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Decision Making of an Autonomous Vehicle in a Freeway Travelling

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ABSTRACT

This paper introduces a trajectory planning algorithm for long-term freeway driving for autonomous vehicles including different modes of motion. In the autonomous driving in a freeway, different maneuvers are needed, including free flow, distance adaption, speed adaption, lane change and overtaking. This paper introduces an algorithm that provides all of these driving scenarios in the trajectory planning for an autonomous vehicle. All maneuvers are classified and proper formulation for each driving mode formulated. Then, an algorithm is introduced to show the procedure of decision making and switching between all driving modes. The relative distances and velocities of the other peripheral and front vehicle from autonomous vehicle are considered as the main factors for decision making during the travelling in the freeway. By the developed simulation programming, validity and effectiveness of the algorithm are verified, and pseudo code and flowchart for the simulation programming are introduced. Later in two simulation studies, different driving conditions are generated and results have been discussed and analyzed by detail.

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1. Introduction

Nowadays, autonomous vehicles (AV) have several abilities to benefit the human life. They have high potential to decrease driving collisions, generally caused by human errors. Moreover, AVs provide better mobility for the aged and the disabled people, and release the passengers from driving tasks, thereby changing driving times with more time for rest, work or activities such as reading or writing. Since, automated vehicles could receive the traffic flow information, they can predict roadway capacity and try to plan their path in a way to minimize traffic congestion, and be a basis for fuel efficiency and cleaner environment. Motivated by all of these advantages, researchers and vehicle makers have shown high interest in the development of AVs [1].

The vehicle autonomy is generally divided in three different steps, perception and localization, trajectory planning and the vehicle control. In the perception step, vehicle collects neighboring environment information using sensors such as vision [2] lidar, radars, inertial accelerometer, etc. [3]. Meanwhile, perception step may use information exchange with environment (V2X) or connecting by vehicle to vehicle (V2V) information exchange [4, 5]. In this step, lane boundaries, lane markings, road traffic and all possible obstacles are detected. The vehicle localization is determined using IMU's (Inertial measurement unit) [3] and GPS (Global Positioning System) sensors.

The second essential step in the vehicle autonomy is the trajectory planning. In this step, AV uses the perception data to plan a secure and smooth trajectory for AV. The trajectory planning plans a trajectory constrained by the vehicle dynamics limits, comfort and safety of passenger, and the traffic rules. Once the desired trajectory is generated, the next step is to control the vehicle actuators, such as steering wheel, accelerator and braking pedal position in order to track this trajectory with the desired speed profile, defined by the planning module [6].

The main focus of this research is trajectory planning of an AV in a multi-lane freeway driving. At any point and time, special kinds of maneuver are possible for the AV, including keeping way by the desired velocity, distance adaption, speed adaption with peripheral vehicles, lane changing or overtaking. Adaptive cruise control (ACC) systems are usually employed for distance and speed adaption to improve the vehicle and passengers' safety, smoother traffic flow, and decreasing driving workload. Hence, ACC have paid significant attention from various research groups and automotive industries [7]. The development of ACC systems is enhanced by different criteria, such as multi-objective optimization [8], obstacle avoidance [9, 10], and platoon of vehicles [11]. The lane changing and overtaking are the other most common driving maneuver of any vehicle in a freeway. When an AV reaches to a slower moving leading vehicle, it decides to overtake that vehicle by a double lane change, to return its default lane at the end of the maneuver, while avoiding collision with surrounding traffic. This is achieved by detecting all static and dynamic obstacles around the AVs path, by measuring their relative distance and velocity. Then, by processing collected information, it makes decision to stay in its lane or possibility performs lane change or overtaking. These maneuvers are complex driving tasks as they include both lateral and longitudinal motions. Any lane changing or overtaking maneuver in the real-world scenarios is unique. This uniqueness gets up from various parameters like numbers of overtaken vehicles, duration of overtake, relative velocity and distance between ego vehicle and other peripheral vehicles [12-16],

Earlier research works considered the autonomous lane changing maneuver, as a static driving behavior, but recently dynamic trajectory is planned for each time step of driving [17, 18]. State-of-the-art and future prospects of trajectory planning and tracking for intelligent overtaking reviewed in [7]. Other research studied the problem of optimal overtaking of a in the presence of dynamic environment with varying vehicles and known longitudinal speeds for the peripheral vehicles [19, 20].

