ISSN 2278-3091
Volume 11, No.3, May - June 2022
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse081132022.pdf
https://doi.org/10.30534/ijatcse/2022/081132022

Lane-Change Maneuver on Overtaking Moving Vehicle on a Two-Way Street

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Received Date : April 16, 2022 Accepted Date : May 18, 2022 Published Date : June 06, 2022

ABSTRACT

This article discusses a safe and collision-free decision for an autonomous car to make when passing another vehicle on a congested two-way roadway. The proposed algorithm considers both the car going the other way and the vehicle in front of the "ego" car that could be an obstacle. The LIDAR, the medium-range radar, and the long-range radar are the three types of sensors that the ego car will use to observe its surroundings. The second sensor's job is to keep an eye on the vehicle blocking the ego lane. Once that car is detected, the ego car will start to pass it, but only if the first sensor has found that the obstruction has been removed. With the help of the third sensor, the ego car can determine if there is a vehicle approaching from the other direction. After that, the algorithm will determine the time needed to pass both automobiles and their final positions and the distance between them. If there is enough space, the ego vehicle will switch lanes and perform the lane-change movements. If there is not enough space, the ego car will continue driving in the same lane. MATLAB simulation confirms the method, which demonstrates significant improvement.

Key words: Autonomous vehicle, overtaking, LIDAR, Radar,

1. INTRODUCTION

A self-driving car is capable of autonomous navigation, entirely driven with no human intervention, as they can navigate themselves by recognizing the environment [1], [2]. The development of autonomous vehicle technology shows a rapid increase over time. Researchers and developers have made a lot of progress in detecting obstacles, making navigational decisions, and planning routes, paths, and trajectories. However, if the vehicles around them were evaluated quantitatively, they might be able to figure out the possible risks to a safe and reliable trajectory for self-driving cars.[3].

One of the more significant aspects and concerns of these self-driving cars are overtaking. It is the most frequently used and challenging maneuver for autonomous vehicles apart from the inherent danger because of the difficulty in assessing the required space to perform safe driving. It is under great focus because of its capabilities toward the goal of full end-to-end autonomy. It includes a combination of lateral and longitudinal motion while avoiding collisions and several sub-maneuvers. Extreme care is necessary to handle it since it encompasses risk on single and multi lanes. [4],[5].

One of these researches dealing with overtaking is [6], which used a Stochastic Model Predictive Control (SMPC) to track the desired motion. An adopted probabilistic prediction model for a safe distance to cope with the limitation of cognitive range to perform overtaking. It overtook the surrounding vehicles following traffic regulations and achieved a safe and comfortable overtaking maneuver because of the consideration of vehicles appearing outside the sensor range. Likewise, the overtaking system of [7] uses the current relative position and orientation concerning the overtaken vehicle to decide when to overtake. The authors used feedback control from onboard sensors and applied standard robotic nomenclature for translational and rotational displacements and velocities. The overtaking maneuvers assure a smooth transition between the adjacent phases without using any roadway marking scheme or intervehicle communication.

Furthermore, the authors of [5] generate a local risk map, identify a safe target, and plan a trajectory using a modular control framework via MPC controller for autonomous high-speed overtaking. Their study can generate trajectories compatible with vehicle dynamics and safety considerations. The system makes sure that the trajectory, speeding up or slowing down, and moving sideways are possible and can be done in real-time.

The studies discussed above contribute significantly and provide an optimal solution for overtaking a slow-moving vehicle for autonomous trajectory planning or lane-change maneuver. However, the said solutions were investigated on one-direction lanes only.

There are some autonomous overtaking researches on a two-direction road. One of these is [8], where overtaking takes place in a two-direction high-speed lane. The authors do overtaking by taking a sample of the relative distance to the vehicle in front, getting the inverse of its speed, and using input-output linearization to make the dynamics linear. The formula lets the self-driving car decide when and how to pass another car, even if that other car is in the same or the next lane.Similarly, the automatic driving system of [9] can perform overtaking maneuvers when a slower car is on a two-direction road. The authors design an overtaking maneuver using a Fuzzy Logic Controller. They can determine if the opposite lane is free of a vehicle via GPS and wireless network environment. Using GPS mapping, defining reference trajectory is no longer needed.

