International Journal of Scientific Research and Engineering Development-– Volume 5 Issue 2, Mar-Apr 2022

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Development of an Algorithm for tracing and Decision making in Automobile Collision Avoidance

Babalola Segun Abioye*, Prof. I.I. Eneh**, Nwabueze Charles Nnaemeka***

Electrical and Electronics Engineering Department, Enugu State University of Science and Technology, ESUT, Enugu

Email; segun7799@gmail.com

--************************----------------------------------

Abstract:

Development of an Algorithm for Tracing and Decision Making in Automobile Collision Avoidance involves communication between all vehicles equipped with an appropriate transponder. Each TCAS-G Equipped vehicle “interrogate” all other vehicle in a 500 meter range about the position (Via a 1020MHZ radio frequency) and all other vehicles reply to the k and j interrogation (1080MHZ). This interrogation and response cycle may occur several times per minute. Through this regular back and forth communication, the TCAS-G system builds a two dimensional map of the vehicles in then-space-cushion, incorporating the bearing and range. Hence this research work present an idea for a road safety alert system, which is realized in the form of a developed model using stochastic numerical integration used to evaluate the confidence of each decision and constant acceleration model for brake system, algorithm for decision making in multiple obstacle is used to search the set of feasible avoidance, manoeuvres and evaluated to study its practical application to real world scenarios. Review of various existing, traffic and Collins alert system (TCAS) in Air transportation & Air traffic controller systems was done to find out to road transportation with a focus on vehicle-to-vehicle (VTV) and Vehicle-to-Obstacle (VTO) collision.

Keywords **—Global Positioning System (GPS), Time to Collision (TTC), Intelligent Transport Systems (ITS), Collision Avoidance System (CAS)**

--************************----------------------------------

I. INTRODUCTION

Over the years the advancement in the safety standards has been restricted to road vehicles alone. There has been a rapid growth in the mobility sector across the world. A majority of these developments belong to road transportation. But this growth has also resulted in the drastic increase in traffic congestion, a number of road accidents and exhaust emissions. To improve the conventional road transportation, one of the most promising developments in last few years is the field of autonomous vehicles (Fossen et al, 2017).

The first and foremost challenge an automobile vehicle needs to overcome is to avoid collision with any static or dynamic obstacle along its path of motion. This signifies that automobile vehicles should possess the capabilities of performing emergency manoeuvres in case it detects any obstacle. To avoid any static or dynamic obstacle on the path of automobile vehicle it has to either decelerate to complete stop on the same lane or to manoeuvre to the neighbouring lane based on the traffic flow of that lane (Brandt et al, 2005). This project is intended to design and simulate a vehicle avoidance system for an autonomous vehicle not only to avoid collision and maintain stability of the vehicle but also to maintain traffic flow.

Generally, an autonomous braking system will use a radar or laser that projects forward to “see” pedestrians, animals, or rapidly approaching rear bumpers. The system will calculate the amount of braking force needed to avoid the hazard. Sometimes the autonomous braking system will determine that the driver is braking, but not hard enough and it will add pressure to the brakes to slow the car properly. If the driver makes no effort at all to brake, many of these systems will bring the car to a complete stop. Automobile Brake System is effective if the driver uses the brakes properly. However, if the driver does not see a hazard in front, due either to sun glare, distraction, or for some other reason, the anti-lock brakes cannot help.

Problem Statement

Driver errors cause a majority of all car accidents. Forward collision avoidance systems aim at avoiding, or at least mitigating, host vehicle frontal collisions, of which rear-end collisions are one of the most common.

The problem statement can be divided into three parts. The class being considered for the thesis has two types of structures:

1. To estimate and predict the dynamics of the machine with the aid of Global Positioning System (GPS) measurements alone. Using the GPS information, other dynamics of the machine has to be estimated and predicted.
2. Using the predictions, the automobile vehicle should be able to avoid collisions with static as well as dynamic obstacles.

In order to achieve this, collision avoidance algorithms will be developed which will have two functionalities: issue threat warnings and brake actively when the warnings are ignored by the driver

Aim and objectives

The aim of Automobile collision avoidance in a failed brake system using decision making system tends to achieve the following objectives

1. To understand the concept of automobile vehicles and associated technologies and investigate the available technologies for collision avoidance and their advantages, potential and limitation.
2. To develop decision making algorithm for automobile vehicle and simulate using MATLAB/SIMULINK
3. To validate the proposed system with existing system

Scope of Study

The model developed will only consider the decision making model of the machine consisting of the parameters namely position, acceleration, velocity. During the development of the machine model, the wheel slip angles will not be considered. The project focuses on developing collision avoidance system for low operating speeds and wheel slip does not play a major effect on the dynamics at low speeds. Although, including the slip produces better estimates and predictions, it increases the complexity of the model.