There are two common methods for the trajectory planning problem: stochastic method and model-based method [21]. Stochastic

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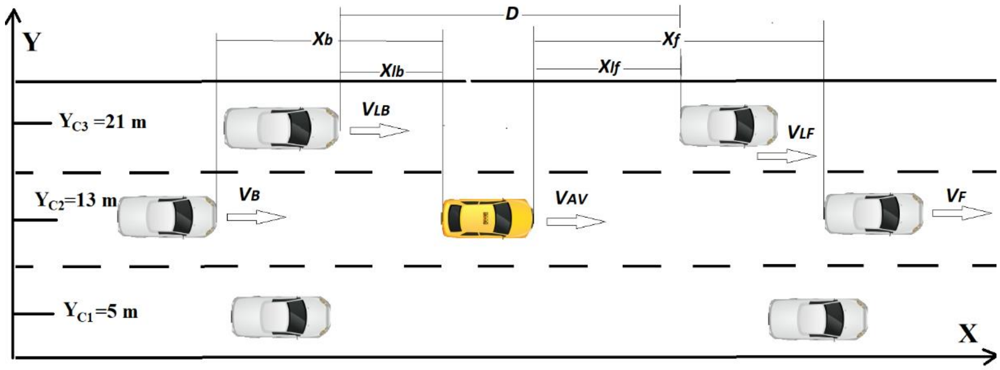

Figure 1: A 3-lane freeway in the presence of AV and other vehicles around, lane and road boundaries

methods are able to launch a relationship between dangers enforced the main vehicle and the lane change trajectory geometry. Some stochastic modeling methods are Hidden Markov Model [20], neural network [22], and fuzzy system [23]. It is known that for models with high nonlinearity stochastic models' loss their capability to model the problems' physical parameters. On the other hand, model-based methods like polynomial [24], sinusoidal and model predictive trajectory tracking models [25] describe the trajectory planning/tracking in the form of equations. But polynomial trajectory curve is the most widely adopted for overtaking. Shim et al. have employed the six-order polynomials for overtaking trajectory planning [26]. In general, polynomial functions with higher order for the overtaking trajectory, create smoother variations for the state variables (e.g., position, velocity, and acceleration). But higher order polynomial function needs more input information to determine the model parameters.

Earlier researches have discussed only about one special kind of maneuver, e. g. ACC, lane changing, or overtaking. This paper introduces a trajectory planning algorithm for long-term freeway driving for an AV, which has not addressed in the earlier research works. Here, it is assumed that environmental information, including the position and speed of the ego vehicle and peripheral vehicles, freeway lane marking and lane boundaries are available from the perception and localization measurements. So that, different kinds of motions and maneuvers are possible, including keeping way by the desired velocity, distance adaption, speed adaption with peripheral vehicles, lane changing or overtaking.

The present work aims to classify the different driving behaviors in a freeway by logical way and find a feasible solution for any situation considering the current capacity of the AV vehicle. To realize this aim, efficient driving rules are derived which cover major possible scenarios in a dynamic environment in a typical freeway. The paper is organized as follows, in section 2, the exact definition of the problem is described and different driving modes are classified and formulated. Trajectory planning algorithms for different maneuvers are presented in Section 3. The simulation study and its result are presented in Section 4, and finally, conclusions are remarked in Section 5.

2. Driving Modes

The main goal of this research is trajectory planning for an AV in a freeway and finding a set of actions, in a long-term driving. This is based on the AVs kinematics and dynamics data, peripheral vehicle motion, desired speed, road geometry, and road and driving rules. Here, these actions are divided in different categories, free flow, car following (distance adaption or speed adaption), lane change or overtake, and stop. In the following, different actions are described with their associated equations.

2.1. Terms and Definitions

Here, the most important terms and definitions for intelligent driving in a 3-lane freeway with specified lane and road boundaries, and in the presence of adjacent vehicles, are defined (Figure 1). It is assumed that lane speed limits are $v_{i_{Min}}$ and $v_{i_{Max}}$ and $v_{i_{Max}} \leq v_{(i+1)_{Min}}$, {i=1,2, or 3 as lane number from right to left}. The peripheral vehicles in the freeway are moving with their desirable velocities and lanes, and they are able to change their lane. The AV must be able to regulate its motion, when faced with a sudden speed and lane change of a nearby vehicle. The AV itself respects the speed limits of the current lane. Each vehicle including the AV and others vehicles around, have a desirable velocity in which they tend to drive. However, AV sometimes needs to change its lane to overtake from vehicle ahead moving slower or decrease its speed to avoid a crash with the vehicle ahead or increases its speed to reach its desired velocity. The AV should also preserve a critical distance with the front vehicle which is equal to the distance required by the AV to stop without crash if the front vehicle stops unexpectedly. The critical distance depends on AVs' current Velocity (v_{AV}) and its braking power and passengers' comfort which affects its allowable deceleration. The lane that the AV tends to drive based on its desired velocity is called the Default Lane (*DL*).

