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Research Article

Development of intelligent active steering with fuzzy, PID controller and uncontrolled

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Abstract

The design of a fuzzy controller entails the concept of input-output fuzzy variables, decision-making procedures for the fuzzy control laws, fuzzy inference logic, and defuzzification. Two input parameters and one output variable comprise a fuzzy controller. The yaw rate error and its derivative are used as inputs. Through the use of appropriate differential equations, fuzzification created the evaluated controller inputs structurally consistent with the circumstance of the information rules. The fuzzy control technique can be used to compensate for the program's various coefficients of road friction and fluctuations. To accommodate for disruptions, the vehicle's side slip angles and yaw rate should be monitored. The proposed framework here considers the system's various coefficient of friction of the road. The mathematical derivation demonstrates that the system meets a contrasting situation. Comprehensive computer tests are performed for a variety of abnormalities, including crosswind and braking torque. The results of the simulation will reveal the effect of disturbance absorption. The implemented controller's efficiency will be evaluated to that of uncontrolled and PID controller techniques. The findings indicate that when opposed to ordinary and PID control schemes, the Fuzzy proposed controller is more effective at attenuating various disturbances for different road correlations. Additionally, the simulation results indicate that the system is unresponsive to external disturbances and competent of compensating for the driver's 'delayed acts' in response to a sudden disturbance on any driving conditions.

Keywords

Fuzzy Mode Controller, Intelligent Control System, Active Vehicle Steering, Disturbance Variables

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Introduction

Numerous dangerous situations arise on the road as a consequence of a driver's failure to react quickly adequate at the initiation of slipping or rollover. Automatic response capabilities enable the driver in navigating through such perilous circumstances. An additional stage is automatic driving based on track references. The control system's robustness in the face of uncertain road tire contact is a crucial component. Over the decades, scholars have applied advanced control strategies for enhancing vehicle performance in terms of uncertain vehicle parameters. A car driver controls longitudinal motion with the pedals and lateral motion and heading with the steering wheel. The steering control technique must be designed in such a way that the lateral displacement, lateral acceleration, and yaw-rate errors caused by step changes in disturbances are minimized. Numerous parameters will be monitored, including the relationship between slip angles and lateral forces on the tyre, as well as the instabilities associated with road surface friction. Latest research and development indicate that a four-wheel steering system (4WS) can significantly improve the vehicle's transient response in a corner. According to theories, when the vehicle is travelling at a high speed, the rear-wheel steering angle and the same contribute to the vehicle's satisfactory stability and passenger safety. When the vehicle is travelling at a low speed, particularly in a geometry car park, the front and rear wheel drivers are identified in the opposite direction to optimize the overall manoeuvrability. According to [1], when a controller is incorporated into a vehicle structure, it has the potential to deteriorate the road handling condition, as most methods are designed using linearized models and ignore nonlinearity in tyre characteristics. These techniques may be effective as long as the vehicle persists within the linear range of the tyre qualities. As an outcome, once the vehicle enters the nonlinear region of the tyre characteristics, the driving scenario may deteriorate significantly in comparison to a conventional vehicle. When designing a controller, it is critical to consider the vehicle's stability. J. Ackermann [2] demonstrated how to decouple the steering dynamic behavior of a car with an uninformed mass distribution. We abandoned the preventive mass distribution presumption and derived a generalized decoupling control law for any mass distribution. The conclusion of the article creates a relationship between modelling the steering dynamic behavior of a single car using two masses and larger control issues such as automatic steering and distance retaining for single mass concepts in a platoon of cars. However, this paper makes several assumptions, including constant velocity, minimal sideslip, and steering angles [3]. Additionally, the active steering structure has been enhanced using intelligent techniques as with fuzzy logic, neural networks, and machine learning. To avoid the use of an uncertain highly nonlinear expression, a fuzzy-rule-based cornering force estimator was developed by M.K. Park et al. [4]. Furthermore, a neural network compensator is used to verify that the estimator finds the cornering force correctly. The results reveal that the proposed control system is adaptable to disturbances in the conceptual system of the vehicle, as in a side gust of wind and uneven road surfaces.

The model presented in this article is based on Ackermann et.al [5]. This section addresses the derivation of the model for active car steering systems for single-track model using a linearization model plant. The algorithm is established in conjunction with the active car steering state space equation. A few corresponding standards of the road coefficient parameter p are performed to differentiate the performance of wet and dry roads. Consequently, disturbance profiles that are regarded as the disturbance input of torque are incorporated into the findings.