Significance of Study

Developing Automobile collision avoidance in a failed brake system in transportation industries will improve the sector towards achieving the following:

1. Reduce road accident in federal highway
2. Reduce the loss of good and service as a result of road accident
3. Improve nation’s economy

II. MATERIALS AND METHODS

Materials

This work will consider a differential drive robot to build the system. The differential robot will be place in a dynamic of 2- environment to enable for simulation. The dynamic 2-dimentional environment consist a square block obstacle. MATLAB software will be employ in this techniques called as occupancy grid mapping.

Hence a square matrix is constructed consist of zeros (0s) and ones (1) as the entire element.

Methodology

In this thesis we need to create highly dynamic environment with vehicles and moving objects. So far for the collision detection and avoidance collision avoidance in a failed brake system, both vehicles and moving object with velocity was considered, particular shape and angle of direction. Now for the simplicity, instead of vehicles and moving object, consider only multiple vehicles with different velocity and different angles of direction. Instead of directly working on the highly dynamic environment, it first focuses on the two vehicles problem. This approach for collision detection and avoidance in a failed brake system is based on the algorithm. Based on this initial approach the problem for the highly dynamic environment will be derived. Further, complexity of dynamic environment cannot be an overhead, once we are considering enough situations for the collision detection and avoidance of the two vehicles. Then the prototype and algorithm will be simulated and implemented using MATLAB software. At the end, the proposed model will be validated whether it is able to avoid the collision or not through suitable strategies

Differential drive modular robot is a simple robot with two active wheels acting in parallel to each other. A caster wheel is provided for support and balance. The drive logic is based on the difference of speed in both the wheels. For example, robot turns rightwards when there is more speed given to the left wheel than the right wheel and vice versa. Wheel speeds of both the wheels are computed by the Differential Drive Inverse Kinematics and Differential Drive Simulation blocks in the Simulink model. Hence this work has consider a differential drive robot to showcase the collision avoidance system in a fail brake

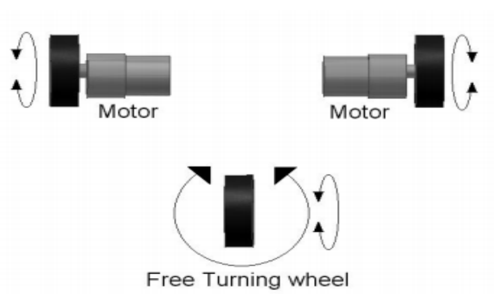

Figure 1: Basic components of a Differential Drive Robot

The control algorithm has two primary functions, namely Path Following an Obstacle Avoidance. Path following ensures that the robot traverses the environment by passing all the waypoints. This is accomplished using the Pure Pursuit block in Simulink. Pure pursuit Cyras et al (2010) is a commonly used path tracking algorithm. Based on the current position of the robot and the trajectory to be followed, this algorithm changes the angular velocity of the robot such that the robot is directly facing the next waypoint. The linear velocity of the robot is not altered by this algorithm and is assumed to remain as a constant.

III. DEVELOPMENT OF MODEL FOR THE SYSTEM

The proposed algorithm

Step 1 First, we have to define the minimum and maximum range of the sensors. We have to write the algorithm capable of identifying the obstacle and its position between the blind zone and the maximum range acceptable for this project.

Step 2 If none of the sensors detects an obstacle, go forward at maximum speed.

Step3 If at least one sensor detects an obstacle, decrease the speed. Check again if the sensors detect obstacles.

Step 4 If at least one sensor is still detecting an obstacle, go to the sensor's state.

Step 5 If the left sensor detects an obstacle, move to the right until the sensor doesn't detect the obstacle.

Step 6 If the centre sensor detects an obstacle, move randomly to the left or right until the centre and left/right sensors do not detect the obstacle.

Step 7 If the right sensor detects an obstacle, move to the left until the sensor doesn't detect the obstacles.

Step 8 If all the sensors detect obstacles, move back and turn left or right until a free obstacle path is detected.

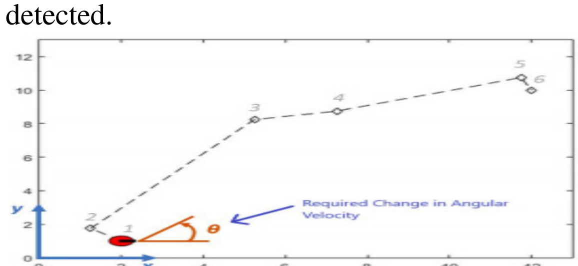

Figure 2: Visual Representation of the Working of the Pure Pursuit Algorithm

The second task of the control algorithm is obstacle avoidance. To achieve obstacle avoidance, we use the Vector Field Histogram block in Simulink. Using the range and angle data of the detected obstacle from lidar sensor and the direction to be followed computed by the pure pursuit algorithm, the vector field histogram algorithm generates a new direction to be followed by the robot in order to avoid obstacle that was present in the trajectory