Here, a set of driving rules is proposed for the AV which is able to make timely decisions to move in free flow or when performs speed or distance adaption to avoid crash or lane change and overtake from slower front vehicle ahead.

2.2. Free Flow

After considering the speed limits of freeway lanes, the road traffic, the weather conditions, and geometry of the freeway, desired speed of the AV (V_d) is selected. In the free flow regime, drivers are not close to their leaders and therefore, have the freedom to move or attain their desired speed. That is when vehicle ahead is far enough from AV or its velocity is higher than AV. Also, in this mode no interaction occurs between the AV and the other surrounding vehicles. Therefore, velocity of AV is selected as,

$$V_{AV}=V_d \tag{1}$$

2.3. Car Following

Two types of car-following modes may happen, distance adaption or speed adaption.

2.3.1. Distance adaption

The model is based on the logic that AV always keep its distance from the front vehicle (X_f) a safe headway named as critical distance (X_{crit}) in a way that it can stop without colliding, if the vehicle ahead comes to a sudden stop. When a vehicle in the neighboring lane changes its lane and appears on the front of the AV in a distance closer than X_{crit} and ($X_f<=X_{crit}$), AV must decrease its velocity to increase its distance from that vehicle, until reaching X_{crit}.

The car following model developed by [27], is employed here. The model is given by

$$a_{da}(t_i) = \frac{\alpha\left(V_f(t_i) - V_{AV}(t_i)\right)^{\gamma}}{\left(X_f(t_i) - X_{AV}(t_i)\right)^{\beta}} \tag{2}$$

Where, $a_{da}(t_i)$ is the distance adaption deceleration at each time, and α, β, and γ are positive model constant parameters. Based on the Eqn. (2) deceleration sensitivity at each time step proportions with relative speed raised to the power γ and inversely proportional to the headway raised to the power β. The coefficient α is selected based on the AVs braking capability and passengers' comfort.

2.3.2. Speed adaption

The speed adaption stage refers to the time interval during which the AV approaches the slower vehicle moving ahead, and matches its speed in a car-following state. After this stage the driver considers overtaking the slower vehicle in the traffic stream if suitable gaps in the left lane become available. The Speed adaption stage normally takes place prior to

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initiating the overtaking. This is when AV moves faster that front vehicle ($V_{AV} \geq V_f$) and its distance is greater than X_{crit}. But left lane vehicles are moving in a way that direct overtake is not safe. This is when, the gap D between two adjacent vehicles in the left lane is not enough or velocity of the vehicle approaching from behind at the left lane, V_{BL} is much higher than V_{AV} and there is a risk of collision. However, in direct overtake this stage can be skipped; i.e., the AV does not slow down to the speed of front vehicle.

The speed plan can be obtained by considering the distance from front vehicle X and safety distance X_{crit}. Again, at each time step, the AVs deceleration depends on the relative distance $X_f(t_i) - X_{crit}$ and relative velocity $V_f(t_i) - V_{AV}(t_i)$. Here, it is assumed that speed adaption starts, when AV reaches to distance $1.5X_{crit}$ with the front vehicle.

$$V_{AV}(t_i) = V_f + \left(V_{AV}(t_0) - V_f\right)\left(1 - e^{-t_i/\tau}\right) \quad (3)$$

Where, the time constant is computed as

$$\tau = a(V_{AV}(t_0) - V_f)/(0.5X_{crit}) \,, a \leq 1 \quad (4)$$

2.4. Overtaking

The overtaking maneuver refers to the situation when the AV in the traffic stream decides to pass the front vehicle with speed $V_f < V_{AV}$ and distance X_f relative to AV, using the left lane. The third vehicle of interest in this process is the vehicle coming from back in the left lane with V_{BL} and distance X_{BL} from the AV. Based on the current available gap (D), the AV checks whether initiating an overtaking is safe or not.

