Nigerian Journal of Technology (NIJOTECH)
Vol. 38, No. 4, October 2019, pp. 1021 – 1029

Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v38i4.27

MODELLING OF AUTOMATIC CAR BRAKING SYSTEM USING FUZZY LOGIC CONTROLLER

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ABSTRACT

The increasing rate of road accident is alarming and any vehicle without an effective brake system is prone to accident with apparently disastrous effect following. This is due to human errors in driving which involves reaction time delays and distraction. Automatic braking system will be developed to keep the vehicle steerable and stable and also prevent wheel lock and collision with an obstacle. The objectives of this study are to: design an obstacle detection model using ultrasonic sensors, model an antilock braking system, develop fuzzy logic rules for both detection and antilock braking system, and simulate the developed model using Simulink in MATLAB software to achieve high braking torque, optimal slip ratio and shorter stopping distance and time. The results show 22% improvement in braking torque thereby giving a shorter stopping time and distance when compared to the normal PID control.

Keywords: *Slip ratio, Model, Ultrasonic Sensor, Antilock Braking System, Fuzzy logic, wheel lock*

1. INTRODUCTION

There is no gainsaying that automobile vehicles would not have made sense without an effective and real time response brake system. The effects of road accidents on lives and properties cannot be overemphasized so any vehicle without an effective brake system is prone to accident and apparently disastrous effects follow [12]. Number of vehicles are increasing day by day likewise the number of automobile users. At the same time, traffic congestion has become a worldwide problem. This problem is mainly due to human driving which involves reaction time delays and judgement errors [5] that may affect traffic flow and cause accidents. Engineers in the automobile industry put a lot of effort in devising systems which ensure safety in road vehicles. Even with all the advancements in vehicle safety technology, the number of people killed in road accidents continue to rise. World Health Organization [20] reported that the total number of road traffic deaths worldwide has reached 1.35 million per year, with the highest road traffic fatality rates in developing countries and the leading killer of people aged 5-29 years. These accidents occur every time and everywhere, and cause worst damage, serious injury and death and they are mostly caused by distraction and the delay of the driver to hit the brakes [4].

Automating the task of assessing the situation and deciding the correct amount of brake pressure to apply for collision avoidance is the aim of this study. By that means, the car brake itself should have a controller to assist a driver along the road. This would significantly decrease the amount of property and monetary loss due to accident damage [3]. Applying fuzzy logic to this intelligent control seems to be an appropriate way to achieve this human behavior [9], because driver's experience can be transformed easily into rules and any kind of non-linearities can be easily tackled. An intelligent mechatronic system which includes an ultrasonic wave emitter [19] provided on the front portion of a car producing and emitting ultrasonic waves frontward in a predetermined distance. Fuzzy logic control in Antilock Braking System was adopted by [5] and [12] to effectively prevent the wheels from locking, braking more effectively, and keep the slip rate closer to the optimum slip ratio around 0.2 but [5] included an extra fuzzy logic control for collision avoidance. Guo, *et al* [7] focused on automotive longitudinal active collision avoidance system which operates with the following techniques: environment

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perception and processing, evaluation of the safety state of traffic, control execution techniques and vehicle dynamics modeling.

In this paper, an obstacle detection system was designed with ultrasonic sensors based on [7] approach to achieve the critical braking distance between moving vehicle and pedestrian or two moving vehicles. A braking system was modelled with antilock system to prevent wheel from locking during heavy braking and maintain the system at optimum slip ratio. Fuzzy rules were developed for both the obstacle detection and braking system to control the operation of the systems and effectively assure safety and stress free driving.

2. AUTOMATIC BRAKING SYSTEM TECHNIQUE

The block diagram in Figure 1 depicts the operation of the system.

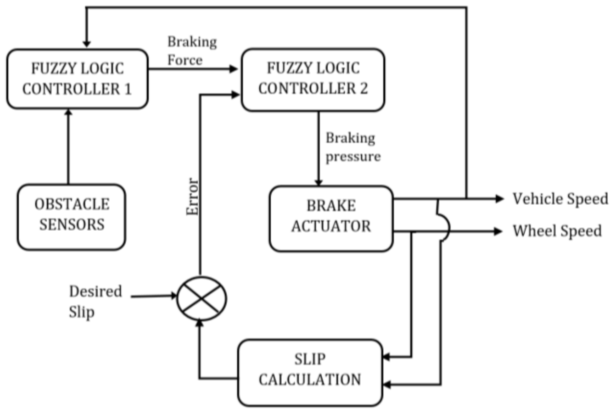

Figure 1: Block Diagram of the modelled System

The block diagram of the Automatic Braking system with two cascaded fuzzy logic controllers and obstacle detection sensors for automatic braking system to avoid collision with obstacle is depicted in Figure 1. The modelled system uses two fuzzy logic controllers for taking actions. The first Fuzzy Logic Controller (FLC 1) decides upon whether to stop the car or reduce the speed of the car depending on the distance of the obstacle and the vehicle speed at that moment. The second fuzzy logic controller (FLC 2) takes in the braking force as input to decide on the intensity of the braking torque to apply to the brake actuator and the slip ratio to maintain to avoid wheel lockup. The slip regulation between the car tyre and road to avoid skidding is controlled by FLC 2 when the wheel sensors detect a sudden deceleration that causes a difference in wheel and vehicle speeds. The obstacle detection system has three ultrasonic sensors (two at the sides of the car while one is in front of the car) for measurement of obstacle distance. This distance determines the amount of braking force when compared with vehicle speed.