In Manila, Philippines, there are many narrow two-way, one-lane streets where small and slow vehicles are moving around, like a tricycle, pedicabs, and the like. There are also public utility jeepneys that stop when there are alighting passengers or slow down when there are persons along for the ride. Overtaking on a two-direction road should consider the oncoming vehicle in the adjacent lane.

The paper [10] of Marcelo H. Ang et al. presented an autonomous overtaking situation on a two-way street using the Receding Horizon formulation that considers a blind spot caused by occluding obstacles. The method determines the amount of overtaking time available by representing the occupancy of barriers, especially those that fully impede the vehicle's visibility and may unexpectedly come from beyond the sensing range of the car. Their framework effectively overtakes a vehicle in a two-way, one-lane street but only on those illegally parked or stationary vehicles. This paper deals with the problem of how a self-driving car overtakes a slow or not moving vehicle on a two-way, narrow street.

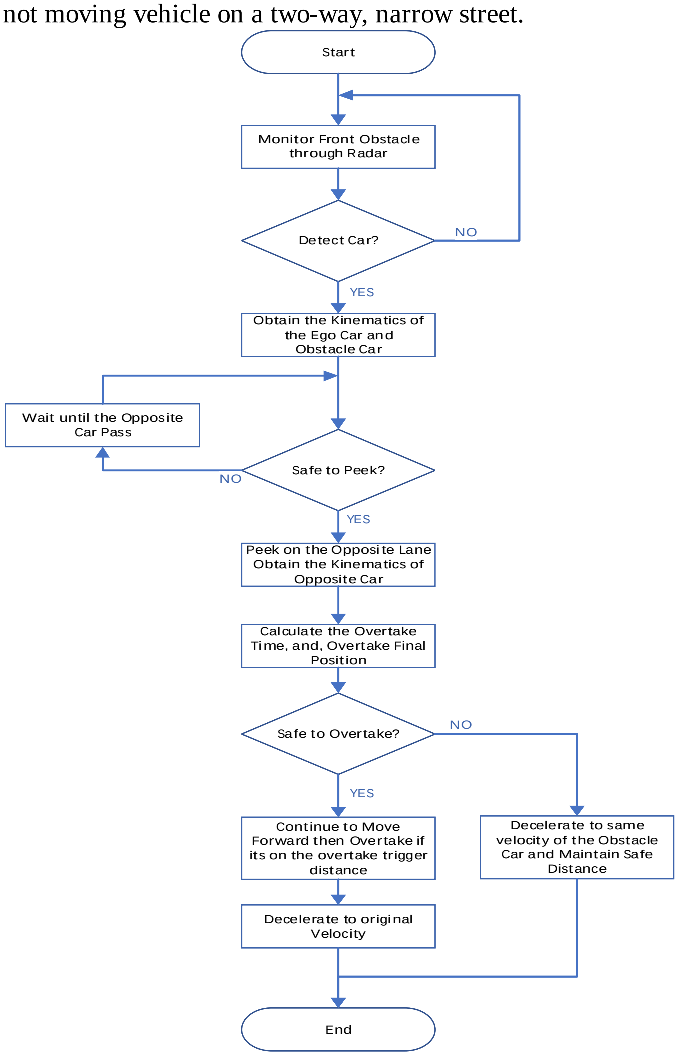


Figure 1: System Flowchart

2. METHODS

Our study is about the opposite-lane overtaking self-driving car. The study's objective is to develop an algorithm that is a safe, collision-free, self-driving car on a narrow two-way street. Figure 1 shows a flowchart of how the ego car or self-driving car keeps track of its surroundings and moves through them.

The ego car can predict the overtaking scenario result based on the kinematics of the ego car, the obstacle car in the same lane, and the opposite car. Our goal is to predict the final position of the ego car and the opposing vehicle. The algorithm can figure out the overtaking time, the final position of the overtaking, and the other vehicle's position during the overtaking using the information from the sensors on the ego car, as shown in figure 2.Once the necessary values are determined, the algorithm will decide if overtaking will occur.