Overtaking is completed in three different phases (Figure 2). in the phase I, when the gap D in the left lane is accepted, AV changes its lane and pulls out to the left lane, then accelerates to his/her desired overtaking speed (usually higher than its normal desired speed) to pass the slower vehicle ahead. The AV continues its path in the left lane (phase II) until a safe gap between the rear bumper of AV and the front bumper of overtaken vehicle is available and finally, in phase III return backs to the default lane. Here it is assumed that, the travel speed of AV during overtake can exceed the speed limit of its default lane. In merge back into default lane, if the return gap (D_R) is shorter than a minimum safe gap, the AV must either overtake the next vehicle if it is safe.

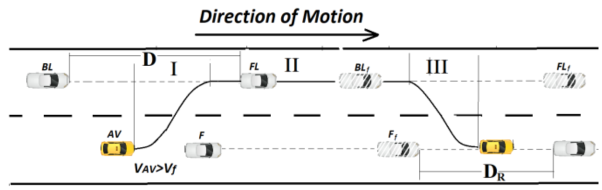

Figure 2: Schematic of an overtaking maneuver, including sub- maneuvers: (I) lane-change; (II) pass front vehicle (F); (III) merge back into default lane.

For the lane change to the left (phase I) of the AV and returning back to default lane (phase III), the 4th order polynomial time dependent curves are used to define the path coordinates (x, y). This curve ensures the smoothness of the path.

$$x(t_i) = a_4{t_i}^4 + a_3{t_i}^3 + a_2{t_i}^2 + a_1t_i + a_0$$
$$y(t_i) = b_4{t_i}^4 + b_3{t_i}^3 + b_2{t_i}^2 + bt_i + b_0 \quad (4)$$

By taking a time derivative from Eqns. (4) we have

$$\dot{x}(t_i) = 4a_4{t_i}^3 + 3a_3{t_i}^2 + 2a_2t_i + a_1$$
$$\dot{y}(t_i) = 4b_4{t_i}^3 + 3b_3{t_i}^2 + 2b_2t_i + b_1 \quad (5)$$

The 10 unknowns including the coefficients a_i and b_i and {i=0,1,..4}, can be executed for the 10 known initial, mid and final state vectors, as

$$S_0 = (x_0, \dot{x}_0, \dot{x}_m, y_0, \dot{y}_0)$$
$$S_f = (x_f, \dot{x}_f, \dot{y}_m, y_f, \dot{y}_f) \quad (6)$$

To solve the problem, the lateral velocity in the middle of the lane change time t=T/2 is considered to be the maximum value ($\dot{y}_m = V_{y(max)}$). The maximum lateral speed is determined based on the passengers' comfort. Also, the longitudinal velocity at time t=T/2, is obtained from the longitudinal velocity variations as $\dot{x}_m = \frac{(\dot{x}_f + \dot{x}_i)}{2}$.

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3. Trajectory Planning Algorithm

This section presents an algorithm for the trajectory planning of an AV in a freeway based on the type of movement of surrounding vehicles. The basis for decision making is the relative distance and speed of adjacent vehicles with AV. Driving cases include keeping way by the desired velocity (free flow), distance adaption, speed adaption or, lane changing for overtaking. Figure 3 proposes the general simulation flowchart for the trajectory planning.

Assumptions:

- It is assumed that the desired velocity of AV and its DL are known. Also, the relative velocity and distance of all adjacent vehicles are measured and known at any time during the travelling in the freeway.
- All vehicles respect the speed limits of all lanes, or

$$v_{i_{Min}} \leq v_* \leq v_{i_{Max}} \qquad (7)$$

Where, index i=1,2, ..,n denotes the lane number, i=1 indicates the right lane and i=n indicates the final left lane. The sign (*) represents all vehicles including AV, and other adjacent vehicles.

3.1. Algorithm of Decision Making

As it is seen at flowchart of Figure (3), at each time step AV checks its relative distance and velocity from forward and rear adjacent vehicles moving in the current and left lane, and make the proper decision as following:

Case 1: If $X_f > X_{crit}$ and $V_{AV} < V_f$ → Free flow with desired Speed ($V_{AV} = V_D$)

Case 2: If $X_f < X_{crit}$ and $V_{AV} < V_f$ → Free flow with desired Speed ($V_{AV} = V_D$). No response needed. Because, speed of the front vehicle is higher than AV, distance X_f increases gradually and reaches to allowable value X_{crit}.