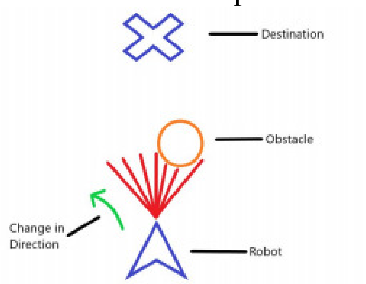

Figure 3: Visual Representation of the Obstacle Avoidance Algorithm

Kinematics and Drive Simulation

The required direction calculated by the control algorithm is sent to the Differential Drive Inverse Kinematics block as an angular velocity value of the robot which is then converted to the appropriate wheel speed of the differential drive robot. The Differential Drive Simulation block is then used to compute the desired position or pose of the robot based on what the wheel speed value. Thus in two simple steps, the change in direction for path following an obstacle avoidance is transformed in to the required position of the robot which is understood by the 2D Robot Visualizer block in the next stage

Output Visualization

The output of the simulation is viewed using the 2D Robot Visualizer block which is available Mobile Robotics Simulation Toolbox. This block receives the user specified waypoints, the robot position or pose from the drive simulation subsystem and the range from the lidar sensor block as the inputs. The block then calculates and converts the inputs into a 2D simulation video which consists of the differential drive robot, environment with obstacles, marked waypoints, range of the sensor and the trajectory of the robot.

Working of the Collision Avoidance System

Simulation of the collision avoidance system requires a constant input of waypoints. These inputs are nx2 arrays with x and y coordinates along every row. We are specifying four waypoints using a Constant block. The waypoints are (2,2), (2,10), (11,8), for the system. This is represented in 12 x 12-meter environment where (2,2) indicates that there is a waypoint at 2 meters from x axis and 2 meters from y axis.

2	**2**
2	**10**
11	**82**

Input trajectory

The Lidar Sensor block senses the distance by illuminating a light pulse for 180 degrees around the front face of the robot reaching a distance up to 5 meters. As the position of the robot is inputted to the lidar sensor, it will illuminate the pulse from that current position. The range of the sensor can be altered to toggle between a smoother drive and better obstacle avoidance. For every position of the robot, the Lidar Sensor block gives the corresponding lidar range values.

The Lidar Sensor block senses the distance by illuminating a light pulse for 180 degrees around the front face of the robot reaching a distance up to 5 meters. As the position of the robot is inputted to the lidar sensor, it will illuminate the pulse from that current position. The range of the sensor can be altered to toggle between a smoother drive and better obstacle avoidance. For every position of the robot, the Lidar Sensor block gives the corresponding lidar range values.

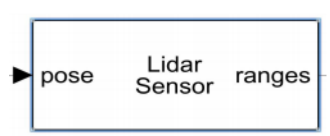

Figure 4: Simulink block for Lidar Sensor

Now, the control algorithm takes the robot position or pose, waypoints and lidar range from Lidar Sensor block as inputs. The robot pose and waypoints are converted into the required linear velocity, angular velocity and target direction by the Pure Pursuit block.

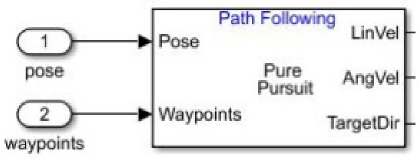

Figure 5: Simulink block for Pure Pursuit

If an obstacle is detected by Lidar Sensor block, the information is sent to the Vector Field Histogram block which accordingly alters the target direction value from the Pure Pursuit block to give us the steer direction to avoid the obstacle

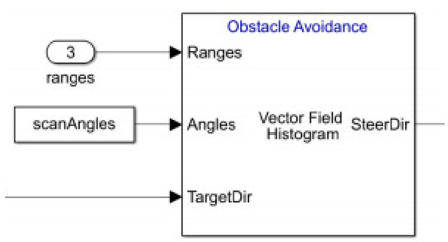

Figure 6: Simulink block for Vector Field Histogram

IV. RESULT

The simulation results for the proposed avoidance system are compared with those of the representative conventional system, PRE-SAFE. Figure 7 shows that the distance between the host and the preceding vehicles when stopped for the proposed system is 4.1 m

Table.1 Distance between the host and the preceding vehicles for the proposed Decision making system

No	Relative Distance
1	0
2	1.25
3	2.50
4	3.75
5	5.00

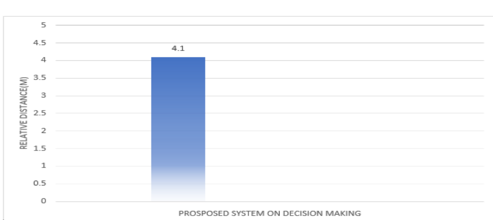

Figure 7 distance between the host and the preceding vehicle for the proposed decision making

Table.2 Distance between the host and the preceding vehicles for the conventional system

