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Study Of Vehicle Handling Characteristics In Design Of Autonomous Vehicle For Sustainable Transportation

Hassan. M. A[1], Moveh Samuel[2],

[1,2] Department of Mechanical Engineering, Modibbo Adama University of Technology, Yola, Nigeria.
corresponding author: mahassan@mautech.edu.ng

***Abstract*— Vehicle handling characteristics are closely related to driving safety. They refer to the response to steering commands and to environmental inputs, such as wind and road disturbances that affect its direction of motion. The main components of modern autonomous vehicle are localization, perception, and control. This paper discusses the dynamic handling for autonomous manoeuvres. Since major causes of traffic accidents are as a result of unexpected handling behaviour of vehicle it is therefore important that an in-depth understanding of vehicle handling behaviour in all conditions of operation is acquired even at the design stage. The motivation behind doing this study is to obtain a guideline for systematic development of control strategy and it involves the modelling of road vehicle lateral dynamics. As such, it is concerned with the turning behaviour of the vehicle in response to control and disturbance inputs. A simple 3 degree-of-freedom vehicle model based on the bicycle model is used in this study. To study the lateral dynamics of the modelled vehicle, step response input to time andbits effect on the stability of the vehicle was considered. For that purpose, measured and known parameters of a scaled remote controlled car were used for the simulation of the developed mathematical model in MATLAB.**

Keywords—vehicle, dynamics lateral, yaw, modelling

I. INTRODUCTION

Present day transportation is for the most part reliant on non-renewable energy source, which is a limited resources unfortunately; an ideal replacement for the non-renewable energy source is not readily available. As interest for transport continues expanding, a proficient transportation framework is critical for the long-haul maintainability of our general public, since numerous exertion have been set up towards accomplishing environmental sustainability (Alkali et al., 2017). Motivated by the recent advances in autonomous vehicle technology, Dresner and Stone showed that by leveraging the capacity of computerized driving systems it is possible to devise a traffic control system that significantly outperforms traditional traffic signals and stop signs, resulting in fuel savings since vehicles are less likely to stop and wait to enter intersections (Dresner and Stone, 2008).

Despite the advancements in autonomous vehicle technology, achievement of transportation sustainability is perpetually an essential and challenging task. Sustainability of transportation involves not only managing go-green transportation, but also establishing effective transportation planning systems for ensuring road traffic safety. It is on this basis that research into various vehicle handling dynamics are being considered in the development of an efficient autonomous vehicle. Over the years, a sustained trend in the development of sustainable transportation means in form of application active safety systems to improve vehicle handling, stability and comfort has been a prominent feature of most result-yielding design efforts. The design of such systems not only recognizes the needs of all stake holders for the development of sustainable transport process; but also, considers its effect on the environment and society at large, As vehicles have become more sophisticated (and hence more expensive), such intuitive development has become very expensive and also risky business (Ahmad et al., 2010). In an effort to predict and quantify the effects of proposed changes in vehicle parameters, designers are increasingly turning to computer simulation techniques to evaluate design proposals. However, computer simulations can only be useful if the software accurately reflects the behaviour of the actual vehicle. If it does, then considerable savings in time and costs can be obtained. Vehicle dynamics models can be developed for simulation using two possible approaches. The first approach uses a multi-body method to generate the equations of motion, where the vehicle is described as a collection of rigid bodies connected by appropriate joints and internal forces and subject to external forces. The equations are automatically generated and solved by software packages such as DADS (Freeman et al., 1995), AutoSim or ADAMS (Katrin et al., 2009). The second approach to vehicle dynamic modelling is known as simplified modelling. There are three main types of simplified vehicle model often used in vehicle dynamics analysis, namely the quarter car, half car and full car models. In the quarter car model, only up–down movements of the sprung and unsprung masses are assumed to take place and the role of the control arm is completely ignored (Mousseau and Markale, 2003) This paper deals with the simulation of handling characteristics of a road vehicle, using a 3 DOF mathematical model of a scaled Remote Controlled (RC)

Car since to this day the steering system is still a major factor for the overall evaluation of the vehicle. At the same time, more and more electro-mechanic steering systems are produced in series. Although electro-mechanical steering systems offer various advantages and many degrees of freedom, the tuning of these systems is becoming more complex (Van Ende at al., 2015) Handling characteristics of a road vehicle refer to its response to the input steering commands that effect the direction of the vehicle. There are two basic problems in vehicle handling: one is the control of the direction of motion of the vehicle; the other is its ability to stabilize its direction of motion against external disturbances.