2.1 Modelling of Obstacle Detection System

A real-time distance is the distance between a moving vehicle and a non-moving body or pedestrian and also a distance between two moving vehicles. The time taken for the to-and-fro movement of the ultrasonic waves after hitting the obstacles is the time of flight (time taken x 2).

The real-time distance d is obtained from the ultrasonic sensor which is given as

$$d = \frac{time\ of\ flight}{2}\ x\ velocity\ of\ sound\ (c) \qquad (1)$$

The walking velocity of pedestrian is neglected in reference to the car A and assumed to be zero [7]. Then the critical braking distance between the car A and the pedestrian is given as

$$d_{c1} = V_A\left(t_r + \frac{t_i}{2}\right) + \frac{V_A^2}{2\mu g} + d_{min} \qquad (2)$$

This equation is used for a non-moving obstacle or pedestrian whose velocity is assumed to be zero. The microcontroller used the velocity of the car (V_A) to determine the critical braking distance (d_{c1}) which is compared with the real-time distance (d) between the vehicle and non-moving obstacle. If the relative real-time distance (d) is larger than the critical braking distance d_{c1}, the vehicle could keep the original velocity and the pedestrian can cross the road in safety. If the relative distance is lower than or equal to the critical braking distance and the driver still does not decelerate or take other security measures, this state is judged to be dangerous and automatic braking deceleration on the car will be carried out by antilock braking system after getting a command from the Fuzzy Logic controller to either reduce the speed or stop the car.

The critical braking distance between two moving vehicle (Car A and Car B) can be obtained according to the safety distance model during the braking process as follows [7]

$$d_{c2} = V_A t_r + \frac{(V_A - V_B)t_i}{2} + \frac{V_A^2 - V_B^2}{2\mu g} + d_{min} \qquad (3)$$

where d_{c1}, d_{c2} = critical braking distance for deceleration, V_A = velocity of Car A, V_B = velocity of Car B, μ = friction coefficient of the road, t_r = sum of response time of the driver and braking coordination time ranging from 0.8s to 1.2s, t_i = growth time of the braking deceleration which varies from 0.1s to 0.2s, g = acceleration due to gravity (9.81 m/s^2) and d_{min} =

Minimum distance between vehicle and obstacle when it stop, ranging from 1m to 4m.

If the real-time distance d between Car A and Car B is greater than the critical braking distance d_{c2}, the traffic state is safe and the vehicle can run with its current velocity. Otherwise, if the driver does not decelerate or take other security measures when the current distance is lower than or equal to the critical braking distance, this state is judged to be dangerous and automatic braking deceleration on car A needs will be carried out immediately by the controller to avoid collision with car B.

From the flow chart in Figure 2, when the driver starts the vehicle, the sensors are in obstacle detection mode. The three sensors will detect if there is any obstacle and if there is none then the sensors will keep sensing till any of the sensors detects an obstacle. If an obstacle is detected, the ultrasonic sensor will measure the distance of the obstacle. If the signal is from the front sensor, the FLC 1 will check if the obstacle is within the safety distance for it to output the maximum braking force to FLC 2 to stop the car. Otherwise, the controller will output a low braking force to reduce the speed as the vehicle gets nearer to the obstacle. If both the Right Obstacle Sensor (ROS) and Left Obstacle Sensor (LOS) sense obstacles simultaneously, the controller decodes and outputs a low braking force to reduce the speed of vehicle till one of the sensors detects the obstacle then the controller calculates the distance of collision avoidance.