Case 3: If $X_f < X_{crit}$ and $V_{AV} > V_f$ → Check gap D between two adjacent vehicles in the left lane.

- Case 3-1: If D >D_{safe}→ Change AVs lane to the left for possible overtaking. (Use Eqns. (3) and (4) by estimating T_f and state variables S_0 and S_f (Eqns. (5)).
- Case 3-2: If D <D_{safe} → Distance adaption. There is not safe gap between two adjacent vehicles in the left lane for lane changing. Use Eqn. 2 to decelerate, until $X_f = X_{crit}$. Wait for a suitable condition in the left lane to overtake.

Case 4: If $X_f > X_{crit}$ and $V_{AV} > V_f$ → Check gap D between two adjacent vehicles in the left lane.

- Case 4-1: If D >D_{safe} → Change AVs lane to the left for possible overtaking. (Use Eqns. (3) and (4) by estimating T_f and state variables S_0 and S_f (Eqns. (5)).
- Case 4-2: If D <D_{safe} → Speed adaption. There is not safe gap between two adjacent vehicles in the left lane for lane changing. Use Eqn. 3 to decelerate, until $V_{AV} = V_f$ and $X_f = X_{crit}$. Wait for a suitable condition in the left lane to overtake.

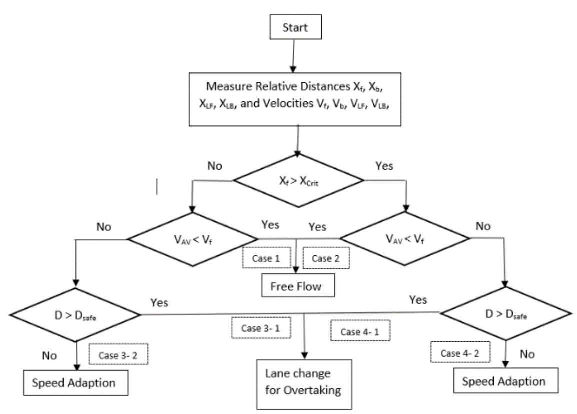

Figure 3: Flowchart of decision making in the long-term Intelligent driving in the freeway

4. Simulation Study

Conducting experiments in the real environment are usually expensive and risky, especially in the intelligent driving context that can cause human

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life threats. Moreover, there are legal limitations for running these tests on real freeways and streets. An appropriate solution to evaluate ideas and research activities is to use a simulation environment to conduct an unlimited number of tests with no risk and legal limitations and very low cost. To demonstrate the effectiveness of the algorithm two different simulation studies in two different conditions are performed. In both simulations freeways' number of lanes were n=3.

4.1. Programming

The simulation program developed in the Matlab 2018 environment. Figure (4) Proposes the general flowchart of the program for trajectory planning, which include the following steps

Input : (V_D) Desired Velocity for the AV

Input : ($v_{i_{Min}}$ and $v_{i_{Max}}$) Speed limits of lanes {i=1,2, or 3 lane number - right to left}

Function (Select DL): This function selects the default lane based on the V_D and speed limits of lanes

Generate traffic of the vehicles around AV: At the start of the program (t=0), program generate random traffic for adjacent vehicles to simulate the traffic of nearby vehicles.

$$v_{i_{Min}} \leq v_* \leq v_{i_{Max}}$$
$$0.5X_{Crit} \leq X_* \leq 1.5X_{Crit} \qquad (8)$$

The distance and speed of the all adjacent vehicles (denoted by subscript *) are generated randomly, in terms of allowable speed limits of lanes and distances between $0.5X_{crit}$ to $1.5X_{crit}$ from AV.

Check: At each time step, check the forward or rear adjacent vehicles distance from AV, and remove the vehicle from the road if its distance is more than 200 m from AV. Then, based on the Eqn. (10) generate a new vehicle closer to AV instead of removed vehicle with random distance and velocity.