Fuzzy Logic Controller

Operational on Fuzzy Sets

In [6] proposed the minimal level operator for the intersection of two fuzzy sets and the optimum operator for the union [7]. When only the membership degrees 0 and 1 are perceived, it is sufficient to prove that these operators correlate to sharp unification and intersection. For example, as illustrated in Figure 1, assume A is a fuzzy interval between 5 and 8, and B is a fuzzy set next to 4.

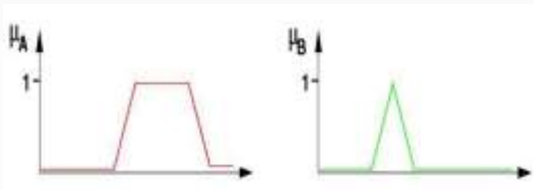

Fig.1 Example Fuzzy Sets

In this scenario, the fuzzy logic around 5 and 8 AND approximately 4 as depicted in Figure 2 will sufficient.

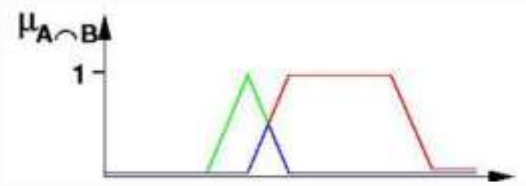

Fig.2 Example Fuzzy AND

Figure 3 illustrates a set around 5 and 8 OR approximately 4.

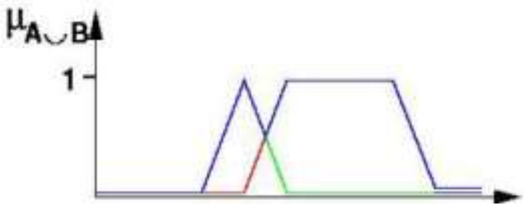

Fig.3 Example Fuzzy OR

The fuzzy set A's Negation is depicted in Figure 4.

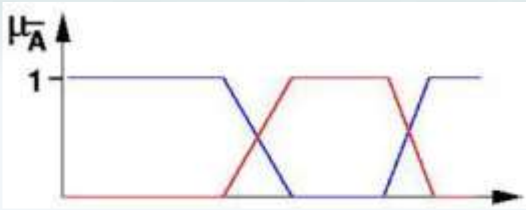

Fig.4 Example Fuzzy Negation

One concept of genetic theory is fuzzy classifiers. By the use of linguistic variables described by fuzzification, expertise is exploited and communicated very instinctually. Presently, human intelligence for these variables can be expressed in the form of rules such as IF function A is low AND function B is medium AND function C is medium AND function D is medium THEN = Class 4. The instructions can be integrated in a table referred to as the classification model, as shown in Table 2.1. (E.g. Rule no.1: IF A is low AND H is medium AND is medium AND A is medium. THEN pixel is class 1).

Table 1

Example for a fuzzy rule base: Rules read

Rule			**Function**		
	A	B	C	D	Class
1	Low	Medium	Medium	Medium	1
2	Medium	High	Medium	Low	2
3	Low	High	Medium	High	3
4	Low	High	Medium	High	1
5	Medium	Medium	Medium	Medium	4

The controller's linguistic rules are split into two categories: a predictor block (that occurs between the IF and THEN statements) and a subsequent block (following THEN). Based on the system, evaluating every possible input combination may not be necessary, as some may occur infrequently or never. This type of analysis, which is typically performed by an equitable approach, allows for the evaluation of fewer rules, simplifying the processing logic and possibly even enhance the efficiency of the fuzzy system. The AND function is used to logically integrate the inputs to generate output correlation coefficients for all expected inputs. For each membership function, the active findings are then added together to form a logical sum. A firing strength is measured for each output membership function. All of that remains is to integrate these logical sums in a defuzzification system to achieve the desired output. Each class called singleton, a rule consequent or a min–max intervention can be deduced that is the distinctive function of the particular set. For instance, the system shown in Figure 5 is for the input pair H = 0:35 and = 30