No	Relative Distance
1	0
2	1.25
3	2.4
4	4.75
5	5.00

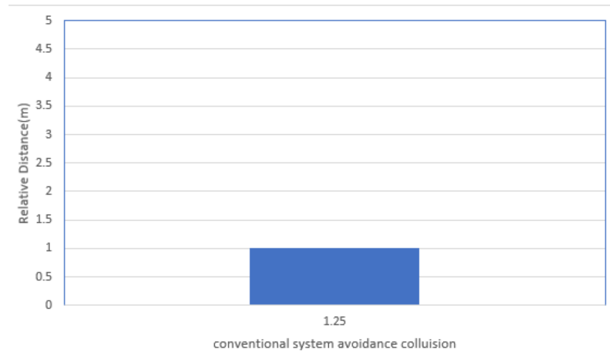

Figure 8: distance between the host and the preceding vehicle for the conventional system

However the distance for the conventional system and proposed system is 2.9m. This difference of 2.9 m clearly indicates larger margin for safety provided by the proposed decision making system.

For timing of collision avoidance intervention, the proposed system intervenes 1.36 seconds earlier than the conventional system Figure 9. This is because the proposed system starts to intervene earlier with distance control based on the safe distance criterion, followed by partial braking around TTC of 1.6 seconds.

Table .3 Intervention timing for proposed decision making system

No	Timing of system intervention (sec)
1	-1.50
2	-1.13
3	-0.75
4	-0.38
5	0

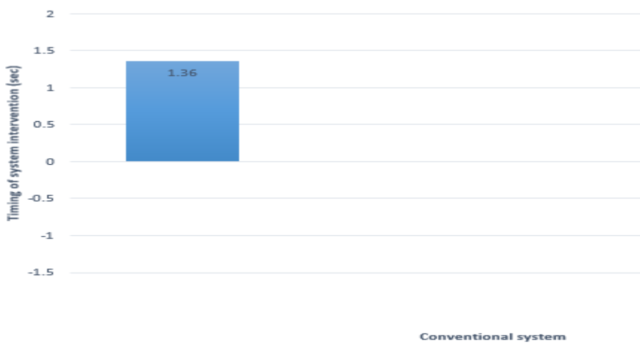

Figure **9:** Intervention timing of the proposed decision making system

Meanwhile the conventional system starts to intervene later with partial braking around TTC of 1.6 seconds

Table.4 Intervention timing for conventional system

No	Timing of system intervention (sec)
1	-1.60
2	-1.14
3	-0.74
4	-0.30
5	0

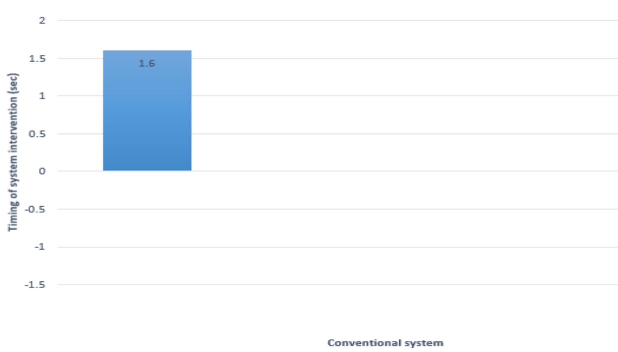

Figure 10: Intervention timing of the conventional system

Comparison of average deceleration rate reveals interesting result, as shown in table.5, 6, and figure 11 and 12 respectively. The average deceleration rate for the proposed decision making system is 3.7 m/sec2

Table.5 Average deceleration rate for the proposed decision making system

No	Average deceleration rate (m/sec2)
1	0
2	1.8
3	3.5
4	5.3
5	7.0

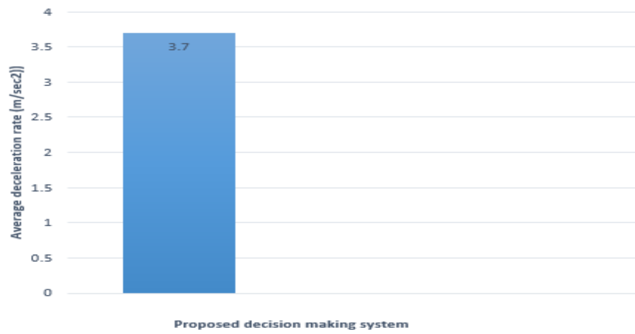

Fig 11: Average deceleration rate for the proposed decision making system

For conventional system the rate for the conventional system is 6.2 m/sec in .This difference shows that the proposed system would reduce jerk felt by occupants and thus make them less uncomfortable.

