INTEGRATION OF CUBIC MOTION AND VEHICLE DYNAMIC FOR YAW TRAJECTORY

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To my beloved parents

To my lovely wife, Noorasyeekeen binti Adinan

To my son, Muhamad Arman Farhan

To my lectures, for the guidance and encouragement

To my friends for their support

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ABSTRACT

Researches in vehicle dynamic simulation have been a subject of interest for researchers nowadays. By replacing costly experiment, simulation of the vehicle dynamics can be the ultimate tools to investigate the vehicle response and producessimilar resultstothat of real experiment. Many of the vehicle simulation inputsdo not consider position of the car as a function of time. Cubic Motion curve will be used as the input to the vehicle simulation and driver model system. Cubic Motion is a curve generated by the integration of Cubic Spline and the dynamics of a vehicle. Cubic spline will generate the curve, while the dynamic of motion will position the vertices based on a given time set. Hence, a new approach has been made to investigate the road input with time function to produce similar response compared to the experimental method. This research focuses on a two- degree-of-freedom vehicle lateral dynamic model. The tests were carried out for a two case studies which are Double Lane Change and Slalom test. Results have shown that, cubic motion can be used as the input for the vehicle simulation because it can produce good trajectory as well as other vehicle response such as vehicle trajectory, lateral acceleration and yaw rate. The significance of this research has a great potential for road safety study related to defining the speed limit of the vehicle according to the curviness of the road.

ABSTRAK

Penyelidikan dalam simulasi dinamik kenderaan telah menjadi suatu bidang penting untuk penyelidik pada masa kini. Dengan menggantikan eksperimen yang menelan kos yang mahal, simulasi dinamik kenderaan boleh menjadi satu kaedah untukmengkaji tindak balas kenderaan dan mampu menghasilkan keputusan yang serupa seperti eksperimen sebenar. Kebanyakan input untuk simulasi kenderaan tidak mengambil kira kedudukan sebenar kereta di dalam fungsi masa. Likungan *Cubic Motion* akan digunakan sebagai input kepada simulasi kenderaan dan sistem model pemandu. Likungan *Cubic Motion* yang dihasilkan adalah gabungan *Cubic Spline* dan dinamik gerakan. *Cubic Motion* akan menghasilkan lengkung, manakala dinamik gerakan akan meletakkan posisi berdasarkan set masa yang telah ditetapkan. Oleh itu, pendekatan baru telah dibuat untuk menyiasat input jalan dengan fungsi masa untuk menghasilkan maklumbalas yang serupa berbanding dengan kaedah eksperimen. Kajian ini memberi tumpuan kepada dua darjah kebebasan dinamik kenderaan. Ujian dijalankan dalam dua kajian kes iaitu *Double Lane Change* dan ujian *Slalom*. Keputusan telah menunjukkan bahawa, input *cubic motion* boleh menjadi input untuk simulasi kenderaan kerana ia boleh menghasilkan trajektori yang baik serta tindakbalas yang lain seperti, pecutan sisian dan kada rulangan. Kepentingan kajian ini mempunyai potensi yang besar dalam membawa kajian keselamatan jalan seperti menentukan had kelajuan kenderaan mengikut darjah lengkuk jalan.

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LIST OF SYMBOLS

t_{max}	-	Maximum time
s	-	Displacement
v	-	Final Velocity
u	-	Initial Velocity
t	-	Time
w	-	Free parameter
ΔDs	-	Delta Displacement
DM	-	Driver Model
W	-	Steering gain
La/L	-	Sight Distance
Tk	-	Time Delay
a_f	-	Slip angle at front tires
L_f	-	Longitudinal distance from c.g. to front tires
V	-	Lateral Velocity
U	-	Longitudinal Velocity
$\dot{v_y}$	-	Lateral Acceleration
δ_f	-	Front wheel angle
$\dot{r}$	-	Yaw rate
a_r	-	Slip angle at front tires
L_r	-	Longitudinal distance from c.g. to rear tires

δ_r	-	Rear wheel angle
m	-	Mass of vehicle
C_{af}	-	Cornering stiffness of front tire
C_{ar}	-	Cornering stiffness of rear tire
ε	-	Aim point angle
y_d	-	Desired path deviation from x0 axis;
x_{os}	-	Longitudinal position, the way covered by the car down the road;
y_{os}	-	Lateral position of the car;
ψ	-	Heading angle
P	-	Proportional
I	-	Integral
D	-	Derivative
δ	-	Steering Angle

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LIST OF ABBREVIATIONS

ABBREVIATION	**DEFINITION**
DOF	Degree of Freedom
VDM	Vehicle Dynamic Model
DM	Driver Module

CHAPTER 1

INTRODUCTION

1.1 Introduction

The objective of this chapter is to give the overall overview of the research. It starts with the review on related research in Section 1.2. This review will establish the need of the research which defines the research problem statement in Section 1.3. The objectives and the scope of research will be discussed in Section 1.4 and 1.5 respectively. Finally, Section 1.6 will overview the structure of the thesis.