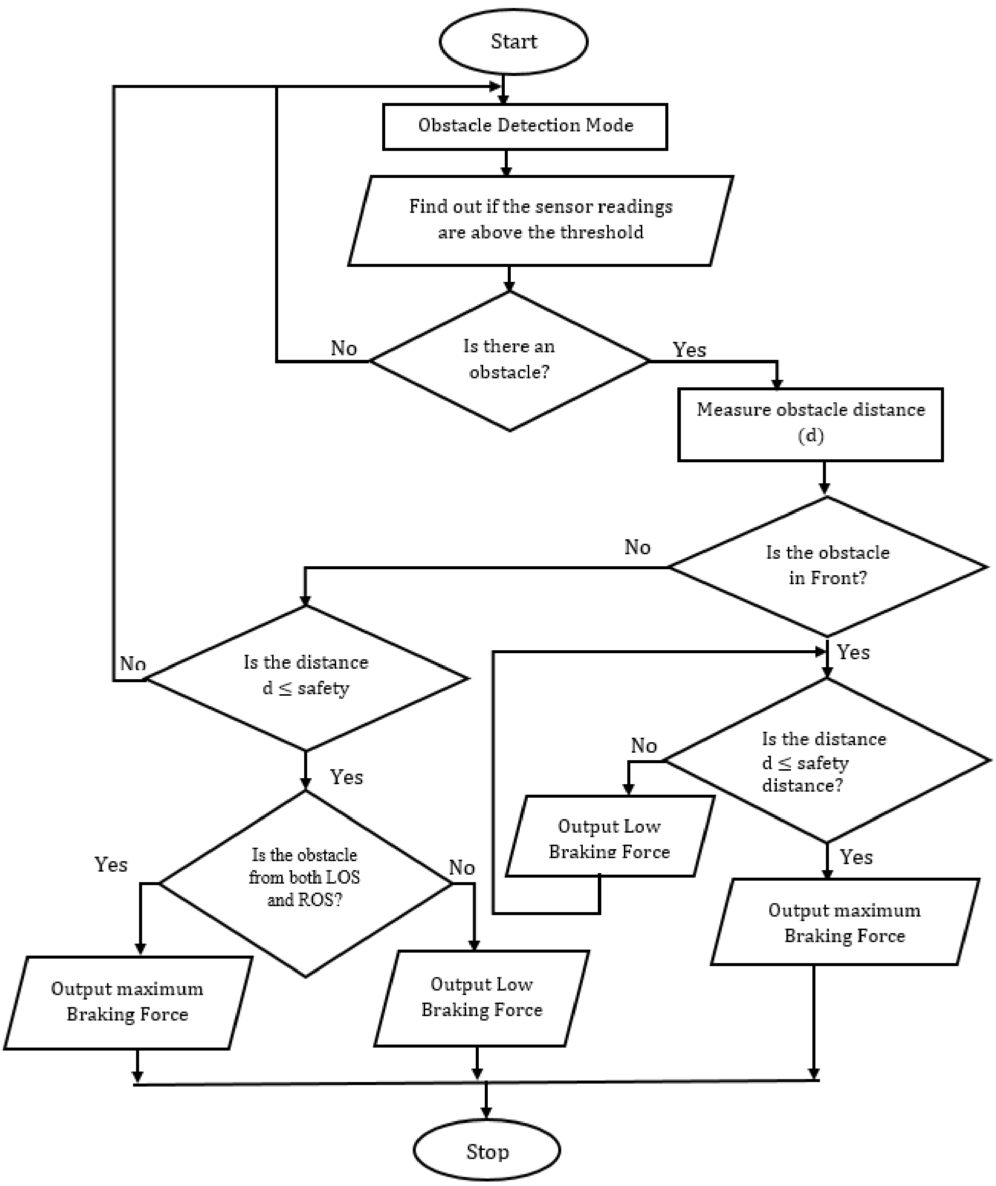

Figure 2: Flowchart of the Obstacle Detection System

If the obstacle is within the safety distance, then a high braking signal will be sent to the FLC 2 to stop the vehicle but if the obstacle is far from the vehicle, the controller will send a low braking force to FLC2 to reduce the speed of the vehicle. The low braking force from FLC 1 continues till the vehicle is within the safety distance then it changes to high braking force or when there is no signal from any of the sensors, it remains in the obstacle detection mode. This sequence continues when an obstacle is detected by the sensors.

2.2 Modelling of Antilock Braking System

For the modeling of automatic braking system, this study made use of the simplified model of a vehicle undergoing a braking manoeuver, which has been used by several researchers to evaluate the performance of the ABS control system. For the purpose of simulation, this study will consider a simple and powerful tool which represents longitudinal friction characteristics and behaviour of different road conditions and types used by several researchers. Using [18] mathematical models to derive the wheel speed, stopping distance and vehicle speed

$$m_t\dot{V} = -F_r - F_a \quad (4)$$

$$J\dot{w} = -T_b + F_r R_w \quad (5)$$

$$G_b(s) = \frac{K}{\tau_{lag}S + 1} \quad (6)$$

Laplace transform of equation 4 and 5 gives the wheel speed, stopping distance and angular vehicle speed while inverse Laplace transform of equation 5 gives braking torque. These equations are used for the simulation model of the Antilock Braking System (ABS)

$$W(s) = \frac{w(0)}{s} + \frac{1}{s}\int_0^\infty \frac{F_r R_w - T_b}{J} \quad (7)$$

$$D_s = sV(s) = \frac{1}{s}\left(\frac{v(0)}{s} - \frac{1}{m_t}\left(\frac{1}{s}\int_0^\infty F_r\right)\right) \quad (8)$$

$$V_w(s) = \frac{V(s)}{R_w} = \frac{1}{R_w}\left(\frac{v(0)}{s} - \frac{1}{m_t}\left(\frac{1}{s}\int_0^\infty F_r\right)\right) \quad (9)$$

$$T_b = K_f * abs(P_b) \quad (10)$$

From the flowchart in Figure 3, the braking force signal is the activation signal from the first fuzzy logic controller which decides whether the signal is high or low. If the signal is high, it engages the braking actuator and controls the values to increase the braking pressure to the car wheel until it stops.