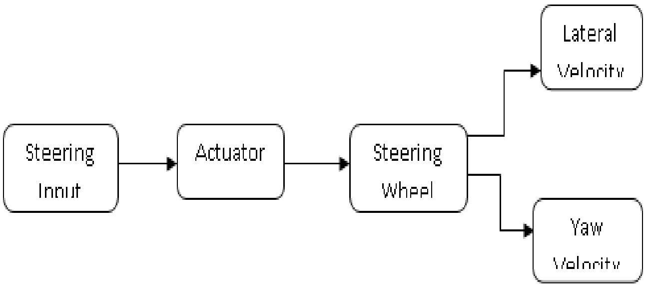

Figure 1: Steering system block diagram

II. Dynamic model of vehicle

The dynamics of the vehicle can be described by a detailed 3-DOF nonlinear model. Since it is possible to decouple the longitudinal and lateral dynamics, a linearized model of the lateral vehicle dynamics is used for controller design. The linearized model of the vehicle retains only lateral and yaw dynamics, assumes small steering angles and a linear tire model, and is parameterized by the current longitudinal velocity. Coupling the two front wheels and two rear wheels together, the resulting bicycle model (Figure 1) is described by the following variables and parameters.

The bicycle model simplifies a vehicle's lateral dynamics by assuming that the vehicle is traveling at a constant speed and does not experience pitch or roll. As a result, the equations governing the dynamics of the front tires and rear tires can be mathematically combined to create one front tire and one rear tire, as is the case with a bicycle. By ignoring a vehicle's roll, bounce, and pitch, a vehicle model with three degrees of freedom, yaw and planar motion, can be produced. Figure 2 represents vehicle motion characterized by its velocity v = (vx,vy) expressed in the vehicle's inertial frame of reference and its yaw rate Ψ. The forces acting on the front and rear wheels are Ff and Fr. The lateral dynamics equations are obtained by computing the net lateral force and torque acting on the vehicle following Newton-Euler equations. The state equations are of the following form. A complete explanation and derivation of the state equations can be found in (Brennan, 1999), and a summary is given in Eq(1). The parameters used in the simulation are presented in Table 1.

(1)

where A = system matrix n x n, B = input matrix n x m, C = output matrix p x n, D = feed forward matrix p x m.

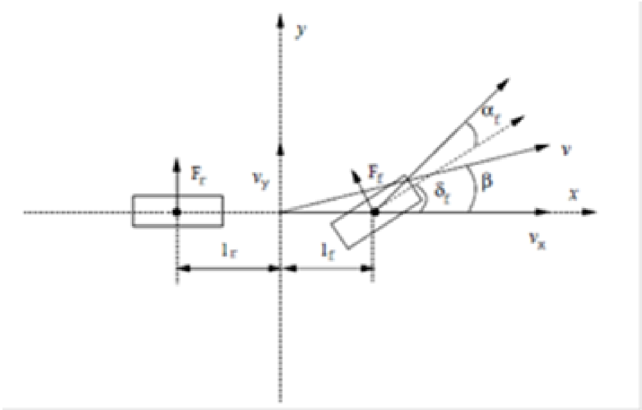

Figure 2: Bicycle Model (Kosecka, 1997)

S/N	Parameter	Know/existing values
1	steering Gear ratio (N_t)	10
2	motor torque constant (K_t)	10
3	damping coefficient of steering system (C_s)	50
4	mechanical trail (zeta)	0.5
5	front tire cornering stiffness (C_f)	2000
6	rear tire cornering stiffness (C_r)	2200
7	vehicle longitudinal velocity (U_x)	20
8	lateral velocity (U_y)	3
9	front tire distance (a)	0.9
10	rear tire distance (b)	0.9
11	yaw velocity rate (r)	0.0
12	motor gear ratio (Nm)	5
13	equivalent moment of inertia of steering system (I_z)	12
14	vehicle yawing moment of inertia (I)	2000
15	motor inertia (I_m)	10
16	mass of the vehicle (m)	2000