Three sensors are used to detect objects or obstacles, as shown in figure 3. The first is the Lidar sensor, capable of monitoring a short-range environment at 360 degrees from the vehicle's center. The second sensor is the medium-range radar that can detect objects within 15 meters. This radar is used to check if there are cars in front of the ego vehicle and control the speed at which the car is going.Lastly, the long-range radar is used to monitor the presence of vehicles in the opposite lane with a very high detection distance, approximately up to 250 meters. Sensors' properties are shown in table 4.

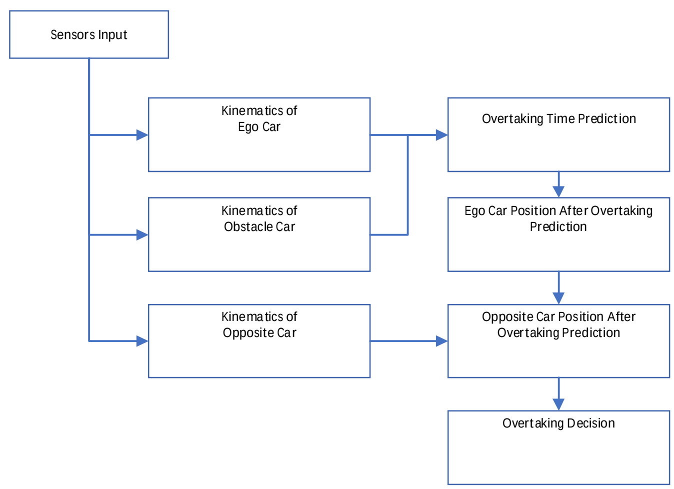


Figure 2: Overtaking Flowchart/Algorithm

Figure 3: Ego Car Sensors

2.1 Mathematical Computation

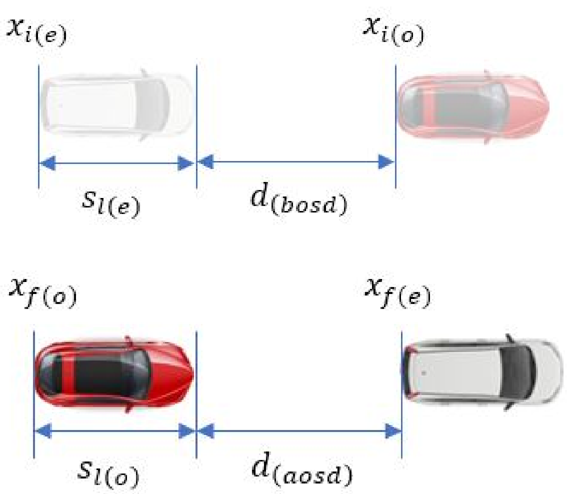
First, we will compute the Overtaking Time using the Kinematics Equation. The data gathered from the sensors are the Ego Car, Obstacle Car, and Opposite Car's position, velocity, and acceleration. As shown in eq.1, the general kinematics equation is used to get the distance traveledimplementing to Ego Car and Obstacle Set Values.

$$x_f - x_i = v_i t + \frac{1}{2} a t^2 \qquad (1)$$

Using eq.1 and setting the overtaking parameters, as shown in Table 1, eq.2 and eq.3 had obtained for the ego car and object car (obstacle and opposite), respectively.

Ego Car: $$x_{f(e)} - x_{i(e)} = v_{i(e)} t_{(ot)} + \frac{1}{2} a t_{(ot)}^2 \quad (2)$$

Object Car: $$x_{f(o)} - x_{i(o)} = v_{i(o)} t_{(ot)} \quad (3)$$



The position relation of the object car to the ego car will be set as:

$$x_{i(o)} = x_{i(e)} + d_{(bosd)} + s_{l(e)} \qquad (4)$$

$$x_{f(o)} = x_{f(e)} - d_{(aosd)} - s_{l(o)} \quad (5)$$

Applying eq.4 and eq.5 to eq.3

$$x_{f(e)} - d_{(aosd)} - s_{l(o)} - (x_{i(e)} + d_{(bosd)} + s_{l(e)}) = v_{i(o)} t_{(ot)}$$

$$x_{f(e)} - x_{i(e)} = v_{i(o)} t_{(ot)} + d_{(aosd)} + s_{l(o)} - d_{(bosd)} - s_{l(e)} \quad (6)$$