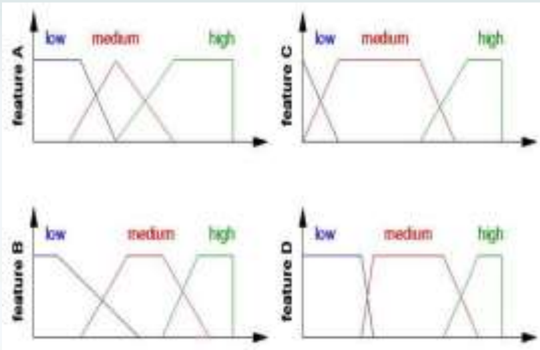

Fig.5 Linguistic Variables

Lastly, the fuzzy outputs of all rules are integrated to create a single fuzzy set. To acquire a crisp decision from such a fuzzy output, the fuzzy set, or set of singletons, must be defuzzified. As an outcome, we must select a single representative value as the final outcome. Numerous heuristic techniques exist for determining the force of mass of a fuzzy set, as described in figure 2.5. This is a frequently used approach for fuzzy sets. Typically, in the discrete case with singletons, the optimum is used, in which the point with the greatest singleton is selected, as illustrated in Figure 6.

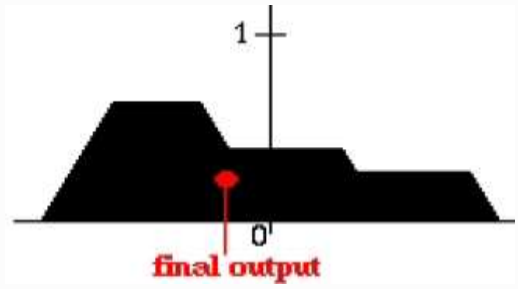

Fig.6 Defuzzification using the center of gravity approaches.

Structure of Fuzzy Sets

To assist in the design process, a fuzzy controller is composed of precise components. The control system between the preprocessing and post processing blocks is represented in Figure 7 [8].

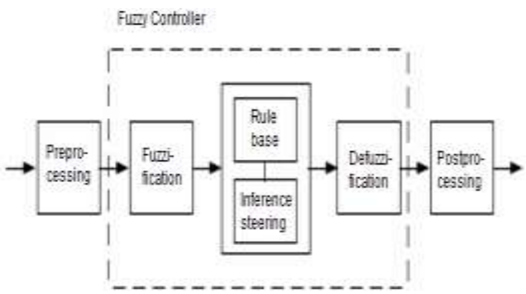

Fig.7 Structure of fuzzy logic controller

Pre-processing

Rather than linguistic inputs, the variables are frequently hard or crisp measurements from some measurement system. A preprocessor, represented by the first block in Figure 3.1, displays the situations under which the capacities were taken attempting to enter the controller [9].

Fuzzification

The controller's first block is fuzzy logic, which changes each piece of dataset to a class label via a lookup in one or more classifiers. The fuzzifier block compares the input data to the conditions specified in the rules. Each linguistic term that relates to the independent variables has a membership functions [10].

Rule Base

A rule base is a structured collection of rules. The rules are enforced in an "If Then" format, with the If side denoting the criteria and the Then side denoting the assumption. The computer is capable of carrying out the rules and generating a control signal is applied to the error (e) and variation in error of the existing frameworks (dE). The system model is stored in a more or less linguistic form in a rule-based controller. A rule-based controller is uncomplicated to use for a non-specialist end user, understand and maintain, and an equivalent controller can be executed using standard technologies [11].

Defuzzification

Since all configured actions are clustered and transformed to a single non-fuzzy output signal that represents as the system's control signal, defuzzification occurs. The output rates are governed by the governing rules of the processes, and the locations are ascertained by the non-linearity of the systems. To accomplish this, evolve the system's control curve, which represents the system's I/O relationship and is analyze the information; identify the output degree of the classifier, with the goal of minimising the effect of non-linearity [12].

Post-processing

Often, the post processing block includes a configurable output gain that doubles as a control system [13].

PID Controller

The PID controller is such a well and frequently used technique for optimizing system behavior and minimizing or eliminating steady state failure. By adding a limited zero to the transfer function, the derivative controller enhances the open loop plant's transient response. The control signal increases network type by one and decreases the steady state confusion caused by a step function to zero by adding a pole at the origin. PID control can be classified into three categories: proportional, integral, and derivative. [14].