Table 1: Simulation parameters used

III. . Input Test Procedure

The step-steer test was carried out to study the sensitivity of the vehicle reaction to sudden change in steering input. The test avails us the to gauge how fast the vehicle reacts to a steering input and how quickly the system can settle to a new equilibrium. The vehicle is driven at test speed in a straight line with initial speed kept within a range not more than 2 km/hr from test speed. Starting from a 0±0.5 o/s yaw velocity equilibrium condition, a steering input is applied as rapidly as possible to a preselected value and maintained at that value for several seconds after the measured vehicle motion variables have reached steady state. In order to keep the duration of steering input relative to vehicle response timeshort, the time taken to achieve between 10 % and 90 % of steering input was kept not greater than 0.15 s.

III. Results and discussions

The time-domain and frequency-domain resonse analysis were carried out to analyse system responses such as, step responses, impulse responses and Bode plots as shown in Figure 3, 4 and 5 of which other system characteristics such as rise time and settling time, overshoot, and stability margins could be extracted if intended to. Most linear analysis commands can either return response data or generate response plots. Figures 3 and 4 represent linear model for the proposed vehicle dynamic analysis, under MATLAB (poles and zeros, frequency response, time-domain response, etc.).

The field of vehicle dynamics encompasses three basic modes of vehicle performance. Vertical dynamics, or ride dynamics, basically refers to the vertical response of the vehicle to road disturbances. Longitudinal dynamics involves the straight-line acceleration and braking of the vehicle. Lateral dynamics is concerned with the vehicle's turning behavior.