Applying eq.2 to eq.6

$$v_{i(e)} t_{(ot)} + \frac{1}{2} a t_{(ot)}^2 = v_{i(o)} t_{(ot)} + d_{(aosd)} + s_{l(o)} - d_{(bosd)} - s_{l(e)}$$

$$\frac{1}{2} a t_{(ot)}^2 + (v_{i(e)} - v_{i(o)}) t_{(ot)} - (d_{(aosd)} + s_{l(o)} - d_{(bosd)} - s_{l(e)}) = 0 \qquad (7)$$

It is shown in eq.7 that it is in the second-degree polynomial in terms of $t_{(ot)}$. To solve this, we will apply the quadratic equation indicated in eq.8 and eq. 9. First, we need to solve for its constants, a,b and c.

Quadratic Formula:

$$a_q x^2 + b_q x + c_q = 0 \quad (8)$$

$$\frac{-b_q \pm \sqrt{b_q^2 - 4 a_q c_q}}{2 a_q} = x \qquad (9)$$

Extracting the value of a, b, and c from the eq.7

$$a_q = \frac{1}{2} a \quad (10)$$

$$b_q = v_{i(e)} - v_{i(o)} \quad (11)$$

$$c_q = -(d_{(aosd)} + s_{l(o)} - d_{(bosd)} - s_{l(e)}) \quad (12)$$

By substituting the constants, a, b, and c, from eq.10, eq.11, eq.12 on Eq.9, $t_{(ot)}$ will be equal to eq. 13. Note that, since we are solving the time of total time of overtaking maneuver, we consider only the positive value of the $t_{(ot)}$.

$$t_{(ot)} = \frac{-(v_{i(e)} - v_{i(o)}) + \sqrt{b_q^2 + 4(\frac{1}{2}a)(d_{(aosd)} + s_{l(o)} - d_{(bosd)} - s_{l(e)})}}{2\left(\frac{1}{2}a\right)} \qquad (13)$$

Once the overtake time, $t_{(ot)}$, is solved, this will be substituted to eq. 2 to solve for the overtake position of the Ego Car. The algorithm will then solve for the opposite car's position by using the change in distance formula regarding the overtake time and the opposite car's velocity, as shown in eq.14.

$$\Delta x_{(p)} = v_{(p)} t_{(ot)} \qquad (14)$$

Then, using the $\Delta x_{(p)}$ from eq.14, we will compute the final position of the opposite car after overtaking.Note that the other car is moving in the opposite direction of the Ego Car. Since it is moving in the opposite direction, it will be calculated with the opposite vector, as shown in eq. 15.

$$x_{f(p)} = x_{i(p)} - \Delta x_{(p)} \qquad (15)$$

Comparing the final position of the Ego Car and the Opposite Car, with consideration to the safe distance given, if the position or distance of the Ego Car plus the safe distance is greater than the final position of the Opposite Car, it is safe to overtake, else, the possibility of collision.

$$x_{f(e)} + sd < x_{f(p)} \quad : safe\ to\ overtake$$

$$x_{f(e)} + sd >= x_{f(p)} : collision$$

Table 1: Overtaking Parameters

Parameter	Units	Description
$x_{i(e)}$	m	Ego vehicle: Position before Overtake
$x_{f(e)}$	m	Ego vehicle: Position after Overtake
$v_{i(e)}$	m/s	Ego vehicle: Velocity after Overtake
a	m/s^2	Ego vehicle: overtake acceleration
$x_{i(o)}$	m	Object vehicle: Position before Overtake
$x_{f(o)}$	m	Object vehicle: Position after Overtake
$v_{i(o)}$	m/s	Object vehicle: Velocity after Overtake
$t_{(ot)}$	s	Overtake time
$t_{(s)}$	s	Time to reach before overtake
$d_{(radar)}$	m	Radar distance
$d_{(bosd)}$	m	Before overtake safe distance
$d_{(aosd)}$	m	After overtake safe distance
$s_{w(e)}$	m	Ego vehicle: car width
$s_{l(e)}$	m	Ego vehicle: car length
$s_{w(o)}$	m	Object vehicle: car width
$s_{l(o)}$	m	Object vehicle: car length

