ANALYSIS OF VEHICLE HANDLING USING A SIMPLE TRACK MODEL OF AUTOMOBILE

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Abstract— **This paper obtains a simplified modelling and simulation for investigation of the behavior of vehicle handling and stability using the automobile single track model. Two control technologies were used in this paper which are the traditional PID control and Fuzzy PID control. To reach the desired results of this paper, full control system must construct which contains linear single-track model of vehicle, nonlinear single-track model, and control method. One driving condition is performed which is the steering input, the steering input in this work is set as step steering angle and a lane change maneuver. The simulation results of this paper show that, the constructed control systems for vehicle models used were successful to achieve better vehicle handling and stability.**

Keywords— Single track model, Vehicle stability, PID controller, Fuzzy PID control.

I. INTRODUCTION

Vehicles are becoming more frequently performance throughout the years, it is obvious that their design procedure require a better knowledge of their performance and behavior. One of the important ways to get that knowledge how to use the mathematical models, which describe the vehicle behavior when given relevant parameters. Knowing of these parameters is very important to run the mathematical models, and to get the expected results [1].

The handling of motored vehicles is one of most important factors because of roads safety. There are a quite variety methods for analyses management of performance, such as objective measurements or analysis of vehicle behavior due to a driving maneuver. these methods are effective to demonstrating an existing vehicle, but simultaneously they are not appropriate in the first part of designing stage of vehicles development, when there is no actual vehicle to run. Furthermore, the earlier potential issues of safety are discovered, the funds and lower that are subsequently needed to redress them.

A procedure which is able to give a detailed analysis of the handling characteristics in the design stage of a new vehicle is the mathematical model. Moreover, the diagnosis of the potential handling trouble using simulations requires less time. In the past, many differences of a handling models have been obtained in the literature, with an emphasis being mostly put on improvements of the vehicle single-track model, discover of `new factors that affecting driving stability.

This paper presents a mathematical model of vehicle which includes a small number of the parameters using simple track model of vehicle [2].

In this article, the PID controller and fuzzy PID controller are introduced for vehicle yaw rate control. The non-linear track model is used as a vehicle plant and linearization of nonlinear track model is utilized for the controller design. To evaluate the controllers performance, the maneuvers vehicle handling test are performed in MATLAB simulations.

In vehicle dynamic studies, the classical single track model as shown in Fig 1 is prominently used for yaw stability control analysis.

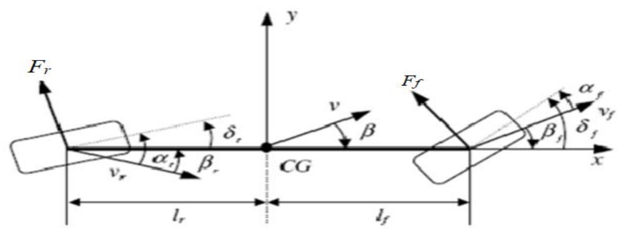

Fig. 1. *Single track model (bicycle model).*

The single track model uses for controllers design and the analysis of yaw stability control prominently. According to some assumptions, linearize the actual model of the vehicle is investigated, these assumptions are: the vehicle moves on flat road (planar motion), the tires forces operate in a linear region, and the left and the right tires at the rear and front axle are lumped together.

TABLE I NOMRNCLATURE USED.

C.G.	Center of gravity	x_o, y_o	Inertial frame of reference
V	Vehicle velocity at c.g.	$x-y$	Chassis fixed frame of reference
β	Vehicle side slip angle	V_f	Velocity at center of front tire
l_f	Distance between front axle and c.g	V_r	Velocity at center of rear tire
l_r	Distance between rear axle and c.g	α_f	Front tire side slip angle
F_f	Front tire lateral force	α_r	Rear tire side slip angle angle
F_r	Rear tire lateral force	β_f	Front tire velocity angle with X axis
δ_f	Front tire steering angle	β_r	Rear tire velocity angle with X axis
δ_r	Rear tire steering angle	ψ	Yaw angle

II. LINEAR AND NONLINEAR VEHICLE MODELS

In this section, the mathematical equations of a nonlinear track model and linear single-track model are given and considered. Both of these models are established for the controller design and vehicle plant respectively, and analyze performance by using a computer simulation tools [3].

To complete this work, Matlab Simulink model of single-track model should be completed as shown in fig 2, this model includes Tire Model, Vehicle Dynamics, Steering Angle Projection, Kinematics/Geometry, Simple Driver Model, and Trajectory Calculations.