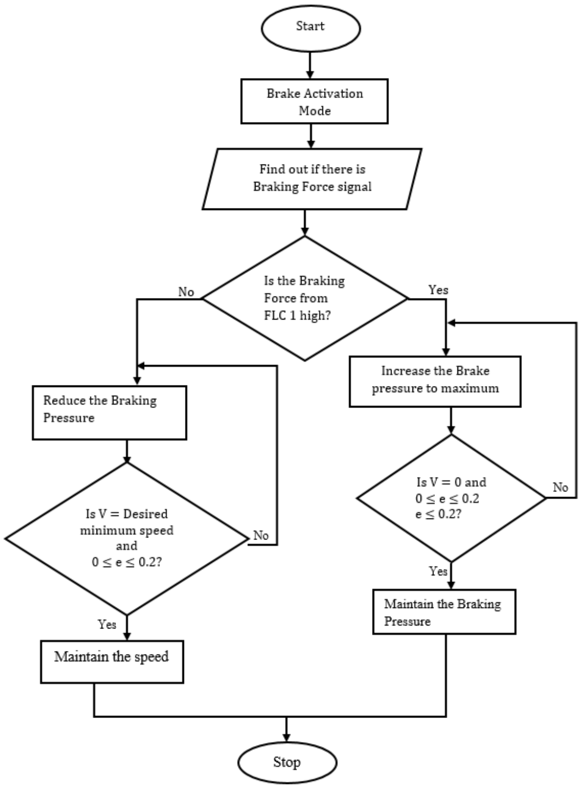

Figure 3: Flowchart of Antilock Braking System

If the signal to the fuzzy logic is low, it engages the braking actuator and control the value to reduce the braking pressure to the car wheel as the car is moving. While doing this, the controller keeps checking if the condition to avoid wheel lock-up and skidding is met ($0< e \leq 0.2$) while the car is moving. If the condition is met, then the controller maintains the speed but only take action when an obstacle is detected. If the condition is not met, the controller keeps reducing the speed till the required condition is met to keep the vehicle from skidding. This controller keeps carrying out these tasks when there is a signal from FLC1.

2.3 Development of Fuzzy Rules for First Fuzzy Logic Controller

In this study, the first fuzzy logic controller is modelled to output a low or high braking signal to the second fuzzy logic controller to either stop the car or reduce the speed of the car. The controller receives signal from the three sensors and use the rules to decide on the action to take. Mamdani Fuzzy logic is used for the design with twenty-seven rules to decide on the obstacle (OB) signal to send to second Fuzzy logic

The following language parameters are used by the membership functions to form the fuzzy rules. The language values of input variable for L-sensor, F-sensor and R-sensor include

FO - Far Obstacle
NO - Near Obstacle
VNO - Very Near Obstacle

The language values of output parameter for Obstacle Braking Signal include:

LB - Low Braking
NA - No Action
HB - High Braking

Table 1 shows the fuzzy rules for obstacle detection for left right and front sensors as the inputs

2.4 Development of Fuzzy Rules for Second Fuzzy Logic Controller

In this study, the Second Fuzzy Logic Controller is designed in such a way as to produce a brake torque so that the actual wheel slip traces the reference slip. This current research is based on slip control and collision avoidance and this controller designed with three control objectives consist of reduce stopping distance, limit slip ratio and improve the performance of controlling system (reducing rise time and overshoot on the ABS brake). Mamdani method is applied for designing the fuzzy controller.

The following language parameters are used by the membership functions to form the rules that guide the operation of the system.

The language values of input parameters for error, error change and FLC1 include

NL - Negatively Large;
NS - Negative Small;
ZE - Zero
PS - Positive Small
PL - Positively Large
LB - Low Braking
HB - High Braking
NA - No Action

The language values of output parameter for Brake Force include:

DPL - Quickly reduce the pressure
DPS - Slowly reduce the pressure
HOLD - Hold the pressure
IPS - Slowly increase the pressure
IPL - Quickly increase the pressure

Table 1: Fuzzy rules for Obstacle Detection System

L-sensor	F-Sensor	R_Sensor	Output
VNO	NO	FO	LB
VNO	VNO	FO	HB
VNO	FO	FO	HB
FO	FO	FO	NA
FO	NO	NO	LB
NO	NO	NO	LB
FO	VNO	FO	HB
NO	VNO	NO	HB
NO	NO	FO	NA
VNO	FO	VNO	HB
VNO	VNO	NO	HB
NO	VNO	VNO	LB
NO	NO	VNO	HB
NO	VNO	NO	NA
NO	FO	VNO	LB
NO	FO	FO	LB
VNO	NO	NO	LB
VNO	FO	VNO	HB
VNO	FO	NO	HB
FO	VNO	NO	HB
FO	NO	VO	LB

Table 2: Fuzzy rules for Antilock Braking System

When FLC 1 is High Braking			
Error-C / Error	NL	ZE	PL
NL	DPL	DPS	HOLD
NS	DPL	DPS	HOLD
ZE	DPS	HOLD	IPS
PS	HOLD	IPS	IPL
PL	HOLD	IPS	IPL

When FLC 1 is Low Braking			
Error-C / Error	NL	ZE	PL
NL	IPL	IPL	IPL
NS	IPL	IPL	IPL
ZE	IPL	IPL	IPL
PS	IPL	IPL	IPL
PL	IPL	IPL	IPL

3.1 Automatic Braking System Simulation Model

The implementation of the modelled Automatic braking system in MATLAB software using Simulink is shown in Figure 4.

