manufacturers and research institute such as the Daimler-Benz, DRI, Ford Research laboratory and IOWA University also begun their own driving simulator development since the mid of 1980s.

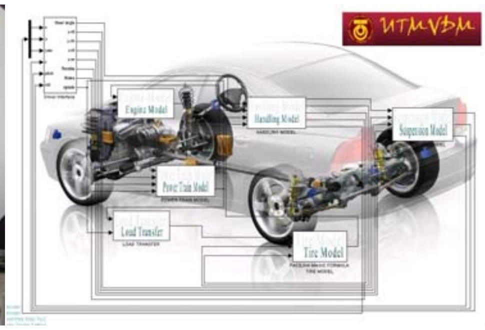
Driving simulators are often used for educational and research purposes. Driving simulators' capability in producing a virtual driving environment resembling real driving condition can be used to train novice drivers before they are exposed to the real world [4]. Aside from that, driving simulators are important in data collection for road safety research, human factor study, vehicle system development and also traffic control device development [5]. These allow designers, engineers as well as ergonomists, to bypass the design and development process of detailed mockups of the automobile interiors for human factor and vehicle performance studies.

1.2 Problem Statement

Road safety has always been a major concern for the Malaysian Government. The rapid increase 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. Various engineering approaches have been taken by the Government to overcome the problem, including proactive actions, reactive actions, road maintenance and building new roads [6]. In conjunction with the effort in the proactive actions, a research in developing a driving simulator was started in 2002, in Universiti Teknologi Malaysia by the Engineering Visualisation Research Group (EngViz). The driving simulator will provide the platform for future research related to road safety and transport. At the end of the first stage research work, a fixed-base driving simulator with visual database and a generic vehicle dynamic model [7]. Figure 1.1 shows the result of the first stage research work. This research work is the second stage and was aimed to design and integrate a motion platform to the existing fixed-base driving simulator. While driving a vehicle, a driver experiences the ride and handling characteristics of the vehicle through motion cues due to angular and linear accelerations of the vehicle chassis. The motion platform for driving simulator is a mechatronic equipment that is capable of giving the realistic feeling of an actual vehicle to the drivers [8]. Motion platform varies in design depending on the design configurations, mechanism used, motion properties and number of degrees of freedom (DOF). To integrate a motion platform to the fixed-base driving simulator, a suitable motion platform must be design and construct. This design process involves motion platform mechanism design and construction, control system design and integration of the motion platform with the existing driving simulator system. The mechanism design and construction is aimed to design and construct the actual motion platform which is suitable for the purposes. Control system design involves the mathematical modeling and control algorithm development which describes the designed motion platform mathematically and to control it. Finally, the integration work is to combine the actual motion platform and its mathematical model with the previous fixed-base driving simulator.



a. Virtual Database



b. Driving Cabin **c. Vehicle Dynamic Model**

Figure 1.1: Virtual reality fixed-base driving simulator.

1.3 Objective of Study

The objectives of the research are to design and construct a motion platform and to develop an algorithm of controlling a six degrees of freedom motion platform for vehicle driving simulator application. The research also verifies and validates the results based on published journals and simulation package. The motion platform is aimed to integrate with the fixed-base driving simulator [7] shown in Figure 1.2.

Figure 1.2: Fixed-base driving cabin.

1.4 Scope of Study

1. To develop the motion platform mathematical model and system control using MATLAB/ Simulink.
2. To design and construct motion platform based on 6-DOF.
3. To develop a digital PID algorithm for controlling a 6-DOF motion platform.
4. To verify and validate the motion platform's motion cues using graphical display of the motion platform and comparing with actual model.

1.5 Research Methodology

The motion platform development process is divided into three major components; mechanism design, control system development and system integration.

1.5.1 Mechanism Design

The specification and system requirements of the motion platform design were first critically reviewed. This is followed by review of various existing motion platform design configurations. Different motion platform configurations were studied and analyzed. The most suitable configuration was chosen based on the system requirements developed for this research [9]. Figure 1.3 shows the general mechanism design process.