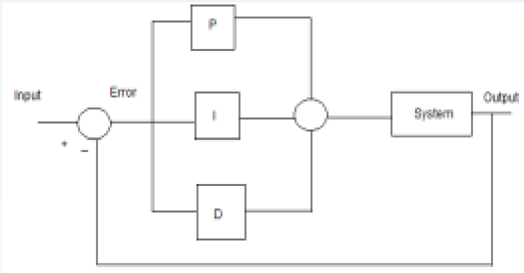

Fig.8 Conventional PID controller

By fine-tuning the three variables in the PID controller classifier in Figure 8, the PID can run control signal based on the unique requirements of a particular process. The controller's response can be defined in terms of its ability to respond to an erroneous, the degree to which it overshoots the predefined, and the level of system oscillation. It should be noted that using the PID controller for influence does not ensure system control. Certain devices may necessitate the use of only one or two mechanisms to provide adequate control signal. This is controlled by changing the gain of unacceptable control outputs to zero. A PID controller is attributed to as a PI, PD, P, or I controller in the lack of mention of a control action. PI controllers are especially prevalent whereas derivative action is extremely sensitive to specific noise and the lack of an integral value inhibits the structure from identifying target benefit as a result of the PID controller.

Proportional Control

This variable makes a major contribution that is proportional to the current value of the measured failure. A proportional controller can be used to control an instability plant, though its performance is restricted and its steady-state errors are not zero. Occasionally, this configuration is triggered by the device's frequency response being surrounded across the entire frequency range: Pterm = Kp x ERROR

Integral Control

The integral parameter generates a control signal proportional to the aggregate error, implying that the integral variable operates in the slow response mode [15]. This is also expressed in the frequency response of its low-pass filter. The control algorithm is crucial for ideal plant reversal at zero frequency. In the presence of a step reference and a disturbance, this forces the steady-state error to zero;

Iterm = KI x ∫ERRORdt

Derivative Control

PID controller has an effect on the rate at which the control error changes. As a result, it is a rapid mode that eventually vanishes in the presence of steady errors. Due to its reliance on the error pattern, it is occasionally referred to as a predictive mode. The derivative mode's

primary limitation is its proclivity for producing large command signal in response to increased control errors, such as set-point changes or parameter variations;
Dterm = KI x (d (ERROR / dt))

Continuous PID Control

Integrating the three types of control results in a PID controller with an output signal;
$CPID(s) = (K_D s^2 + K_P s + K_I) / S$
Where,
Kp = proportional controller gain
Ki= integral controller gain
Kd = derivative controller gain

The following are the basic steps in the architecture of a PID controller.

1. The site and identify the fundamental steps involved in the design of a control system.
2. Kp is use to decrease the rise time.
3. K_D I use to reduce the settling time and overshoot.
4. K_I use to eliminate the error of steady-state.

4. Simulation and Analysis

Previously, researchers obtained the single-track model for car steering. The systems' variables are analyzed in this section. It is expected in the modelling that the road disruption is an input to the system. The effectiveness of this system will be evaluated by examining its effect on a variety of disturbance profiles and varying coefficients of road friction. The methods can be divided into two road conditions: wet road condition =0.5 and dry road condition =1.
4.1 Simulink Model Based on Disturbance Profiles.
To investigate the reliability of active car steering in the presence of multiple categories of disturbances, a variety of disturbance profiles is used. Ackermann et al. in their studies on active car steering systems, they used two distinct types of disturbance profiles f(t): side wind and -split braking torque. Following that, these profiles are classified. For both = 1 (dry road) and = 0.5 (wet road), these two types of disturbance profiles will be used.

Disturbance Profile 1

f (t) = 3000 t ≥ 3,
f (t) = 0, Otherwise

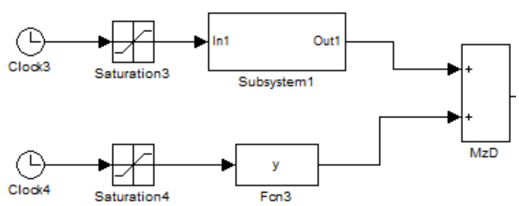

Fig.9 Function Block Disturbance 1

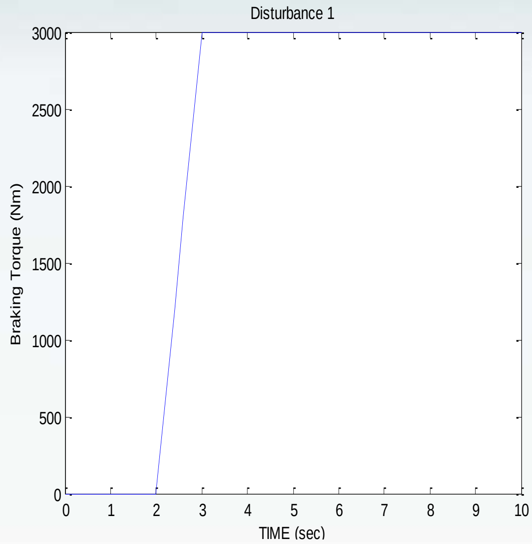

Fig.10 Braking Torque Disturbance Profile

Figure 10 represents the results of disturbance 1, which provides the system with Braking Torque (Nm) versus time (sec) as an input. Disturbance Pattern 1, derived from the physical equation of a step unit function, represents by -split braking torque by step process planning.