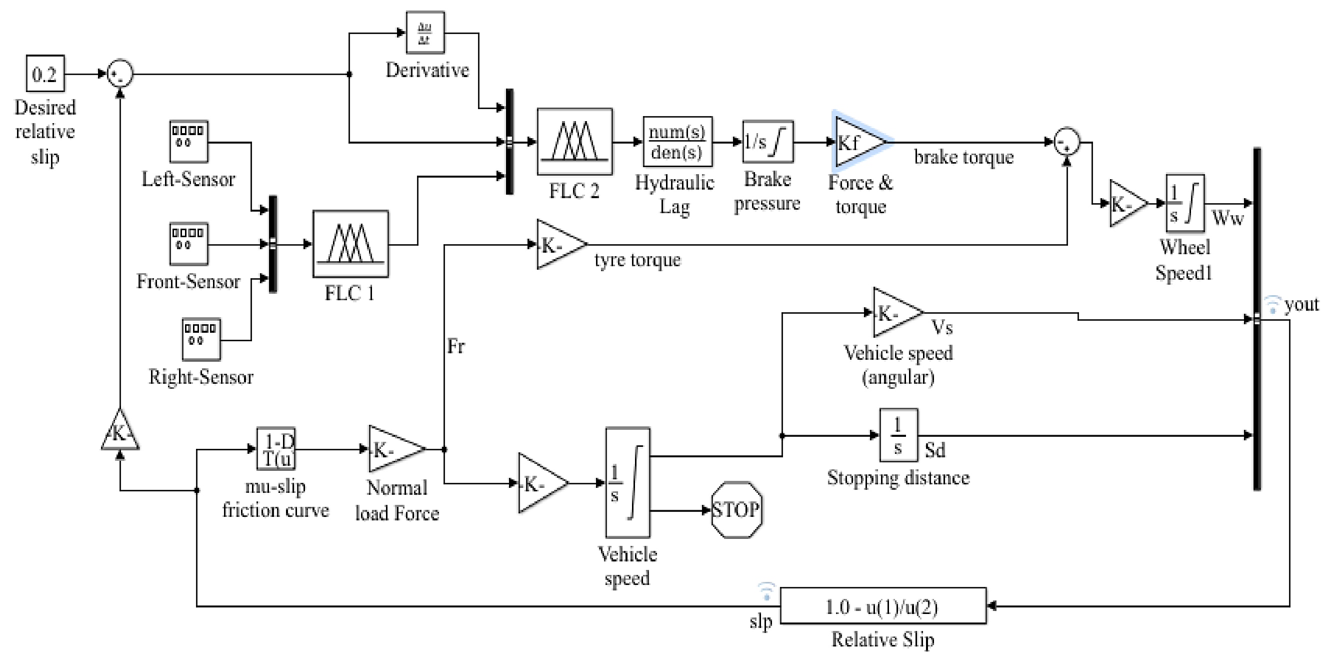

Figure 4: Automatic Braking System Simulation Model

3. RESULTS AND SIMULATION

The braking manoeuver depends on the road conditions which vary in frictional coefficient and wheel slip. Optimal frictional coefficient to achieve maximum braking pressure in stopping the car is obtained at slip value of 0.2. Thus, this value serves as the reference slip value to obtain optimum braking torque. The variables and parameters used in this system Simulation model include initial velocity V_o as 22m/s, mass of vehicle m as 40kg, wheel radius R_w as 0.34m, wheel inertia J_w as 5 kgm^2, braking torque T_b as 1500Nm, Hydraulic system amplification factor K as 100, desired slip ratio as 0.2 and gravitational acceleration as 9.81m/s^2.

The model was simulated on a PC having 64-bit operating system Intel® coreTM i5 processor with 2.50 GHz frequency and with 8GB RAM and Simulink of MATLAB version 9.2.0.5380627 (R2017a). The results of the simulation of Automatic Braking System using Fuzzy Logic controller are shown in Figures 5 to 10.