Table.6 Average deceleration rate for the conventional system

No	Average deceleration rate (m/sec2)
1	0
2	1.95
3	3.6
4	5.37
5	7.7

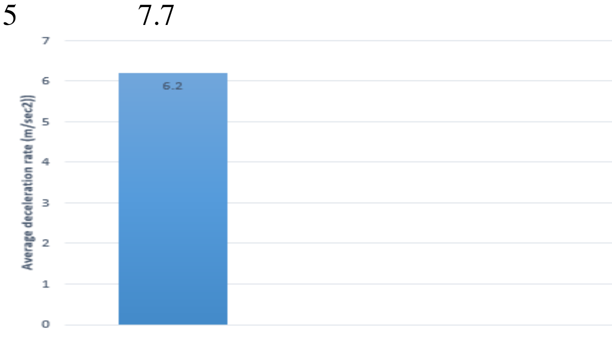

Figure 12: Average deceleration rate for the conventional system.

The second evaluation scenario involves sudden cut-in by a vehicle in the next lane. While the host vehicle moves with the speed of 110 km/hr approximately, the vehicle in the next lane suddenly cuts into the driving lane with the speed of 60 km/hr.

Figure 13 and 14 shows that the proposed decision making system intervenes 1.43 seconds earlier than the conventional system. This difference is because the decision making system keeps track of vehicles in neighbouring lanes for collision risk estimation, and starts to intervene as soon as the vehicle in the next lane starts to cross over the lane, meanwhile the conventional system starts to intervene after the vehicle cuts into the driving lane.

Table.7 Intervention timing of the proposed decision making system

No	Timing of system intervention (sec)
1	-1.6
2	-1.2
3	-0.8
4	-0.4
5	0

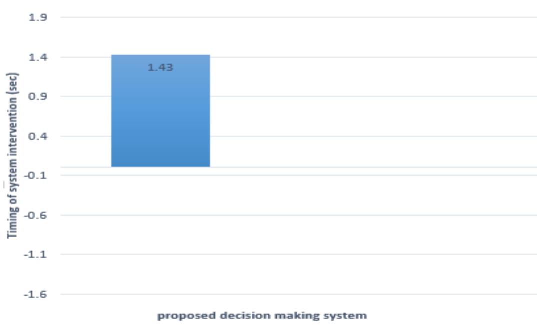

Figure 13: Intervention timing of the proposed decision making system

Table.8 Intervention timing of the conventional system

No	Timing of system intervention (sec)
1	-1.6
2	-1.2
3	-0.8
4	-0.4
5	0

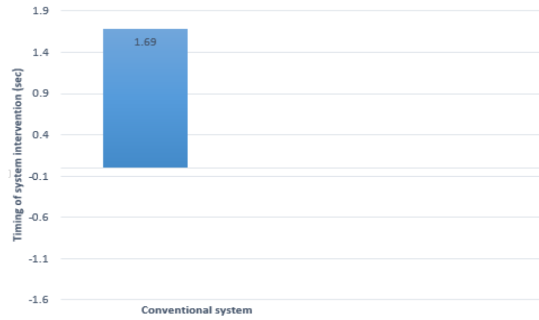

Figure 14: Intervention timing of the conventional system

As a result, the distance between the host and the preceding vehicles after cut-in for the proposed and the conventional systems are 20.8 m and 16.4 m, respectively.

Table.9 Distance between the host and the preceding vehicles for the proposed decision making system.

No	Relative distance after cut-in (m)
1	0
2	5.5
3	11.0
4	16.2
5	22.0

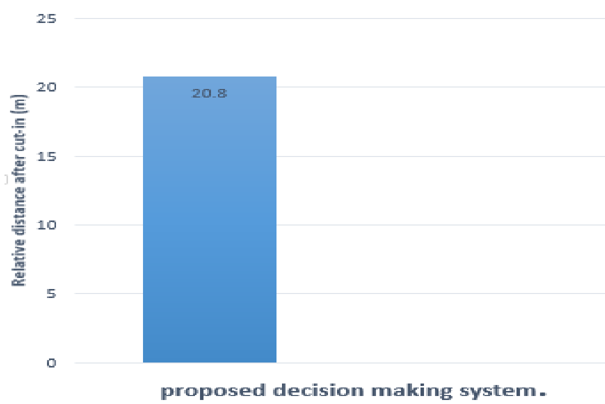

Figure 15: Distance between the host and the preceding vehicles for the proposed decision making system.

Table.10 Distance between the host and the preceding vehicles for the Conventional system

No	Relative distance after cut-in (m)
1	0
2	5.5
3	11.0
4	16.2
5	22.0

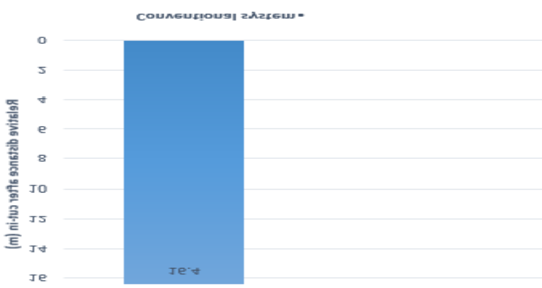

Figure 16: Distance between the host and the preceding vehicles for the Conventional system

Hence, when the preceding vehicle becomes directly ahead of the host vehicle, the speed of the host vehicle for the proposed system is reduced by 13.1 km/hr, meanwhile the speed for the conventional system is not reduced yet. This difference in the distance to the preceding vehicle and the speed reduction of the host vehicle causes the proposed system to avoid collision, but not the conventional system at.