1.2 Research Background

In Malaysia, the number of traffic accident has increased dramatically (Nizam 2005). According to him, the traffic accident is rising at the average of 9.7% per annum over the last three decade. At the same time, the number of fatalities also increased, but at slower rate compared to total number of road accident from 2,303 in 1974 to 6,200 in 2005.

The upward trend of fatalities dropped in 1997 after Malaysian government established a 5-year national road safety target to reduce road accident deaths by 30% by the year 2020.

Malaysia government proposed a module which is JKR *Arahan Teknik (Jalan) 8/86 (JKR*, 1986) are codes that govern the design of the road. However, these codes have not yet taken the dynamic effect of the vehicle into consideration despite the importance of vehicle dynamic to predict the vehicle response during maneuverings.

Furthermore there are many factors that contribute to road accidents. The factors can be grouped into these three basic categories, which are road user errors, road environment faults, and vehicle defects. About 80% of road accident is due to road environment and human error (Peden, 2004). Many researches have been conducted to investigate the road environment in accident factor including roadway design. Human error is the errors caused by the driver him/herself. This includes the driving behavior.

To simulate the vehicle factors for road safety purposes, the researchers have developed the vehicle dynamic model or VDM which firstly introduced by Segel (1956). Segel is become the pioneer in developing a theoretical prediction of the vehicle simulation. Since then, a lot of researchers work on this field to improve the vehicle dynamic model and use it as a reference. The bicycle model that has been proposed by Chul (2001) is the basic model for VDM that can be used to predict vehicle response for road safety purposes.

Then, driver model becomes the research issue as vehicle factor alone is not sufficient in road safety studies. A number of driver models has been developed to replace human factor in vehicle simulation. The main objective of integration of driver model and VDM is to investigate the vehicle handling in the plane of road and its response to steering. Many of researchers come out with solution to relate the realistic driver maneuver with the road information. Namekawa (2007) proposed road data information using the digital map that can be used in traffic simulation. However, the road data information is not considering time function, which provides useful information such as position of the vehicle at the current time. Hence, new approach has been made to investigate the road input with time function for the purpose of vehicle responses using vehicle dynamic model and driver model.

1.1 Problem Statement

When curve is used as the input for VDM and driver model, the time function is not embedded in the curve. Since the current input to VDM and driver model is lack of time function, this research will address the issue of time function by the introduction of Cubic motion curve. Cubic Motion curve will be used as the input to vehicle simulation and driver model system. However, the accuracy to predict the defined trajectory is depend on the curve fitting algorithm and methods used in integrating it with vehicle model and driver model. This integrating system will provide data set which contain the position of the vehicle based on time set that can be interpret by the driver to produce a defined trajectory. Since this research is just an initial work, this research focuses on the applicability of Cubic Motion as road path in the study of vehicle dynamic and driver model.

1.2 Objective

There are several objectives in this research. There are:

1. To develop VDM and driver model (DM) with time function,
2. To integrate Cubic Spline and dynamic of motion to produce Cubic Motion curve ,
3. To conduct the two of case studies (Slalom test and Double Lane Change to study its applicability of the cubic motion as the input for VDM)

1.3 Scopes

The scopes of the research are as in the following:

1. Two Degree of Freedom VDM (bicycle model) is used for VDM system with only consider X and Y direction for both road path, constant velocity for both VDM and cubic motion, perfect road condition (dry only) and linear tire condition
2. Cubic Spline has been used as the spline method to perform mathematical model to be used as Cubic Motion Data
3. Andrej Ren'ski Driver model is used as the controller for the system (Renski ,1998)
4. Double Lane Change test and Slalom test are used as the case studies for this research.
5. Saga BLM vehicle properties are used in the VDM system

1.4 Significant of Study

The main objective of the research is to study the applicability of the Cubic Motion Curve as the input for the VDM and DM system. With implementation of the Cubic Motion Curve, curve and dynamic of motion can be integrated and the vehicle response when the Cubic Motion is used as the input for the present work. Vehicle Dynamic Model can be one of the ways to obtain vehicle response. For automotive industries, this is opportunity to bring the research field to another level. By combining with suitable driver model and proper road input, the integration of cubic motion and vehicle simulation will become a great combination for driving simulator. This research can also be implemented in designing road especially curve road and road safety. In the long run, the research is the initial work to bring the road safety analysis for path planning into desktop. Furthermore, this proposed system can be the one of the methods to determine vehicle maneuver behavior.

1.5 Thesis Summary

Starting with chapter 1 describes the objectives of this research. Besides that, research scope is explained to reduce any complexity to carry out this research. Then follows with the discussion on the significance of this research.

The remainders of this thesis is comprised five further chapters as summarized below

Chapter 2: Reviews related research available in the literature. The literature is related to the application of the cubic spline and the road safety.

Chapter 3: Briefly describes the methodology adopted by the research. The methodology starts with development of cubic motion and ends with the application of cubic motion in Double Lane Change and Slalom vehicle path construction integration with vehicle simulation.

Chapter 4: Explains the cubic motion properties. This chapter also describes the cubic motion as the input for vehicle simulation.

Chapter 5: Discusses the result for these case studies as well as the implementation of cubic motion curve as the input for vehicle simulation.

Chapter 6: Concludes the research and gives recommendation for future work

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