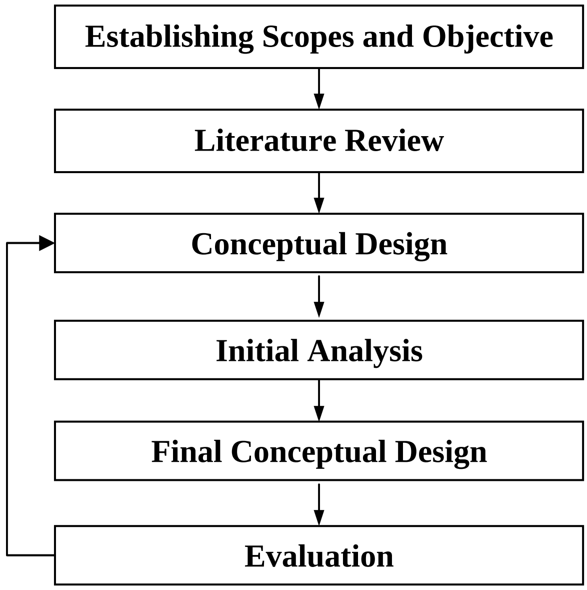


Figure 1.3: Design process.

1.5.2 Control System Design

The control system design is aimed to accurately control the 6-DOF motion platform using Proportional-Integral-Derivative (PID) controller. The motion platform was first mathematically modeled. From the mathematical model of the motion platform, the control variable was identified. In this research, the control variable is the linear motion of the actuation unit for the motion platform. Validation and verification of the mathematical model was carried out to determine the accuracy of the mathematical model representing the motion platform. Next is to determine the control strategy and develop a digital PID algorithm for motion platform. Simulation was carried out through the assistance of MATLAB/ Simulink. The performance of the PID controller in the motion platform was then evaluated and improved. The process of control system design is shown in the Figure 1.4 [10].

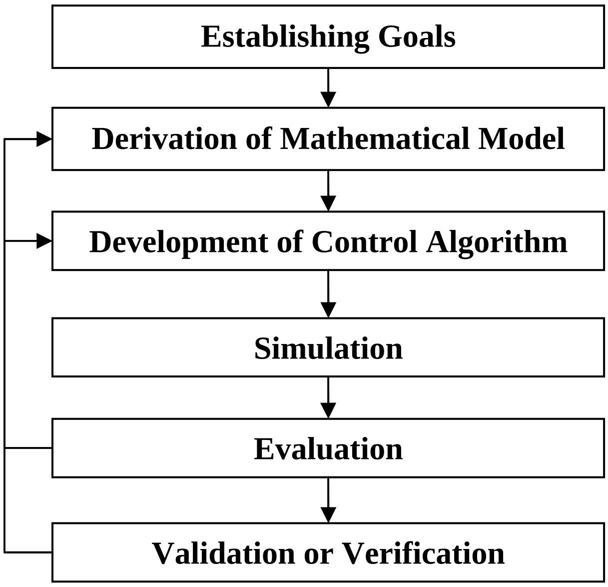


Figure 1.4: Control system design process.

In addition to the modeling and controller design, the research work also involves the development of a data acquisition system (DAQ). Generally, data acquisition is the sampling of the real world to generate data that can be manipulated by a computer. The data acquisition system is designed to measure and log parameters. A data acquisition system consists of hardware and software. The hardware includes sensors, cables and other electronics component. As for the software components, it consists of the data acquisition logic and the analysis software. This software can be developed using various programming languages such as BASIC, C, Fortran, Java or Pascal. Data logging carried out by a data acquisition system, can be used to measure parameters such as sensor's voltage which is the information for motor position. These data are then stored for analysis to improve the quality of the system [11].

1.5.3 System Integration

The system integration stage is very much dependent on the work done in the previous two. This stage can only begin when both mechanism design and control system design are done. The developed control system needs to be integrated with the designed mechanism in order to obtain the desired output of the system.

1.5.4 Summary

The Figure 1.5 shows the summary of the research methodology.