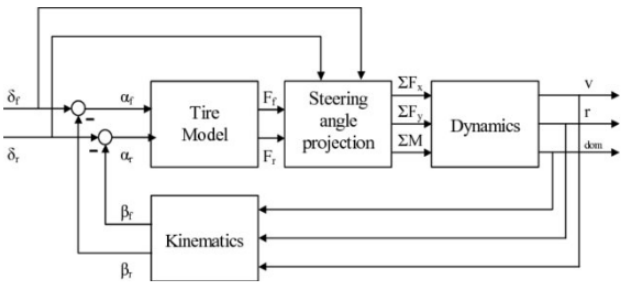

Fig. 2. *Simulink model of single track model.*

A. Nonlinear Track Model.

The mathematical equations of vehicle motions of the nonlinear model can be expressed as follows

Nonlinear Model Equations:

Tire Model:

Linear tire model is used in this case:

$$F_f = cfo \times (\delta_f - \beta_f) = cfo \times \alpha_f \quad (1)$$

$$F_r = cfo \times (\delta_r - \beta_r) = cfo \times \alpha_r \quad (2)$$

Vehicle Dynamics:

$$mv(\dot{\beta} + \dot{\psi}) = -F_x sin\beta + F_y cos\beta \quad (3)$$

$$m\dot{v} = F_x cos\beta + F_y sin\beta \quad (4)$$

$$J\ddot{\psi} = M_z \quad (5)$$

Steering Angle Projection:

$$\sum F_x = -F_f sin\delta_f - F_r sin\delta_r \quad (6)$$

$$\sum F_y = F_f cos\delta_f + F_r cos\delta_r \quad (7)$$

$$\sum M_z = l_f F_f cos\delta_f - l_r F_r cos\delta_r \quad (8)$$

Kinematics/Geometry:

$$\beta_f = tan^{-1}\left(tan\,\beta + \frac{\dot{\psi}\, l_f}{v cos\beta}\right) \quad (11)$$

$$\beta_r = tan^{-1}\left(tan\,\beta - \frac{\dot{\psi}\, l_r}{v cos\beta}\right) \quad (12)$$

Simple Driver Model:

A simple driver model was added to keep the longitudinal speed constant. The simplest PI cruise controller was used.

$$\sum F_x \rightarrow \sum F_x + G_{PI}(s)(v_{desired} - v_{measured}) \quad (13)$$

B. Linear Track Model

In vehicle dynamic investigation, the linear single-track model is prominently used for controller design and yaw stability control analysis.

Tire Model;

Equations (1) and (2) are represented linear tire model.

Vehicle Dynamics;

The force moment coordinate transformation equations will become as follows with small beta and constant velocity assumptions:

$$mv(\dot{\beta} + \dot{\psi}) = F_y \quad (14)$$

$$J\ddot{\psi} = M_z \quad (15)$$

Force / Moment Coordinate Transformation;

$$\sum F_y = F_f + F_r \quad (16)$$

$$\sum M_z = l_f F_f - l_r F_r \quad (17)$$

Kinematics Geometry;

The kinematics/geometry relation equations will become as follows with small chassis front and rear slip angles assumptions:

$$\beta_f = \left(\beta + \frac{\dot{\psi}\, l_f}{v}\right) \quad (18)$$

$$\beta_r = \left(\beta - \frac{\dot{\psi}\, l_r}{v}\right) \quad (19)$$

In this paper, yaw rate and vehicle sideslip angle have been taken from the linear model as a desired yaw rate and desired sideslip angle as shown in the following figures.