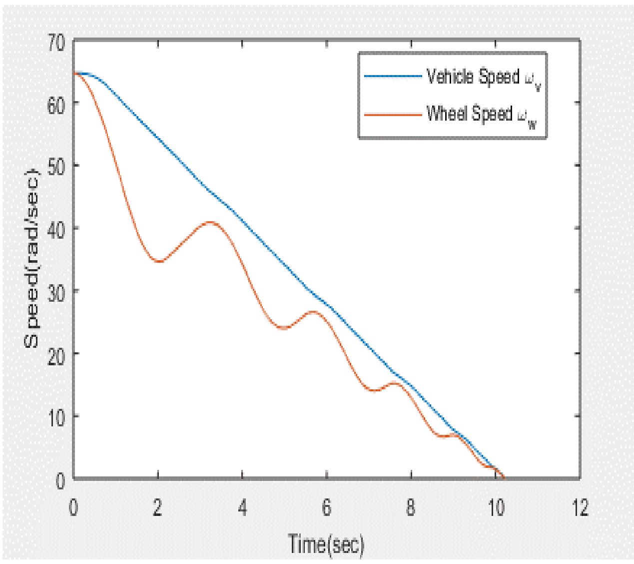

Figure 5: Relationship between the vehicle and when Braking Wheel speed

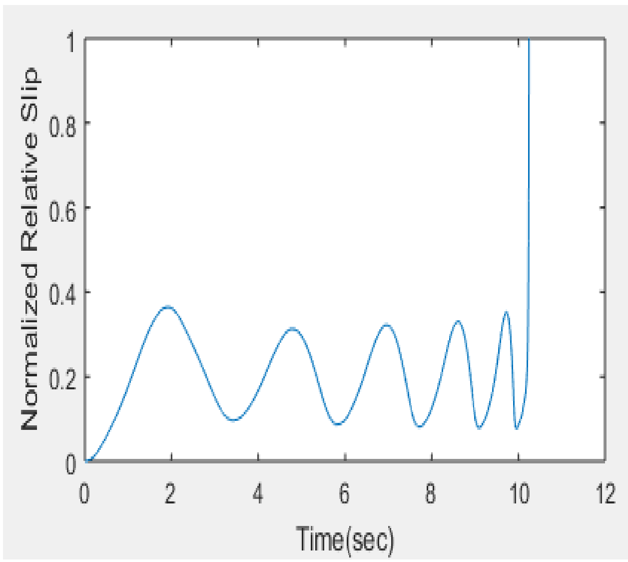

Figure 6: Normalized Relative Slip variation When brake is applied

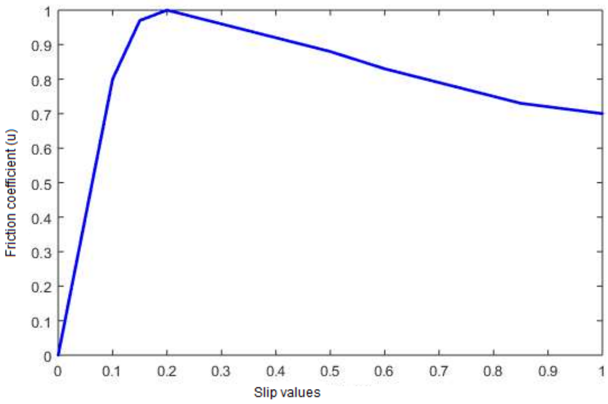

Figure 7: Slip Friction Curve

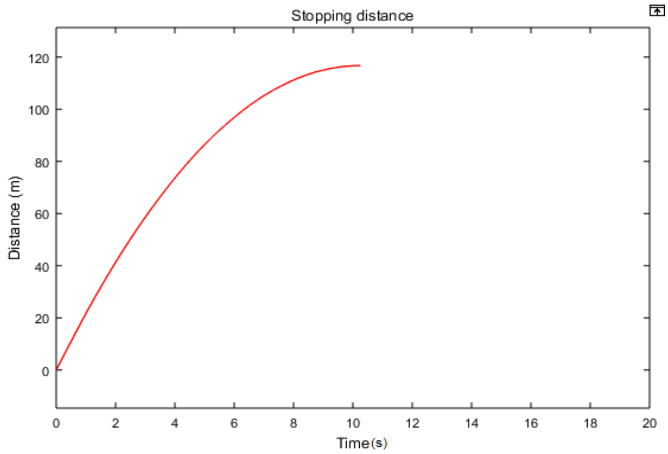

Figure 8: Stopping Distance Btwn the Car and Obstacle

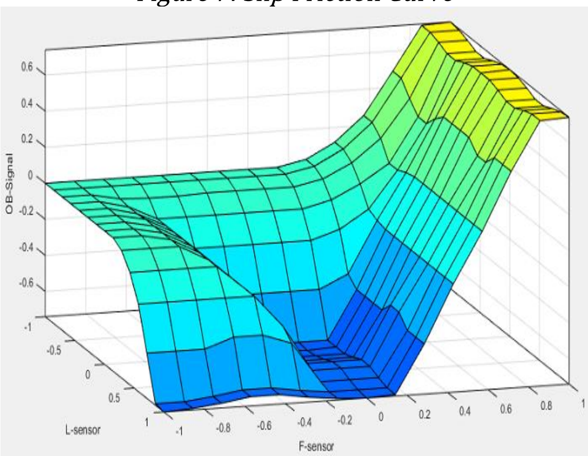

Figure 9: Surface view of the rules of FLC 1

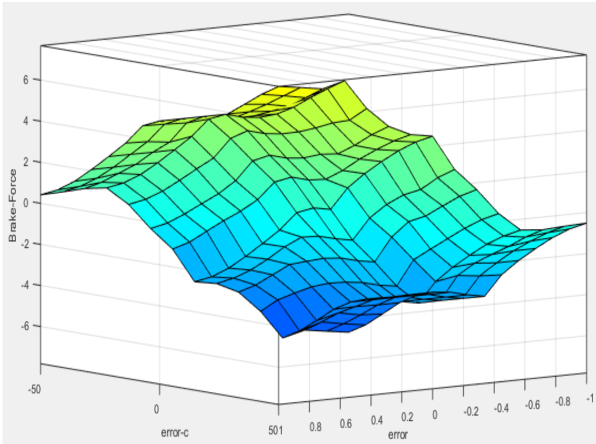

Figure 10: Surface view of the FLC 2

The control objective is to reduce stopping distance, limit slip ratio and improve the performance of the controlled system. The results of the simulation during various readings of the scope are shown from Figure 5 to Figure 11.