4.1.2 Disturbance Profile 2

f (t) = 100 3 ≤ t ≤ 7

f (t) = 0, Otherwise

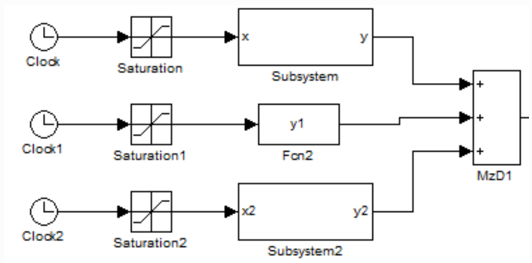

Fig.11 Function Block for the Disturbance 2

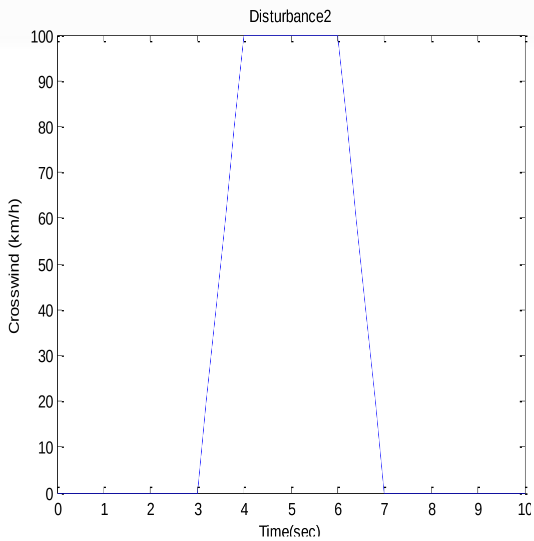

Fig.12 Crosswind Disturbance Profile

Figure 12 depicts the Disturbance Profile 2, which is crosswind velocity (km/h) versus time (sec). As an input pulse, the function block receives the computational formula of a single pulse.

4.2 Simulation Results.

4.2.1 Braking Torque (DPI) – Dry Road

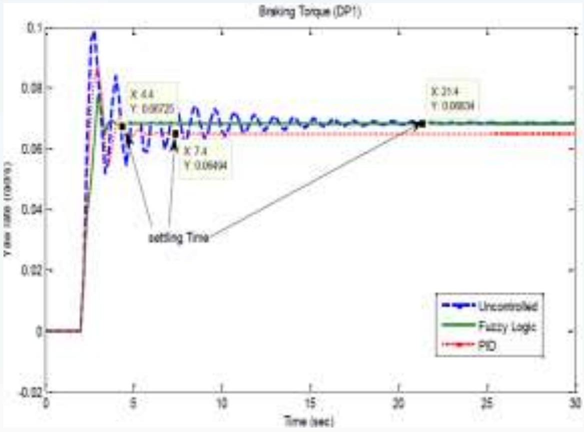

Fig.13 Yaw rate (DP1)

Table 2

Steady state response yaw rate (DP1, dry road)

Controller	Second (s)	
	Settling Time	OS%
Fuzzy Logic	4.4	1.021
PID	7.4	2.22
Uncontrolled	21.4	3.041

Figure 13 illustrate performance of yaw rate when input disturbance is Braking Torque (DP1). Fuzzy Logic controller show settling time 4.4s to achieve steady state compared with PID is 7.4s and Uncontrolled is 21.4s.