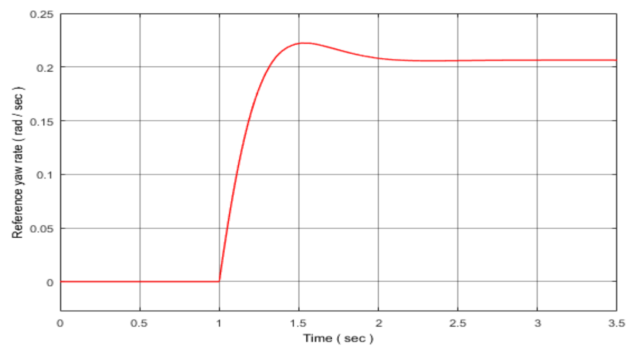

Fig. 3. *linear single track model yaw rate at a step signal of steering angle.*

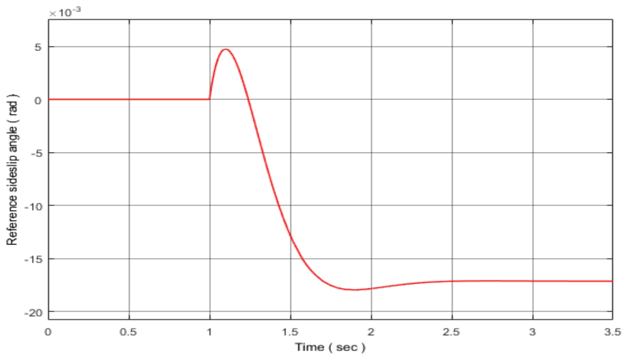

Fig. 4. *vehicle sideslip angle at a step signal of steering angle.*

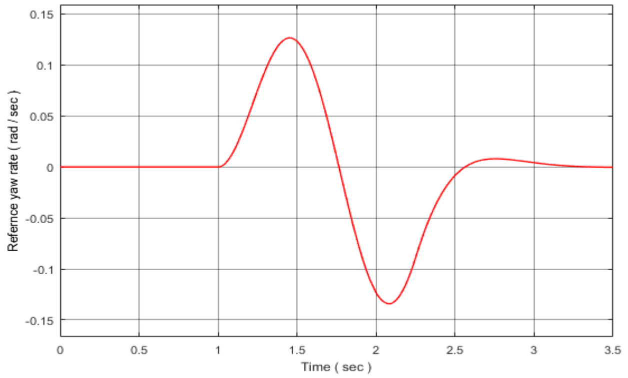

Fig. 5. *linear single-track model yaw rate on a lane change maneuver.*

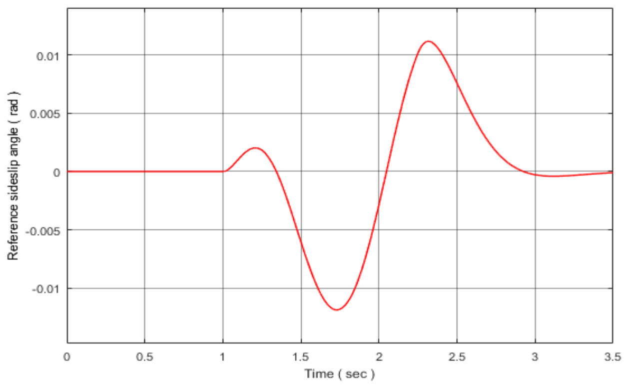

Fig. 6. *vehicle sideslip angle on a lane change maneuver.*

III. CONTROL TECHNIQUES AND STRATEGIES

The purpose of this section is to give some principles and explanation about two of control methods used which are conventional proportional, integral, and derivative (PID) controller and Fuzzy PID controller (FPIDC). The most commonly structure, design, and meaning of Fuzzy PID controller will be obtained.

The vehicle model structure with these two controllers is presented as below.

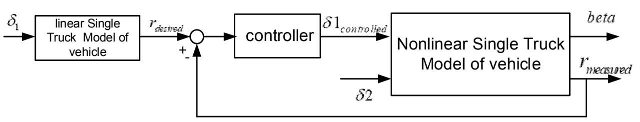

Fig. 7. *The vehicle model structure with controller.*

Optimal PID controller

Transfer function of a PID controller is described as equation (20), which, the output of controller is a compound of three terms, proportional, integral and derivative term. To produce a control signal, three terms of controller operating on the error signal. The u(t) is the actuator output which sent to the system, r(t) is the desired output and y(t) is the actual output, and tracking error e(t) is the input of controller.

$$G_c(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \quad (20)$$

By correcting the parameters of PID controller k_p, k_i and k_d, the desired closed loop dynamics can be founded. often iteratively with "tuning" and without specific knowledge of a plant model. by using the proportional term, the stability will be obtained. And through second term which is integral term grants the eliminating the steady-state error and rejection of a step disturbance. The last one is derivative term supplies reducing the overshoot and increasing the stability of the system, PID controller is the most well-established class of control systems, however, they cannot be used in quite a lot of complicated cases, almost in the MIMO systems.

Fuzzy Self Tuning of PID Controller

The performance of system can be improved and modified by proper adjusting and scheduling of the three parameters of PID controller (k_p , k_i and k_d). The most known structure of the Fuzzy PID controller (FLPIDC) is obtained in the following figure (8).

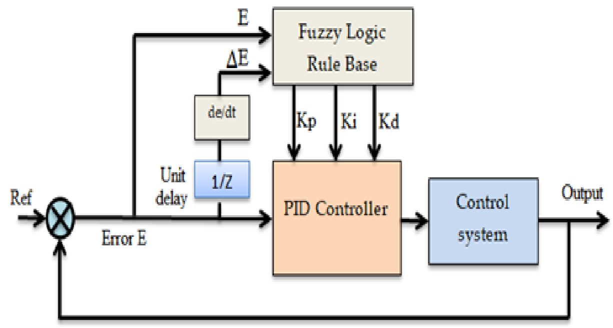

Fig. 8. *The structure of FPIDC.*

In Fuzzy self-adjusting PID controller, it takes the error E (the deviation between the desired set point and the output of the system) and ΔE (change in error or error rate with unit delay) as two inputs. The parameters of PID controller (k_p , k_i , k_d) are tuned and adjusted by using fuzzy inference automatically to meet and verify the requirements of E and ΔE for PID parameter self-setting in different time.