For every time increment the following pseudo code represents the sequence of algorithm execution until the simulation stop time is reached (T_f)

```
While t < Tf Do
    If      Xf ≥ Xcrit & VAV < Vf
        If      VAV = VD
        Free Flow
        Else
        Accelerate until VAV = VD
        End
    Elseif Xf ≤ Xcrit & VAV < Vf
     Free Flow (Car Following with Current Speed)
    Elseif Xf ≥ Xcrit & VAV ≥ Vf
        If      D ≥ Dsafe
        Change lane to the left lane and overtake if it is possible
        Else
        Speed adaption (Decelerate until VAV = Vf and Xf = Xcrit)
        End
    Elseif    Xf < Xcrit & VAV > Vf
        If D>Dsafe
        Change lane to the left lane and overtake if it is possible
        Else
        Distance Adaption (Decelerate until VAV = Vf and Xf = Xcrit)
        End
    End
End
```

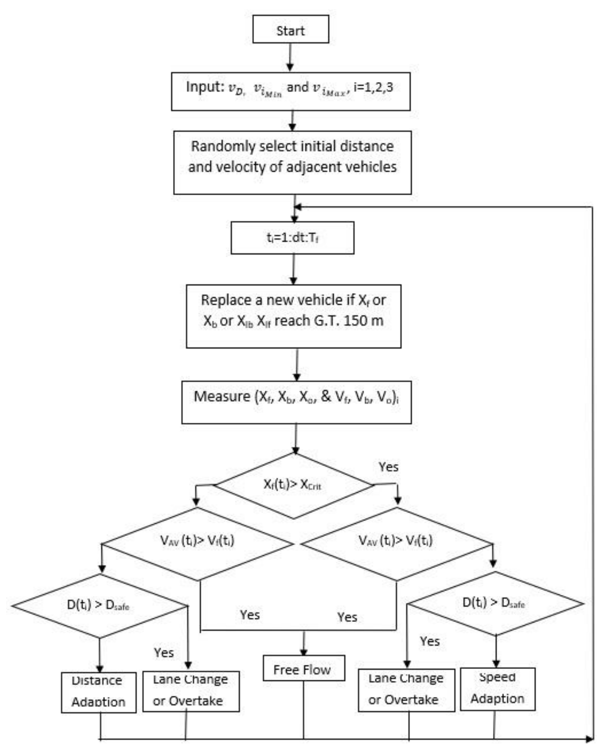

Figure 4: General simulation flowchart for the trajectory planning

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At each time step of simulation, subject to the vehicle's status (free-flow, car following (distance or speed adaption), or overtaking), an appropriate acceleration/deceleration is planned for the corresponding driving condition. Also, at every time step, conditions are checked as whether switching from a driving condition to another condition is required.

Therefore, considering speed limits of each lane in Table 1, the right lane (1) is selected as default lane for the AV. At every time program generates two vehicles one at rear and other in front of the AV at the default lane, and two other vehicles in its left lane (in this case mid lane). The distance and speed of all adjacent vehicles are generated randomly, in terms of allowable speed limits of lanes and distances. The AV overtakes the slower front vehicle, according to