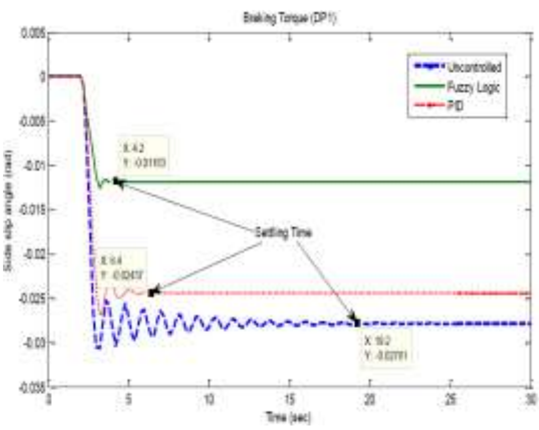

Fig.14 Side-slip angle (DP1)

Table 3

Steady state response Side-slip (DP1, dry road)

Controller	Second (s)	
	Settling Time	OS%
Fuzzy Logic	4.2	0.078
PID	6.4	0.25
Uncontrolled	19.2	0.273

Figure 14 show the performance of side-slip angle when input disturbance is Braking Torque (DP1). Fuzzy Logic controller produce better response in term of settling time 4.2 s to achieve steady state compared with PID is 6.4 s and Uncontrolled is 19.2 s.

Braking Torque (DPI) – Wet Road

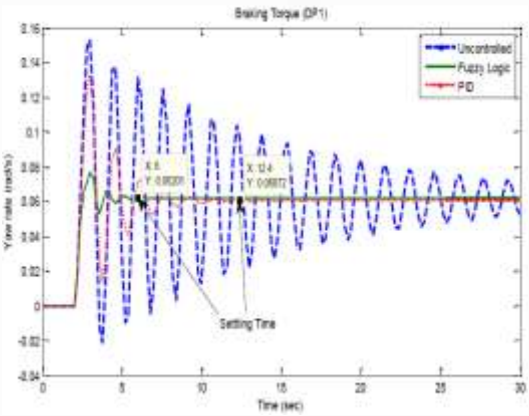

Fig.15 yaw rate (DP1)

Table 4

Steady state response yaw rate (DP1, wet road)

Controller	Second (s)	
	Settling Time	OS%
Fuzzy Logic	6	1.46
PID	12.4	7.268
Uncontrolled	-	9.228

Figure 15 is shown yaw rate angle performances when Braking Torque as an input and the condition road is wet (μ=0.5). The finding showed that when the settling time is 6 seconds, the disturbance is substantially lowered when using the Fuzzy Logic Controller.

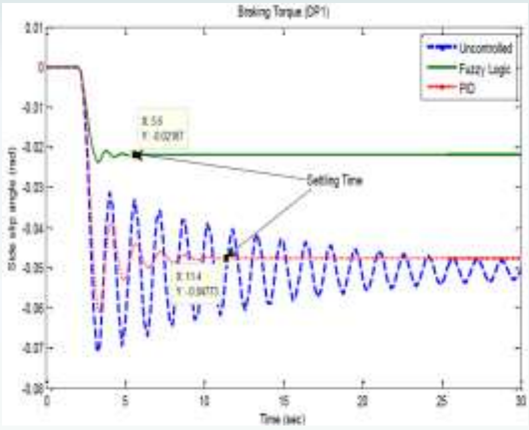

Fig.16 Side-slip angle (DP1)

Table 5 Steady state response sideslip (DP1, wet road)

Controller	Second (s)	
	Settling Time	OS%
Fuzzy Logic	5.6	0.184
PID	11.4	1.364
Uncontrolled	-	2.05

Figure 16 is shown side-slip angle performances when Braking Torque as an input and the condition road is wet (μ=0.5). The result shows that, once contrasted to two other controllers, the designed method performs the best. When settling time is only 5.6 sec to back to the steady state condition.

Crosswind (DP2) – Dry Road

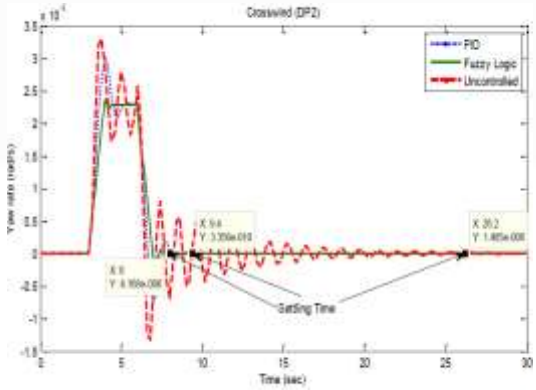

Fig.17 Yaw rate (DP2)

Table 6
Steady state response yaw rate (DP2, dry road).