IV. *SIMULATION STUDIES*

two different simulation studies are conducted to test the proposed controller system which are step steering angle and lane change maneuver, the final results of vehicle yaw rate and sideslip angle using PID controller and Fuzzy PID controller are represented as shown in figures 9 to 12.

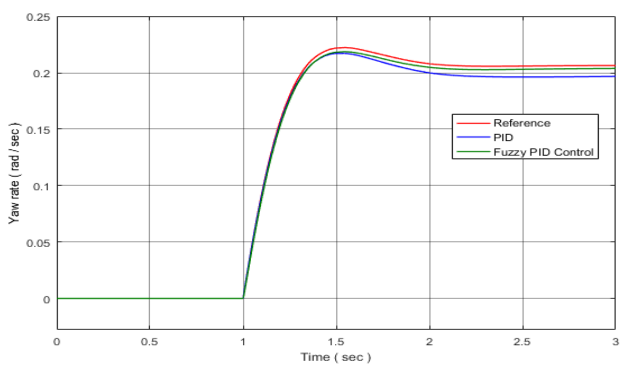

Fig. 9. *The vehicle yaw rate behavior at a step signal of steering angle.*

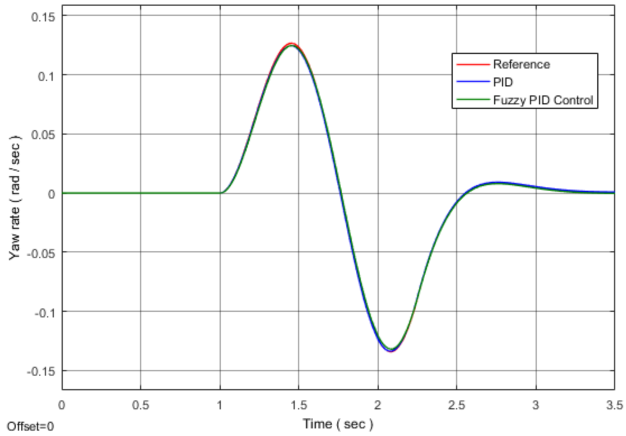

Fig. 10. *The vehicle yaw rate behavior on a lane change maneuver*

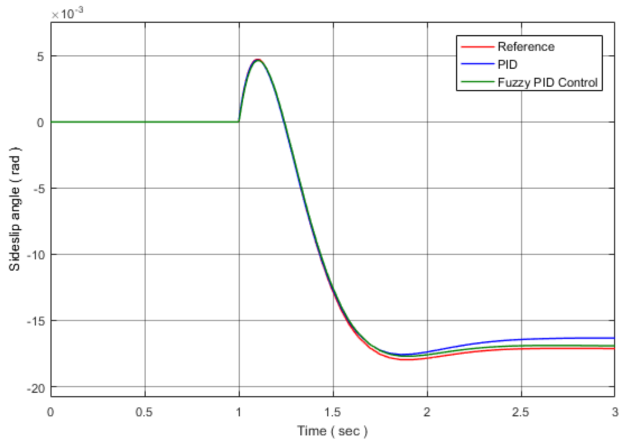

Fig. 11. *The vehicle Sideslip angle behavior at a step signal of steering angle.*

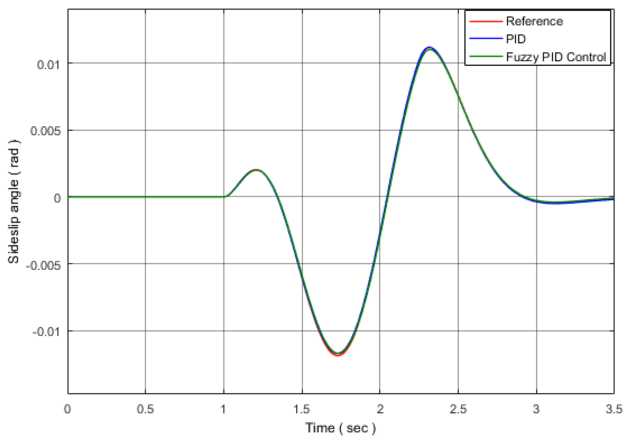

Fig. 12. *The vehicle Sideslip angle behavior on a lane change maneuver.*

V. CONCLUSION.

In this paper, a control system evaluates and analysis the vehicle handling and stability using the automobile single track model and two different control methods which are the traditional PID control and Fuzzy PID control. The simulation results and plots indicate that fuzzy PID have very close behavior to the reference vehicle yaw rate compared to the traditional PID controller.

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