Table.11 Distance between the host and the preceding vehicles for the proposed decision making system.

No	Relative distance after cut-in (m)
1	0.
2	4.0
3	8.0
4	12.0
5	16.0

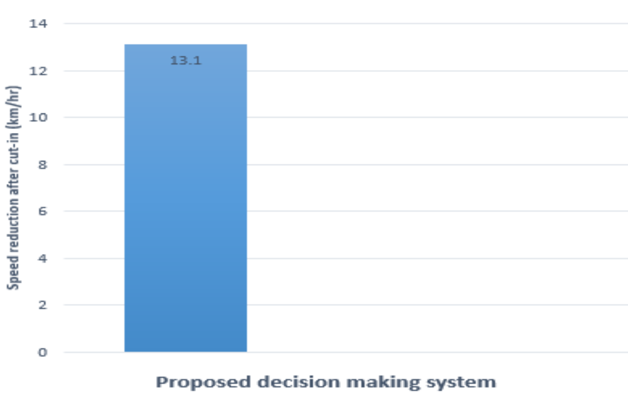

Figure 17: Distance between the host and the preceding vehicles for the proposed decision making system.

Table.12 Distance between the host and the preceding vehicles for the Conventional system

No	Relative distance after cut-in (m)
1	0.
2	4.0
3	8.0
4	17.0
5	22.0

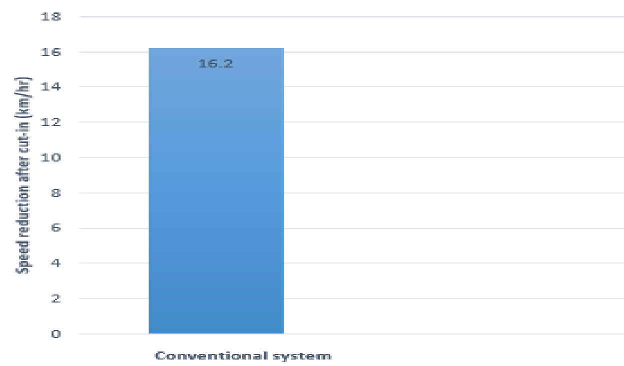

Figure 18: Distance between the host and the preceding vehicles for the Conventional system

V. CONCLUSIONS

The proposed decision making collision avoidance is to integrate automatic distance control and emergency braking in accordance with likelihood of collision. The driving simulation results showed the improvement in collision avoidance in terms of earlier system intervention, increased relative distance and reduced relative speed to a preceding car. Meanwhile, reduced deceleration rate implies that vehicle occupants will feel jerk less during system intervention. Reliable sensing of hazards is critical for successful collision avoidance. Implementation and evaluation of a low-cost camera vision sensor on our driving simulator showed the potential of using the vision sensor for detecting lanes and vehicles, and estimating collision risks.

However, 0 5.5 11.0 16.5 22.0 Proposed system decision making and Conventional system 16.4 20.8 Relative distance after cut-in (m) 0 4.0 8.0 12.0 16.0 Proposed system decision making and Conventional system 0 13.1 Speed reduction after cut-in (km/hr) 9 more intensive effort will be required to deal with sensor's inherent dependence on lighting conditions effectively and make the sensor more practical.

However the proposed algorithm considers vehicle dynamics and environmental conditions for decision making on lane change. In addition of taking into consideration the lateral position of other vehicles and maximum tyre-road friction coefficient potential, the proposed algorithm outputs a suitable time interval for lane change.

Future Work

Future research will focus on evaluation and improvement of the proposed approach on large-scale driving simulator experiments with a variety of emergency scenarios. Objective performance and subjective feelings will be evaluated in more detail.

Another area which can be research more is the threat assessment system where instead of a deterministic approach, probabilistic approach is applied. Probabilistic approach tends to be more computationally heavy but helps in providing better understanding of a risk of a collision. In another approach, the future driver inputs of the surrounding objects can be modelled as random variables. In order to capture realistic driver behaviour, a dynamic driver model can be implemented as a probabilistic prior, which computes the likelihood of a potential manoeuvre. A distribution of possible future scenarios can be then approximated using Monte Carlo sampling. Based on this distribution, probability of collision or time to collision can be calculated

The threat assessment system can be further improved by improvising a gain scheduling controller which could control the deceleration of the vehicle based upon the distance of the machine from the obstacle. This will help in braking the machine with smoother transitions rather than braking the machine instantly causing discomfort to the driver. Furthermore, path planning algorithms can also be integrated which can help provide more accurate predictions since the Vehicles trajectory will be predefined.