Table 2: Vehicle's Classification and Characteristics

Vehicle	Classification	Length	Width
car	Ego Car Opposite Obstacle	4.3m	1.7m
tricycle	Obstacle	2.15m	1.68m
bus	Obstacle	8.0m	2.1m

Table 3: Constant Values

Constant Values	Set Value
Initiate Overtake	5m
Trailing Distance	3m
Acceleration(Ego Car)	3m/s
Change Factor	0.1

Table 4: Sensor's Properties

Sensors	Range(m)	Angle(deg)
Lidar(Radius)	6	360
Medium-Range Radar	15	90
Long-Range Radar	250	9

2.2 Overtaking Maneuvers

2.2.1. Obstacle Car Detection

When the Ego Car's Medium-Range Radar detects an Obstacle Car within its range, the Ego Car will get the obstacle car's kinematics (position and velocity). The visual representation of the overtaking maneuver is shown in figure4.

2.2.2. Peeking

- Before

Before the Ego vehicle peeks, LIDAR will be used to detect any obstacles in the opposing lane. There will be no peeking if the opposite car is located within the LIDAR field.

- During

When the LIDAR does not identify an opposing vehicle, the automobile will begin to peep by lane-changing. During peeking, the Ego vehicle rechecks for the presence of an opposite vehicle within the LIDAR range or the long-range radar's field of view. If the LIDAR sensor detects an approaching car, the system will prevent the driver from passing. Alternatively, if the Long-Range Radar detects an opposing vehicle, its position and speed will be determined.

2.2.3. Overtaking Decision

Once the Ego Automobile returns to its ego lane, it will use the provided formula to compute the overtaking time and final positions of the Ego Car and the opposing car. As shown in Table 2, the vehicle's characteristics are also examined. The final location will be evaluated to determine if it is safe to pass.

2.2.4. Lane Change and Overtaking

Setting the overtake trigger distance (initiate overtake) tells the ego car when to start moving into the other lane. This overtakes trigger distance is the distance from the back of the obstacle car that must be at least this far away. Once the medium-range radar gets to the trigger, the ego car will speed up and change lanes to the other side while speeding up.

There is a setting for the overtake return distance to return to its original lane. It's the safe distance between where the obstacle car starts and the ego car ends. When the distance is reached, the ego car will start to move back toward the lane it was in before.

The ego car will keep speeding until it gets to its original lane. Once it gets to the target lane, it will start slowing down. Table 3 shows the overtake trigger distance, overtake return distance, and acceleration values.

3. RESULTS AND DISCUSSION

The simulation is carried out using MATLAB. Figure 5 depicts its Graphical User Interface (GUI). The suggested algorithm determines whether the current car should pass an oncoming vehicle in the adjacent lane. In three steps, simulations were run with ten different scenarios to see how well the proposed algorithm worked.Before or during peeking, the first testing phase occurs when an opposing vehicle comes or is within the LIDAR sensor's field of view. When the ego vehicle has reached its maximum speed, the sensors will collect the required data to evaluate whether it is safe to pass. The second testing phase focused on collision inputs between the ego automobile and the opposing car. For the final portion of the testing, it is assumed that the information will permit a safe overtaking. Figure 6 shows theanticipated LIDAR, velocity, acceleration, andactualbody-to-body distance of the ego automobile during safe overtaking.