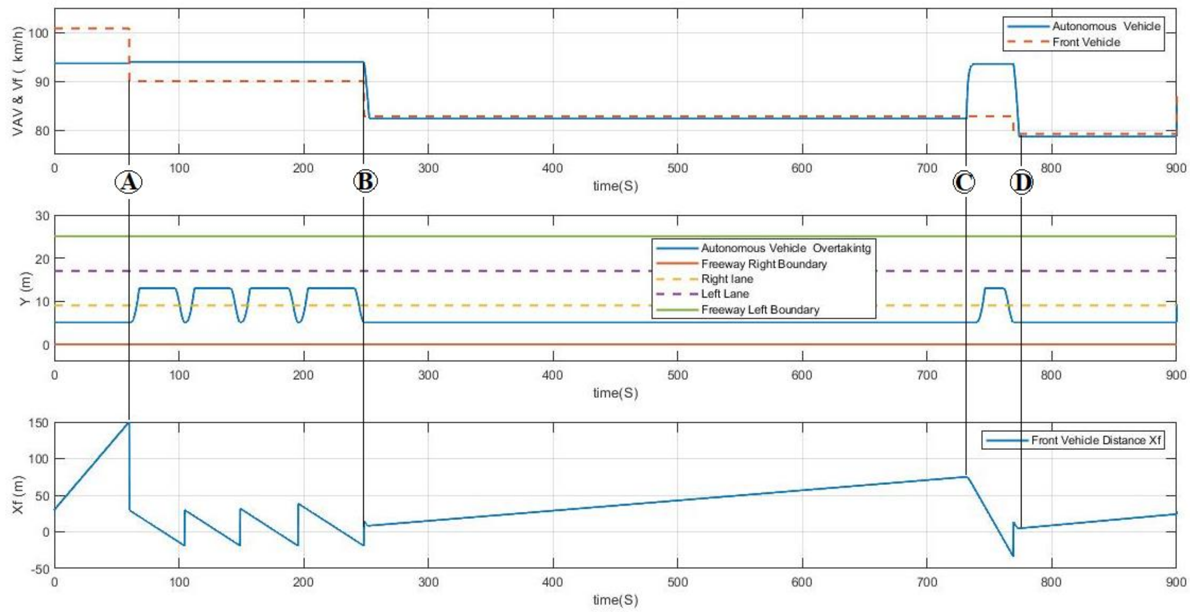

Figure 5: Simulation 1: Above) AVs and different front vehicles velocity, Middle) Lane change and overtaking of the AV, and Bellow) Relative distances between the AV and overtaken vehicles.

safety consideration for possible collision with the vehicles traveling in its left lane. In the other case it adapts its speed with the vehicle ahead, until finds a suitable time to overtake. In the other situations AV may travels with its desired speed or decelerate/accelerate to adjust its distance and speed with the front vehicle. In this simulation, adjacent vehicles are moving with different speeds and are able to change their lane. The program omits a vehicle, when its distance reaches to 150 m with AV and generates a new vehicle instead with distances between $0.5X_{crit}$ to $1.5X_{crit}$ from AV.

For every lane speed limits and their centerline (Y_c) are represented in Table 1 and depicted in Figure 1. Also, the total width of the freeway is 26 m.

Table 1: The lanes speed limits in the freeway with 3 lanes

Lane (No.)	v_{min} (km/h)	v_{max} (km/h)	Yc(m)
Right (1)	80	100	5
Mid (2)	100	120	13
Left (3)	115	130	21

4.2. First Simulation

For the first simulation case, desired speed of the AV is selected as 93.6 km/h (26 m/s).

The results of simulation are shown in Figure 5 and Table 2. For the simplicity, and better presentations of simulation results, only the trajectories of the AV and its front vehicle

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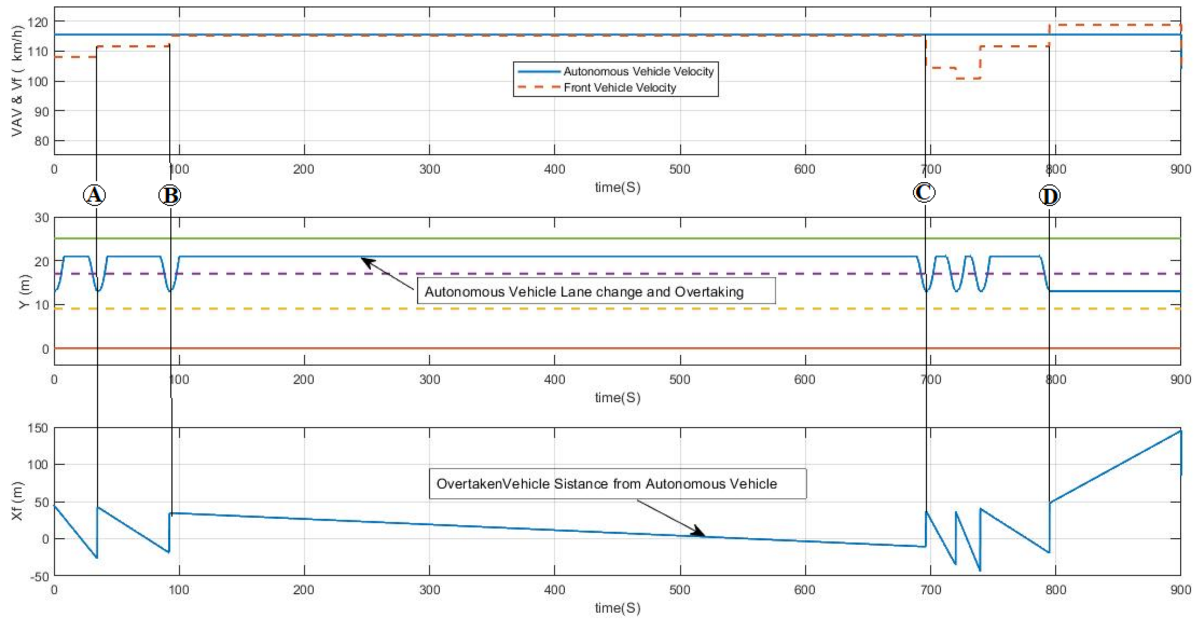

Figure 6: Simulation 2: Above) AVs and different front vehicles velocity, Middle) Lane change and overtaking of the AV, and Bellow) Relative distances between the AV and overtaken vehicles.