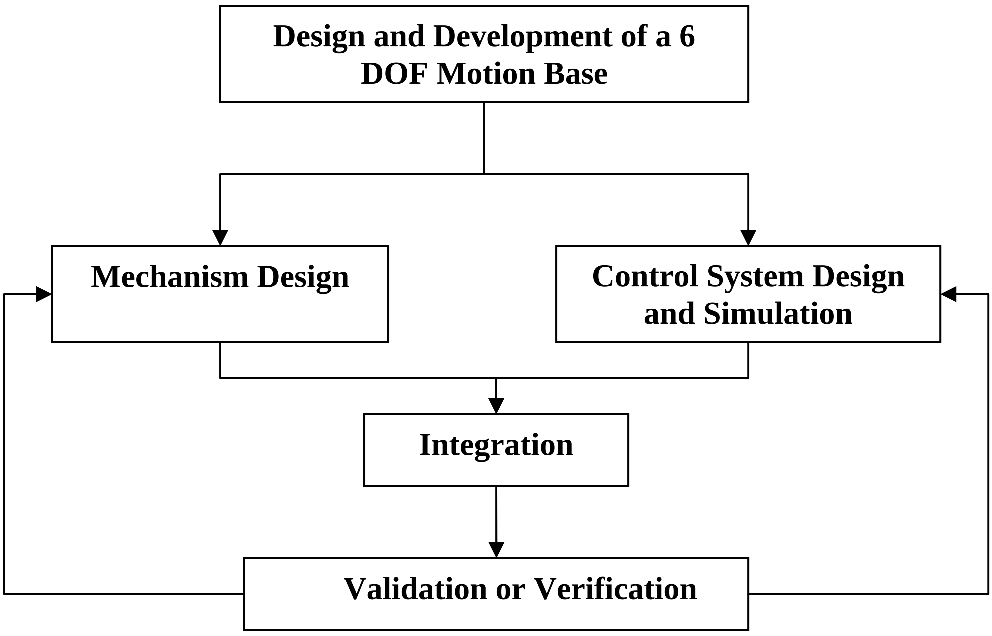


Figure 1.5: Methodology overview.

1.6 Research Contribution

The contributions of this research are:

1. This research is the initial attempt to control the motion platform in real time. In this research, Proportional-Integral-Derivative control algorithm (PID) is used and the details will be explained in Chapter 2.

2. To develop the frame of integrating motion platform with other driving simulator subsystem such as the visual database and vehicle dynamic model.
3. Acquiring the technology behind the motion platform control and design. This motion platform was developed from scratch and the use of computer application software was minimal to avoid ‘black-box’ in the development process.

1.7 Gantt Chart

This research was scheduled for 18 months duration. Thus careful planning is required for the research to proceed and to be completed. Figure 1.6 shows the Gantt chart of the research.

	Month																	
Work	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Obtain Title & Discuss Objectives	■	■				■	■											
Literature Studies		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Log & Progress Writing				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Math Formulation				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Modeling				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Design Selection & Purchasing				■	■	■	■	■	■									
Programming							■	■	■	■	■	■	■	■	■	■	■	■
Control and Construction							■	■	■	■	■	■	■	■	■	■	■	■
Validation and Implementation														■	■	■		
Report Writing								■	■	■	■	■	■	■	■	■	■	■

Figure 1.6: Gantt chart.

1.8 Thesis Organization

This thesis is divided into six chapters. The first Chapter gives an overall introduction of the research project. It consists of preface, problem statement, objective of study, scope of study and research methodology. The Chapter ends with the research contribution and a Gantt chart showing the planning for the research. Chapter 2 presents the fundamental concepts and literature review pertaining to the focus of study. This includes the classification of driving simulators, different motion platform configurations, and mathematics (kinematics) involved in motion platform design. A brief review on the simulation software and the control strategy used is also presented. Chapter 3 focuses on the motion platform mechanism design. It clarifies the design requirements and design specifications. The conceptual designs and design evaluation are shown. At the end of Chapter 3, the final design concept and the motion platform system layout is shown. Chapter 4 discusses simulation and system integration development process of the inverse kinematic model, independent vehicle dynamic model, S-function, SimMechanics model, single motor control model and motion platform Graphical User Interface (MPGUI). The integration of the control system with the motion platform is also briefly discussed. Chapter 5 discusses the simulation results together with validations with real time test results. The PID tuning test results are also shown in Chapter 5. The complete motion platform system with calibration of the motion cues are presented in the end of Chapter 5. Finally, Chapter 6 concludes the research and several recommendations on further research works are given.