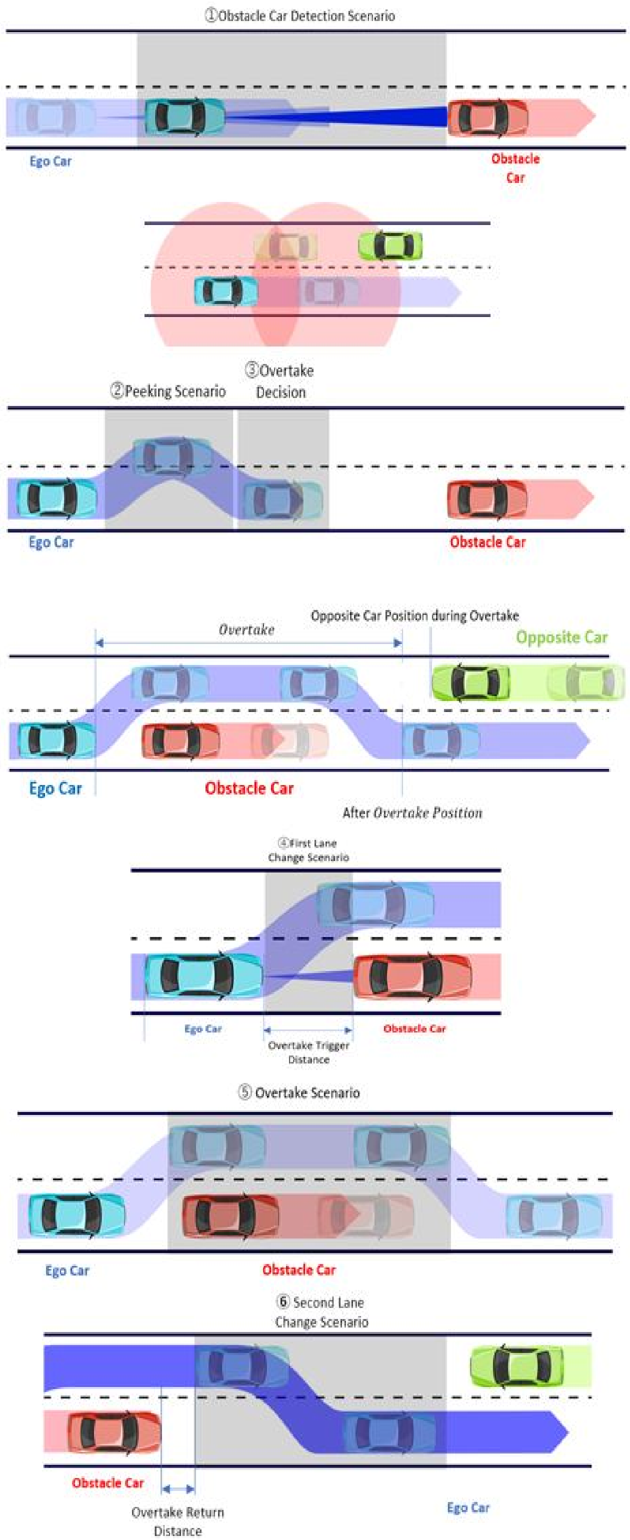


Figure 4: Lane Change and Overtaking Maneuvers

Figure 7 shows the graph of successful overtaking scenarios with different initial velocities and distances of the ego car, obstacle car, and the opposite vehicle. It is shown that the expected graph of LIDAR is the same as the actual outputs; likewise, the expected production of body-body