The vehicle and wheel speeds are not uniform when the brake is applied suddenly but the vehicle decelerate and stop within the shortest time of 10.20 seconds due to the smooth control of the fuzzy logic controller as shown in Figure 5. The fuzzy logic controller synchronizes the vehicle and wheel speeds before the vehicle stops or steers to avoid skidding. The controller monitors the vehicle speed and adjusts the wheel speed to synchronize with vehicle speed before the vehicle stops as shown in Figure 5.

Compared to the bang-bang PID controller, the fuzzy logic controller sustains the slip level at 0.15 – 0.25 which is within the acceptable tolerance level. Figure 6 shows the normalized relative slip during deceleration from the wheel speed sensor. The graph shows that when the vehicle decelerates and the slip value is within 0.15 – 0.20, the controller commands the hydraulic brake circuit to release the brake which increases the slip value to within 0.20 – 0.25. This happens continuously but in microseconds to maintain stability and easy steering of the vehicle while applying brakes and the slip value increases to one when the vehicle stops meaning that the angular wheel velocity is zero (vehicle is at rest).

Figure 7 gives the graph of frictional coefficient with slip value. It could be seen from the graph that at slip value of 0.2, the frictional coefficient is at its maximum point of 1. At this point, the system achieves the maximum braking torque to stop the vehicle. The Fuzzy logic controller keeps the braking system within this slip value to achieve optimum performance. The advantage of the fuzzy logic over the PID controller is that the rise time and overshoot are minimized.

The stopping distance of the vehicle has been reduced to 120 m in 10.20 seconds to avoid collision as shown in Figure 8. When the system detects an obstacle, it calculates the critical braking distance which is always higher than the stopping distance. The fuzzy logic sends a signal to the hydraulic braking system immediately the vehicle is within the critical braking distance. Assuming the speed of the vehicle is 40 m/s, the critical braking distance using Equation 3.1 will be 165.5 m. meaning that the vehicle is 45.5 m away from the obstacle when it stops.

Figure 9 shows the smooth surface view of the rules in the First Fuzzy logic Design. This gives the response of the fuzzy logic when signals are received from the three sensors. When obstacle (OB) signal is high, it means the controller will send a high braking signal to the second fuzzy logic to apply maximum braking force to stop the vehicle. But if it is low, then the controller will command the second controller to apply a minimal braking force to reduce the speed. Adjustment when made can be viewed here to know if the system responds as desired.

Figure 10 gives the surface view of the rules of the Second fuzzy logic design. This shows the response of the second fuzzy logic when signals from error, error change and FLC1 are received and tasks carried out based on the fuzzy rules. The Brake Force is seen to be high if the first controller has sent a high braking signal which commands the second controller to increase the braking pressure. Brake Force is low when low signal from FLC1 is received or vehicle is about steering which commands the hydraulic braking system to reduce the braking pressure.

The relationship between the wheel speed, vehicle speed and stopping distance when brake is applied is displayed in Figure 11. When an obstacle within the safety distance is detected, the controller commands the hydraulic circuit to apply brake which brings the vehicle from its initial velocity of 65 m/s to 0 m/s. At 65 m/s, the brake was applied and the stopping distance began from 0 m till 120 m when the speed of both the vehicle and wheel is 0 m/s. It takes the vehicle at a speed of 65 m/s to stop the vehicle at 120m in 10.20 seconds. This means as the speed reduces the stopping time reduces likewise the stopping distance and vice versa. The control objective is achieved here using fuzzy logic controller which has minimized the stopping time and distance while maintaining the stability of the system.

Table 3 shows the comparison of the fuzzy logic controller and the PID controller used in the existing system of automatic car braking system.

4. CONCLUSION

This paper focuses on modelling of an Automatic Braking system using fuzzy logic controller based on sensor fusion indented to use in vehicles that can solve the problem where drivers fail to apply brakes on time in an emergency situation and can reduce speed automatically due to obstacles detection. With the connection of ultrasonic sensors in the vehicle, the resulting system can achieve measurements with high accuracy, short stopping time and improved short distance measurement. The system is very suitable in case of tight parking, heavy traffic conditions, emergency situation and restricted areas. The existing system used PID controller in the electronic control unit of the vehicle to prevent the locking up of wheels while the modelled system uses Fuzzy Logic to design the controller and hence the system is more reliable and stable than the existing system and will have consumer acceptance. From the table 3, it can be summarized that the modelled system has high values of braking deceleration, short stopping time and high braking torque compared to that of the existing PID controller. Hence, the vehicle could be stopped in a short distance compared to the existing system. The simulation results showed that the curve settles down smoothly when decelerating and the vehicle will not experience any jerks at high braking conditions in contrast to the existing PID system.