Table 2: AV's 3-lane freeway driving simulation results (15 minute period)

Simulation No	Number of Lanes	Default Lane	Desired Speed (km/h)	Average Speed (km/h)	Distance Traveled (km)	Speed Adaption	Successful lane changes	Distance Adaption	Free Flow
First	3	Right (1)	93.6	88.2	22.05	2	5	1	1
Second	3	Middle (2)	115.2	115.2	28.8	1	5	0	1

are presented in Figure 5. At time t=0 s, program selects front vehicles' initial distance from the AV as X_f =30.6 m, and V_f=100.8 km/h (28 m/s) that is higher than AVs default velocity (DV), 93.6 km/h (26 m/s). Therefore, AV moves freely, with its DV, until front vehicle distance from AV increases to 150 m (Section A), at t=60.6 s. Then, program selects randomly new front vehicles with velocity, V_f =100.8 km/h (25 m/s), and initial distance X_f =29.8 m. Therefore, AV overtakes 4 times from vehicles ahead with the same velocities from section A until reaching to the section B at time t= 253 s, and each time it returns back to its default lane at a distance between 18 to 19 m from overtaken vehicle (minus values for the Xf). In section B, a new front vehicle is generated with velocity 82.8 km/h (23 m/s), and distance X_f =14.8 m. Due to the high traffic in the left lane, overtaking is not possible, therefore AV decelerates until its speeds reaches to 82.8 km/h that is 0.5 km/s lower than V_f. In this condition, their distance X_f increases gradually until it reaches to 75 m, at t= 741 s, in the section C. At

section C, the left lane is free to overtake, and AV increases its speed to its default velocity 93.6 km/s, and overtakes from its front vehicle and returns back to its default lane at t=775 s, in section D. Finally, in section D, it is faced with a front vehicle with V_f =79.2 km/h (22 m/s) at the distance 14.2 m ahead, and adapts its speed and

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distance with it and simulation completed at t=900 s. The mean speed of the AV during the driving cycle is 88.2 km/h (24.5 m/s) which is close to the AVs default velocity, DV=93.6 km/h.

4.3. Second Simulation

In the second simulation case, the desired speed of the AV is selected higher than the first simulation, equal to 115.3 km/h (32 m/s). Therefore, AV has to move in the middle lane, except when it has to overtake its front vehicle, which should go to its left lane (lane 3). Similar to the first case, distance and speed of adjacent vehicles are generated randomly.

The results of simulation are shown in Figure 6 and Table 2. At the starting point, program selects front vehicles' initial distance from the AV as X_f =44.0 m, and V_f =108.0 km/h (30 m/s) which is slower than AV. Hence, AV checks the left lane for available gap to overtake, and after ensuring that there is no risk of collision it overtakes from vehicle ahead. After, completing the first overtake, at section A, the AV finds another vehicle ahead with X_f = 34.6 m and V_f =104.6 km/h (29 m/s). Again, it performs the second overtake, by checking the safety precautions, and completes it at time t=116 s (Section B). Then, it changes its lane to the left lane to complete its third overtake. But, because it cannot find enough space to return to its desired lane and follows a vehicle in the left lane which has same speed with its desired speed, until reaching to the point C, at t= 696 s. At point C, the AV return backs to its default lane and overtakes three different vehicles ahead with speeds slower than its desired velocity. The AV completes the third overtake at t = 796 s (point D). After, the program generates a vehicle ahead with speed V_f = 118.8 km/h (33 m/s), which is higher than AVs desires velocity. Therefore, the AV follows it freely, until simulation is finished at t = 900 s.

5. Conclusion

The problem of motion planning for AVs in a dual carriageway is studied. This is a problem that has been relatively un-touched in the literature. Unlike the previous works where only one particular type of trajectory planning is studied, in this work a general structure for trajectory planning of an Intelligent vehicle for a long-term freeway driving was developed. Different models employed to support trajectory planning for the most essential maneuvers including, distance adaption, speed adaption, lane changing, overtaking and free flow driving. The algorithm for the maneuver classification and decision making for the AVs motion planning is presented. By simulation studies performance and accuracy of the proposed algorithm were examined, which shows the Intelligent vehicle is easily able to adapt to different freeway traffic conditions and follow its own desired motion.

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