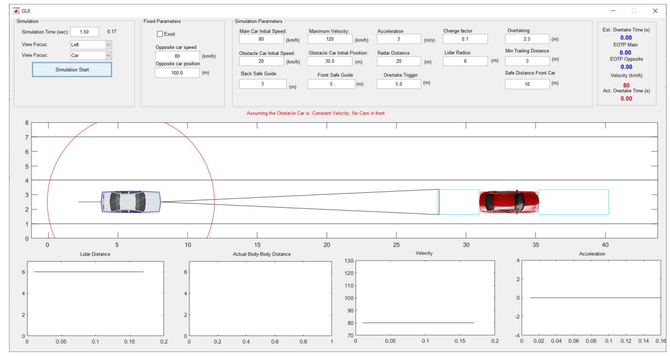


Figure 5: MATLAB Simulation Environment

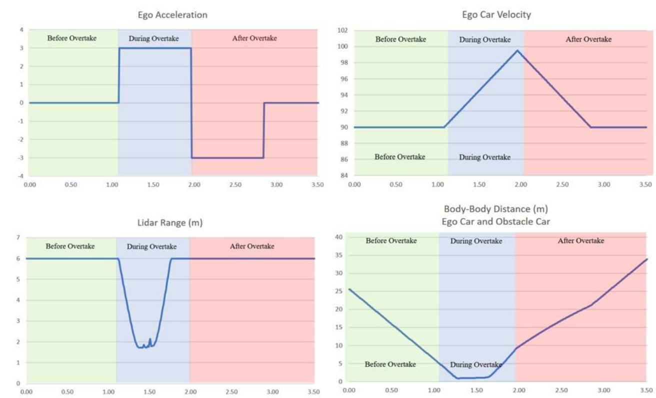


Figure 6: The graph of the LIDAR, Velocity, Acceleration, and the Actual Body-Body Distance of the Ego Car during Overtaking

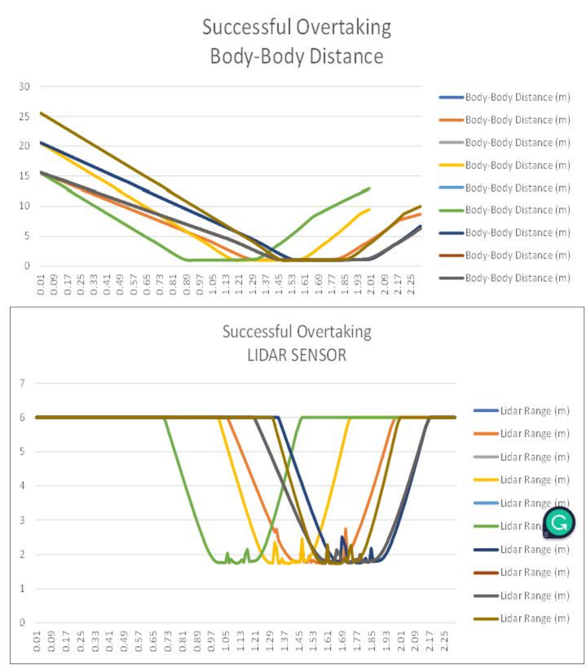


Figure 7: Successful Overtaking Simulation on Different Scenarios

Table 6: Collision Detected - The distance of the Ego Car from the Opposite Car is not safe to overtake

#	Ego Car		Obstacle Car		Opposite Car	
	Velocity	Distance	Velocity	Distance	Velocity	Distance
1	90	0	50	20	70	100
2	80	0	40	20	60	90
3	80	0	30	25	50	80
4	80	0	25	30	60	100
5	60	0	40	20	70	110
6	60	0	50	20	80	130
7	70	0	30	25	90	130
8	70	0	40	25	80	150
9	90	0	40	25	70	120
10	90	0	30	25	80	110

distance of the ego car and the opposite vehicle is the same as the tangible outputs.

Several tests were done to see if passing won't happen once the algorithm decides that it's not safe to pass. Tables 5 and 6 show how fast each car was going and how far away it was when it started.

In the first part of the simulation, the data given in table 5 were used. The simulations show that when the opposite car is inside the lidar sensor, the overtaking will be aborted when it is about to do the peeking action.

On the other hand, the second part of the simulation determines if the ego car will pass another vehicle if long-range radar spots it. Testing was done using the information in Table 6, and the simulations show that all overtaking scenarios were stopped.

4. CONCLUSION

This article studied the problem of overtaking stationary or slow-moving vehicles on a two-way street, considering approaching cars on the opposite lane. By using sensors, the ego car can determine if there is a surrounding obstacle. The lane-change and overtaking maneuver will be executed if a slow-moving vehicle is in front of the ego car and the Lidar sensor does not detect vehicles in the opposite lane. The maneuvers include peeking, first lane-change, acceleration, and second lane-change.The algorithm was tested in different scenarios in MATLAB. The thirty tests conducted show that the algorithm can execute safe overtaking.

In the future, we will apply a prediction analysis to overtake in different scenarios using the data gathered in the proposed overtaking method.

ACKNOWLEDGEMENT

The author would like to recognize De La Salle University-Manila and Engineering for Research and Development for Technology (ERDT) of the Department of Science and Technology (DOST) for funding this study.

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