Table 3: Comparison of Existing Bang-bang PID controller with Fuzzy Logic Controller

Parameters	Fuzzy Logic Controller	Bang-bang PID controller
Stopping time (s)	10.20	14
Braking Deceleration (m/s^2)	-8.92	-5.64
Braking Torque (Nm^2)	581.93	476.72

5. CONTRIBUTION TO KNOWLEDGE

1. This study will address the problem of road accidents due to driver's failure to apply brakes on time.
2. In automobile industry, this study will be used to design a system that limit speed of vehicle when approaching an obstacle.
3. In education, this study will enlighten students on the need for automation of vehicle to avoid human errors.

6. REFERENCES

[1] Ayman, A. Aly. "Intelligent Fuzzy Control for Anti-lock Braking System with Road-Surfaces

Identifier", *Proceedings of the IEEE International Conference on Mechatronics*, Xi'an, China, 2010, 699-705.

[2] Bamigboye, O. O and Obaje, S. E. "Intelligent automatic car braking control system using neural network classifier". *International Journal of Engineering Inventions*, Vol, 5 Number 6, 2016, pp 51-56

[3] Deepak, C. C., Guruprasath, P., Kumar, Kumar S. H. and Anthony, V. L. *. Intelligent Braking System in Automobile Applications* International Conference on Latest Innovations in Applied Science, Engineering and Technology, 2017, pp 103-108

[4] Dhanya, K. R. and Jeyanthi, R. "Automatic braking system with sensor fusion concept", *International Journal of Emerging Trends in Engineering and Development*, Vol 3 Number 2, 2012.

[5] Dhivya P. and Murugesan A. "Intelligent car braking system with collision avoidance and ABS". National Conference on Information and Communication Technologies. *International Journal of Computer Applications*, 2015, pp 16-20

[6] Eneh I.I. and Okafor P. U. "Design of an automatic brake control system using artificial neural network", *International Journal of Scientific and Engineering Research*. Vol 5 Number 4, 2014, pp 1239-1245

[7] Guo, L., Ren, Z., Ge, P., and Chang, J. (2014). Advanced emergency braking controller design for pedestrian protection oriented automotive collision avoidance system. *The Scientific World Journal*. Hindawi Publishing Corporation. Vol. 2014, 6 July 2014, pp 1-11.

[8] Hahn, J-O., Rajamani, R. and Alexander, L. "GPS-based real-time identification of tire-road friction coefficient", *Control Systems Technology, IEEE Transactions on,* Vol. 10, 2002, pp 331–343.

[9] Jain, R. S., Harel, T. S., Mulik,V. H., Pathak,V. T. and Lunawat, S. S. "Smart Control System in Automobile", *International Journal of Research in Advent Technology* Vol 6 Number 12, 2018, pp 3572-3575.

[10] Jingang G., Xiaoping J. and Guangyu L. Performance Evaluation of an Anti-Lock Braking System for Electric Vehicles with a Fuzzy Sliding Mode Controller. *Energies Journal* 7: 2014; pp 6459-6476.

[11] Jitesh, S. "Antilock Braking System (ABS)", *International Journal of Mechanical Engineering and Robotics Research* Vol 3, Number 4, 2014, pp 252 – 259

[12] Luo, X., Li, H., and Wu, J. "Modeling and Simulation of Antilock Braking System Based on Fuzzy Logic Control". *International Advanced Research Journal in Science, Engineering and Technology.* Vol 3, Number 10, 2016, pp 110-113

[13] Meenakshi, S., Asha, R. and Vijender, S. "Wheel Slip-Based Intelligent Controller Design for Antilock Braking System", *Advanced Research in Electrical and Electronic Engineering*. Vol 1, Number 3, 2014, pp 82-88

[14] Parrila, M., Anaya J. J. and Fritsch, C. "Digital Signal Processing Techniques for High Accuracy ultrasonic Range Measurements", *IEEE Transactions on Instrument and Measurements*. Vol 40, Number 4, 2000, pp 112-117

[15] Samuel, J. and Jimoh, O. P. "A Comparative Study of Two Control Schemes for Anti-Lock Braking Systems", *Proceedings of the 9th IEEE Asian Control Conference*. 2013, pp.1-6.

[16] Sharkawy, A. B. "Genetic Fuzzy Self-tuning PID controllers for Antilock Braking Systems", *Engineering Applications of Artificial Intelligence* Vol 23 Number 7, 2010, pp 1040 -1053.

[17] Shrey M., Yingzi L., Zhang W.J. and Yang G.S. "A Driver-Automation System for Brake Assistance in Intelligent Vehicles*". Proceedings of the 10th IEEE International Conference on Industrial Informatics*, 2012, pp.446-451.

[18] Tianku F. "*Modeling and Performance Analysis of ABS Systems with Nonlinear Control* " M.Sc. Dissertation. Concordia University, Montreal Quebec, Canada, 2000.

[19] Tushar K., Harshal S. and Minal R. "Design and Analysis of Intelligent Braking System". *International Journal of Engineering Development and Research.* Vol 5, Number 1, 2017.

[20] World Health Organization. "*Global Status Report on Road Safety*", Geneva, Switzerland, https://www.who.int/violence_injury_prevention/road_safety_status/2018/en/ Retrieved on 12th January 2019