Controller	Second (s)	
	Settling Time	OS%
Fuzzy Logic	8	0.2371
PID	9.4	1.3022
Uncontrolled	26.2	0.3292

As shown in Figures 17 the performance of yaw rate is respectively for disturbance profile 2 when μ = 1 (dry road). The results show that the disturbance has been caused the system's response to be uncontrolled. In comparison to the PID technique, it is ascertained that the Fuzzy Logic approach basically suppresses the disturbance.

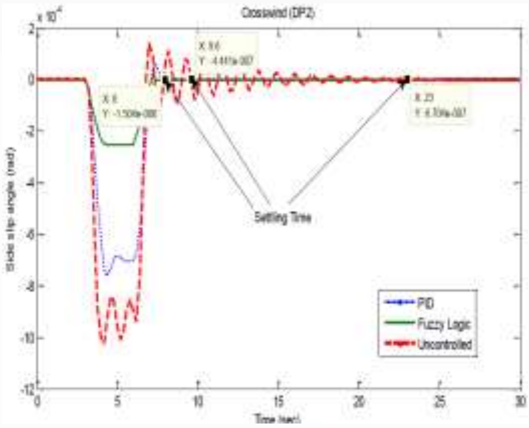

Fig.18 Side-slip angle (DP2)

Table 7
Steady state response sideslip (DP2, dry road).

Controller	Second (s)	
	Settling Time	OS%
Fuzzy Logic	8	0.0252
PID	9.6	0.0762
Uncontrolled	23	0.1021

As shown in Figures 18 the performance of Side-slip angle is respectively for disturbance profile 2 when μ = 1 (dry road). The Settling Time and Overshoot of Fuzzy Logic Controller is inhibited the annoyance in comparison to the PID technique and uncontrolled response.
4.2.4 Crosswind (DP2) – Wet Road

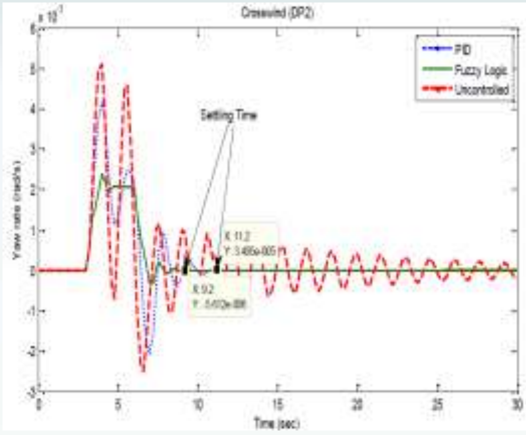

Fig.19 yaw rate (DP2)

Table 8

Steady state response yaw rate (DP2, wet road)

Controller	Second (s)	
	Settling Time	OS%
Fuzzy Logic	9.2	0.2375
PID	11.6	0.4162
Uncontrolled	-	0.5087

Figures 19 illustrate yaw rate response when disturbance profile 2 at road condition μ = 0.5 (wet road). Based on result, the response takes a relatively long time to achieve Settling Time but Fuzzy Logic still produce the best performance compare with others.

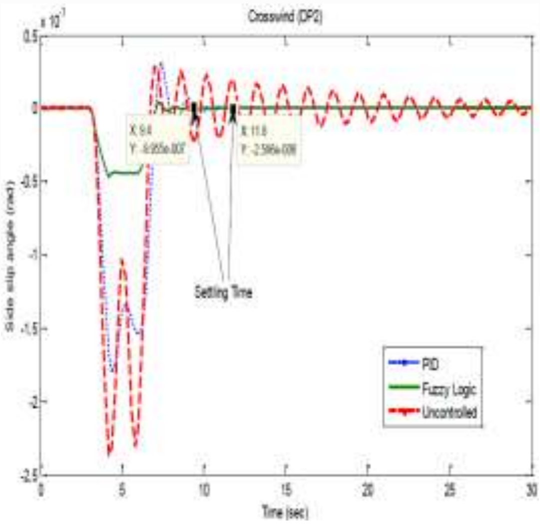

Fig.20 Side-slip angle (DP2)

Table 9
Steady state response Sideslip (DP2, wet road).

Controller	**Second (s)**	
	Settling Time	OS%
Fuzzy Logic	9.4	0.0469
PID	11.8	0.1809
Uncontrolled	-	0.2367

Figures 4.12 illustrate Side-slip angle response when disturbance profile 2 at the road condition μ = 0.5 (wet road). The response takes a relatively long time in term of Settling Time where 9.4 sec for Fuzzy Logic while 11.8 sec for PID.