VI ACKNOWLEDGMENT

Let me first of all acknowledge the hands of the beginning and the end, the lion of the tribe of Judah (God Almighty) on me, for given me strength to carry out this research work up to this level: truly, I can do all things through God that strengthened me.

My appreciation cannot complete without acknowledge the good work and fatherly advice of my supervisor; Professor I.I. Eneh, may you live too long to paddle the cause of many more Electrical Engineering Students.

Also appreciated is moral adviser, the shoulders that make cloth fitted on my neck. My very wonderful wife; Mrs Oluomachukwu Babalola and my Children, Chukwumachi Babalola, Chidera Babalola and Chineecherem kossisochukwu Babalola.

REFERENCES

[1] Adouane, L., 2015. *Autonomous Vehicle Navigation*. Taylor & Francis.
[2] Anwar, A. (2017). A Smart Stick for Assisting Blind People. *IOSR Journal of Computer Engineering*, 19(3), pp.86-90.
[3] BBC (2018). *Rush hour drivers 'lose 31 hours a year'*.
[4] Brandt, T. Sattel, T. Wallaschek, J. 2005. *On automatic collision avoidance systems*, Proceedings SP1920 of SAE World Congress 2005, Detroit, April 11.-14., USA.
[5] Carvalho, A. Gao, Y. Gray, A. Tsengy, E. H. Borrelli, F. 2013. *Predictive Control of an Autonomous Ground Vehicle using an Iterative Linearization Approach*.
[6] Cheng, H. 2011. *Autonomous Intelligent Vehicles*.Springer London.
[7] Dhivya, P. Murugesan, A. 2015. *Intelligent Car Braking System with Collision Avoidance and ABS*.
[8] Dorfman, A. (2013). *Classical and modern engineering methods in fluid flow and heat transfer*. [New York, N.Y.] (222 East 46th Street, New York, NY 10017): Momentum Press.
[9] Driels, M. (2010). *Linear control systems engineering*. New York: McGraw-Hill.
[10] Durali, M. Javid, A. G. Kasaiezadeh, A. 2006. *Collision Avoidance Maneuver for an Autonomous Vehicle*.
[11] Falcone, P. Borrelli, F. Asgari, J. Tseng, H. E. Hrovat, D. 2007. *A model predictive control approach for combined braking and steering in autonomous vehicles*, 15th Mediterranean Conference on Control and Automation.
[12] Fazlollahtabar, H., 2016. *Autonomous Guided Vehicles*.Springer International Publishing.
[13] Fossen, I. T. Pettersen, Y. K. Nijmeijer, H. 2017. *Sensing and Control for Autonomous Vehicles*. Springer International Publishing.
[14] 2002. *General estimates system*,
[15] Han, G., Fu, W., Wang, W. and Wu, Z. (2017).The Lateral Tracking Control for the Intelligent Vehicle Based on Adaptive PID Neural Network. *Sensors*, 17(6), p.1244.
[16] Jansson, J., 2018. *Collision Avoidance Theory*.Department of Electrical Engineering, Linkoping University Press.
[17] Jiménez, F. Naranjo, E. J. Gómez, Ó. 2012. *Autonomous Manoeuvring Systems for Collision Avoidance on Single Carriageway Roads*.
[18] Jones, E. and Childers, R. (2001). *Contemporary college physics*. Port Elizabeth, Eastern Cape: McGraw-Hill.
[19] Jurgen, K. R. 2017. *Autonomous Vehicles for Safer Driving*.SAE International.