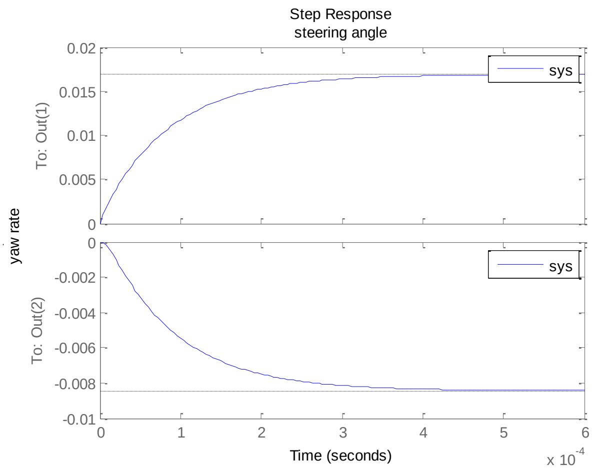

Figure 3: Step response

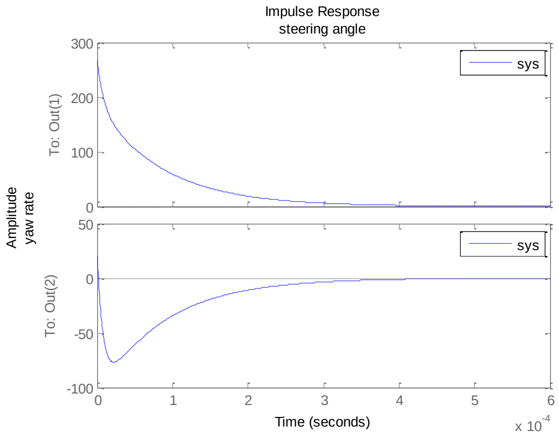

Figure 4: Impulse response

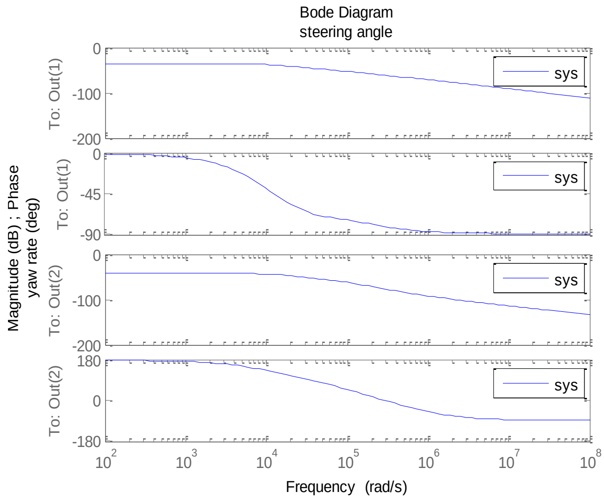

Figure 5: Bode diagram

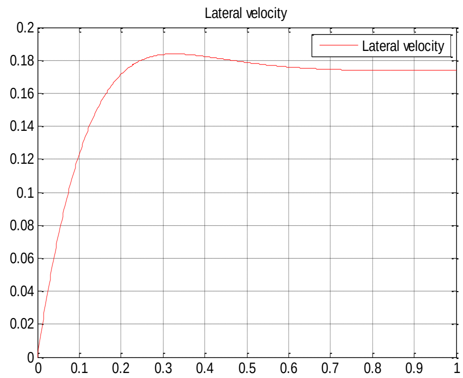

Figure 6: Lateral velocity vs time

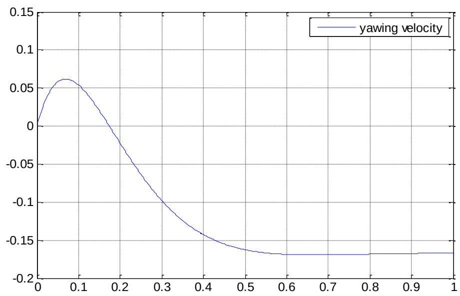

Figure 7: Yaw rate vs time

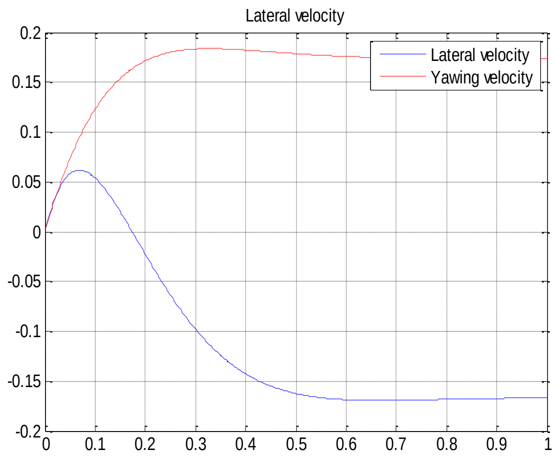

Figure 8: Combined plot of lateral and yaw velocity against time

Achieving acceptable performance in each of these modes is necessary in order for a vehicle to meet the requirements of the consumer, and the government in terms of sustainable transport development, with regards to reduction of traffic, low fuel consumption, comfort, controllability, and safety. Therefore, from the figures, it can be see that the behaviour of the two states is very similar. This is due to the fact that each state depends on both the inputs and any change in input is distributed equally due to vehicle symmetry conditions. This can be verified from matrices in Eq(1),

The three-degree-of-freedom vehicle model's equation of motion was rewritten in first order differential equation form to enable using first-order numerical integration methods, such as the third order Runge-Kutta, which was used for this study. The third order Runge-Kutta integration routine was used to integrate vehicle equations of motion. MATLAB command ode45 was used to solve simultaneous first order differential equations. The state space representation of dynamic system as seen in Eq(1) with vehicle parameters in Table 1 were used for the simulation and results shown in Figure 6 and 7. Figure 8 is a combine plot of both Figure 6 and 7. Where the result in Figures 6 and 7 shows that the trajectory that the vehicle would follow in response to a steering input from the driver if the road were dry and had a high tire-road friction coefficient that prevent vehicles from spinning and drifting out. These high friction coefficients will provide the required lateral force which the vehicle will need to negotiate the curved road

IV.Conclusions

Although Autonomous vehicles alone are unlikely to have significant direct impacts on energy consumption and greenhouse gas emissions, when Autonomous vehicles are effectively paired with other technologies and new transportation models, significant indirect and synergistic effects on economics, the environment, and society are possible in de-congesting traffic thereby reducing fuel consumption. In conclusion, the simulation result for a 3 Degree of freedom Remote Controlled Car using MATLAB gave a better understanding of a vehicles cornering behaviour and showed what happens when an input command is sent to the steering. And how fast the vehicle would respond Therefore in planning sustainable transport process, the handling dynamic of a vehicle needs to be considered throughout the entire planning process and development process from initial conceptualization through production if performance goals are to be metand

V.Acknowledgments

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VI.References

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