Discussion

Most computational tests are conducted on a dry road with a road adhesion of 1 and a wet road with a road adhesion of 0.5, with no regard for air slide or road rolling resistance movements. For controlled and uncontrolled vehicles, the time response of the yaw rate and sideslip angle are shown. The result responses show the performance of vehicle with controller is improved than the uncontrolled vehicle. Nevertheless, all responses will be returned to the stable but for the wet road condition it will take a long time compared with dry road condition. Both yaw rate and sideslip angle can be nearly identical to the measured value. As can be seen, the controlled vehicle's yaw rate and sideslip angle responses can identify their precise value, indicating that the vehicle is reliable. Nevertheless, after three seconds, the sideslip angle of the uncontrolled vehicle appears to be greater than those of the controlled vehicle and varies with increase. As demonstrated by the simulation results, the proposed fuzzy logic controller is capable of maintaining the vehicle's steadiness while also enabling the system to react promptly. Additionally, the simulation results revealed that the application of the side-slip and yaw rate on wet roads is worse than the effectiveness on dry roads, which reveals a greater magnitude of accelerates. As a result, the vehicle is more likely to skid on a wet road than on a dry road.

The simulation results shown that step speed responses of two types of controllers where Fuzzy Logic and PID are difference. In comparison to the PI controller, the Fuzzy Logic controller has a faster rise time, a smaller overshoot, a faster settling time, and a lower steady state inaccuracy. The results demonstrate the speed reactions as a function of torque variance over a 30-second period. According to the inferences, the fuzzy logic controller has a smaller undershot and a faster settling time during the torque change duration. Additionally, whenever the road condition changes, Fuzzy Logic can restore the scenario to a steady state. Once again, the fuzzy logic controller surpasses the proportional integral (PI) controller. The steady state of the responses is observed from the overshoot where it is whether the peak value exceeds the steady state value, normalized against the steady state value. Consequently, settling time requires a reading from the evaluated to determine the time required for the system to achieve its steady state.

The fuzzy based logical control system is evaluated through a series of experiments. In comparison to the vehicle without a controller, the vehicle with a controller does have a faster reaction characteristic, but also adheres to the yaw rate and sideslip angle predicted value excellently. The experiments demonstrate that the control system is capable of stabilizing the vehicle during critical steering input variables and processing superior handling and consistency. Nevertheless, the active steering system and proposed controller are competent of compensating for the driver's "late action" in response to current road conditions.

Conclusion and Future Work

The steering system was successfully established using a passive control strategy in this research paper. The effectiveness of active steering under the developed model is investigated using a single track car model in order to prevent the car skidding and enhance the quality of the results. This research found a statistical equation of a single track car. It will be shown that this system will be stable with the controller that has proposed to avoid disturbance from external. However, the fuzzy logic control has been proposed in solving the matched uncertainties and nonlinearities complicated system. The implemented fuzzy logic control system is evaluated through a series of computations. The theory demonstrates that the vehicle equipped with a controller does indeed have superior step response, but also accurately describes the goal yaw rate and sideslip angle values.

The fuzzy controller is developed using MATLAB's Fuzzy Logic Toolbox to identify areas of improvement for the side-slip angle and yaw rate. Based on computer simulations, it was determined that the suggested control system can significantly optimize the transient response of each state variable, reduce vehicle side-slip, and bring the steady state value of yaw rate closer to the vehicle, thereby significantly improving vehicle stability without increasing the driver's driving strain.

The fuzzy logic controller was preferred since it provides many advantages over other classical controllers, including control simplification, cost effectiveness, and the ability to develop without determining the proper mathematical framework. Otherwise, it reduce the very detailed models of a particular subsystem.

There is few number of future works could be considered as an extension to the present study. At the high speed, the controller designed must show in high value of yaw rate and side-slip angle zero when vehicle takes a turn, control strategy to ensure vehicle is in steady state. Then, Disturbance from another angle is considered to make steering more easily controlled. Additionally, the correlation between lateral and longitudinal movements of the vehicle should be examined further, even though it has been demonstrated that these two motions could be approximately detached. Specifically, how to ensure ride safety since both steering and braking happen is a critical issue that should be thoroughly investigated. Finally, despite significant investment in steer-by-wire investigation, the challenge of integrating an intelligent steering controller with driver orders remains a challenging problem that has yet to be completely vanquished. Several previous studies revealed that this problem is quite complex, requiring further examination of the driver's attributes, emotions, and driving condition.

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