[20] Khairnar, H., Phalle, V. and Mantha, S. (2015). Estimation of automotive brake drum-shoe interface friction coefficient under varying conditions of longitudinal forces using Simulink. *Friction*, 3(3), pp.214-227.
[21] Kharchenko, V., Barabanov, Y. and Grekhov, A. (2013).MODELING OF AIRBORNE COLLISION AVOIDANCE SYSTEM PERFORMANCE USING MATLAB. *Proceedings of National Aviation University*, 56(3).
[22] Kim, D. Moon, S. Park, J. Kim, J. H. Yi, K. 2009. *Design of an Adaptive Cruise Control / Collision Avoidance with Lane Change Support for Vehicle Autonomous Driving*.
[23] Liu, C. and Chen, G. (2013).Based on the MATLAB Self-Tuning Fuzzy PID Controller Design. *Applied Mechanics and Materials*, 313-314, pp.443-447.
[24] Magrab, E. and Azarm, S. (2000). *An engineer's guide to MATLAB*. Upper Saddle River, NJ: Prentice Hall.
[25] Mahmassani, H. (2005). *Transportation and traffic theory*. Amsterdam: Elsevier.
[26] Mikleš, J. and Fikar, M. (2007). *Process modelling, identification, and control*. Berlin: Springer.
[27] Padula, F. and Visioli, A. (2013).Set-point weight tuning rules for fractional-order PID controllers. *Asian Journal of Control*, 15(3), pp.678-690.
[28] Pawelec, J. (2008). An Information-Communication System for Early Warning and Collision Avoidance in Road Traffic. *Journal of Communications*, 3(5).
[29] Riaz, F. Niazi, M. 2012. *Designing Autonomous Vehicles: Evaluating the Role of Human Emotions and Social Norms*.
[30] Rosolia, U., Braghin, F., Alleyne, A. and Sabbioni, E. (2015).NLMPC for Real Time Path Following and Collision Avoidance. *SAE International Journal of Passenger Cars – Electronic and Electrical Systems*, 8(2).
[31] Schorn, M. (2009).Obstacle avoidance for passenger cars. *ATZ worldwide*, 111(9), pp.84-90.
[32] Sotelo, M. A. 2003. *Lateral control strategy for autonomous steering of Ackerman-like vehicles*, Robotics and Autonomous Systems 45, 2003, pp. 223~233.
[33] Srinath, N. and Ramakanth, K. (2009).Collision Avoidance for Airborne system using GPS data and RADAR data. *International Journal of Computer and Electrical Engineering*, pp.317-322.
[34] Tedesco, F., Raimondo, D. and Casavola, A. (2013).Collision avoidance command governor for multi-vehicle unmanned systems. *International Journal of Robust and Nonlinear Control*, 24(16), pp.2309-2330.
[35] Verma, R. 2014. *Safety in Semi-autonomous Multi-vehicle Systems: A Hybrid Control Approach*.
[36] Erik Coelingh, Andreas Eidehall and MattiasBengtsson.Collision Warning with Full Auto Brake and Pedestrian Detection - a practical example of Automatic Emergency Braking. 2010 13th International IEEE Annual Conference on Intelligent Transportation Systems Madeira Island, Portugal, September 19-22, 2010.
[37] Lee Yang; Ji Hyun Yang; Feron, E.; Kulkarni, V. Development of a performance-based approach for a rear-end collision warning and avoidance system for automobiles. Intelligent Vehicles Symposium, 2003.Proceedings. IEEE
[38] Zhang S, Deng W, Zhao Q, Sun H, Litkouhi B. Dynamic Trajectory Planning for Vehicle Autonomous Driving. IEEE International Conference on Systems, Man, and Cybernetics (SMC). 2013; p. 4161-4166.
[39] Toledo T, Zohar D. Modeling Duration of Lane Changes. Transportation Research Record: Journal of the Transportation Research Board. 2007; p. 71-78. doi: http://dx.doi.org/10.3141/1999-08.
[40] Xiaorui W, Hongxu Y. A Lane Change Model with the Consideration of Car Following Behavior.Procedia - Social and Behavioral Sciences. 2013;96:2354-2361. doi:10.1016/j.sbspro.2013.08.264.
[41] Shamir T. How Should an Autonomous Vehicle Overtake a Slower Moving Vehicle: Design and Analysis of an Optimal Trajectory.IEEE Transactions on Automatic Control. 2004;49(4):607-610. doi: 10.1109/ TAC.2004.825632
[42] Gipps PG. A Model for the Structure of Lane-changing Decisions. Transportation Research Part B: Methodological. 1986;20(5):403-414. doi: 10.1016/0191- 2615(86)90012-3
[43] Hetrick S. Examination of Driver Lane Change Behavior and the Potential Effectiveness of Warning Onset Rules for Lane Change or "Side" Crash Avoidance Systems [Master Thesis]. Virginia Polytechnic Institute & State University; 1997
[44] Zhang S, Deng W, Zhao Q, Sun H, Litkouhi B. Dynamic Trajectory Planning for Vehicle Autonomous Driving. IEEE International Conference on Systems, Man, and Cybernetics (SMC). 2013; p. 4161-4166.
[45] Toledo T, Zohar D. Modeling Duration of Lane Changes. Transportation Research Record: Journal of the Transportation Research Board. 2007; p. 71-78. doi: http://dx.doi.org/10.3141/1999-08
[46] Penghui L, Mengxia H, Wenhui Z, Xiaoqing X, Yibing L. Steering Behavior during Overtaking on Freeways. Proceedings of the 5th International Conference on Computing for Geospatial Research and Application; 2014 Aug 4-6; Washington DC; 2014. p. 117-11
[47] Xiaorui W, Hongxu Y. A Lane Change Model with the Consideration of Car Following Behavior.Procedia - Social and Behavioral Sciences. 2013;96:2354-2361. doi:10.1016/j.sbspro.2013.08.264.
[48] Shamir T. How Should an Autonomous Vehicle Overtake a Slower Moving Vehicle: Design and Analysis of an Optimal Trajectory.IEEE Transactions on Automatic Control. 2004;49(4):607-610. doi: 10.1109/ TAC.2004.825632.
[49] Lee HK, Barlovic R, Schreckenberg M, Kim D. Mechanical Restriction Versus Human Overreaction Triggering Congested