2021 IEEE Intelligent Transportation Systems Conference (ITSC)
Indianapolis, USA. September 19-21, 2021

Safe Overtaking Maneuver for Autonomous Vehicle under Risky Situations based on Adaptive Velocity Profile

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***Abstract*— An overtaking is among the main risky maneuvers for Autonomous Vehicles (AVs) in highway, due to the uncertainties of the dynamic surrounding vehicles. This paper proposes a new approach named Distance Awareness for Adaptative Velocity Profile (DA-AVP) to ensure the safety of an engaged maneuver. This strategy is based on the authors' previous work [1] and takes into account the actual actuation capacity of the Ego vehicle and the new dynamic of the surrounding vehicles. This solution consists in applying an acceleration profile on the pre-planned path to always maintain a safety margin with others vehicles, even with those showing dangerous behaviors. Several simulations show the efficiency of the proposed strategy.**

I. INTRODUCTION

The automation of an overtaking is an important challenge in the development of autonomous vehicles due to uncertainties on estimations of the behavioral risk of the surrounding road users. An overtaking or an avoidance must be performed according to the object which has to be avoided [2], where the path is adapted cognitively if the obstacle is static or very slightly dynamic, or adapted reactively if the obstacle is highly dynamic. According to [3] a maneuver is considered successful when this three sub-maneuvers are complete: lane change to overtaking lane, pass lead vehicle(s) and lane change back to original lane. In [4], [5] and [6], an approach is proposed by defining the path based on clothoids to perform an overtaking around a dynamic obstacle. If the dynamic of this obstacle changes, and is susceptible to cross dangerously the Ego's trajectory (which represents AV's trajectory), there are two solutions. First one, the Ego has to compute a new smooth and flexible trajectory with a continuous curvature path by limiting variations in steering speeds. The second consists, particularly in [7], in keeping the same trajectory but adapting the speed to avoid the collision. In the literature, the Time To Collision (TTC) which is the ratio of relative distance to relative speed between two vehicles is extensively used as a metric to assess lane change associated risks [8]. On the other hand, this metric has its limits like described in [9]. The authors say that TTC alone is insufficient to make a decision. In cases where the Ego vehicle and the Obstacle are side by side on two lanes with a very small relative speed, TTC is unusable. An additional risk metric for the risk assessment is needed and introduced by the minimal safety margin to evaluate the distance between two vehicles and to take an appropriate decision. Others metrics are also used like the Time Exposed Time-to-collision (TET) or the Time Integrated Time-to-collision (TIT) for the risk assessment [10], [11]. According to [8], the authors evaluate the risk on the capacity, of the rear vehicle on the left lane, to decelerate during the Ego lane change at a constant speed. This approach introduces the nuance between a safe and polite lane change and a safe but impolite lane change where in the two situations the Ego lane change imposes a greater or lesser deceleration to the obstacle. During an overtaking, on two lanes with two directions, and when a speed profile is applied, evaluating the power reserve to manage a possible dynamic change from an obstacle, is a critical task [12]. The authors discussed a method by rationalizing the distribution of the speed during the overtaking. In [13], another approach considering the gap acceptance is proposed to evaluate the lane change decision. The longitudinal gap between two obstacles on the targeted lane has to be considered to estimate if the lane change can be performed. That way, the lane change duration is also tackled. Another approach as shown in [14] uses a Model Predictive Control to determine the appropriate throttle, brake and steering angle actuators for a car which provide a safety overtaking maneuver.

In this paper, the case of an overtaking on a two lanes highway is treated considering the Ego's capacities to maintain a safety distance based on TTC during the first sub-maneuver. The new Distance Awareness for Adaptive Velocity Profile (DA-AVP) approach consider the Ego's capacities to create its own gap and maintain it with the obstacle, the aim is to ensure the overtaking feasibility (in the case where a solution exists obviously). This paper is structured as following. Section II presents the main technical prerequisites adapted to the proposed paper. Section III formalizes the proposed strategy on the overtaking feasibility. The simulation results will be presented in Section IV and this paper concludes with perspectives on future work.

II. TECHNICAL PREREQUISITES RELATED TO PREVIOUS WORK

The proposed strategy for safe overtaking is based in part on Risk Assessment (RA) metric developed in previous works. The aim of the proposed work is to enhance this RA metric and use it to propose an appropriate strategy for Risk Management (RM) in order to guarantee the AV safety, while taking into account the dynamical change of

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the surrounding vehicles. The following subsections (II.A-C) introduce the main components, already proposed in [15] and [1], in order to understand better the main paper's propositions (cf. Section III).

A. Automatic lane change

Automatic lane change is based on the generation of an Elliptic Limit-Cycle (ELC) trajectory which is defined according to an elliptic periodic orbit corresponding to an ellipse of influence [2], [17], [18]. This ellipse of influence is generated around the obstacle vehicle (cf. Fig. 1) and allows the Ego vehicle to overtake [1], it is defined according to a set of differential equations:

$$\begin{cases} \dot{x_s} &= my_s + \mu x_s(1 - x_s/a_{lc}^2 - y_s^2/b_{lc}^2 + cx_s y_s) \\ \dot{y_s} &= -mx_s + \mu y_s(1 - x_s/a_{lc}^2 - y_s^2/b_{lc}^2 + cx_s y_s) \end{cases} \quad (1)$$

with $m = \pm 1$ according to the direction of avoidance (clockwise or counterclockwise). (x_s, y_s) corresponds to the position of the obstacle vehicle according to the center of the ellipse, a_{lc} and b_{lc} characterize the major and minor elliptic semi-axes respectively. c gives the orientation of the ellipse which is also the obstacle's orientation and μ a positive constant that enable us to modulate the convergence of the ELC trajectory toward the ellipse of influence.

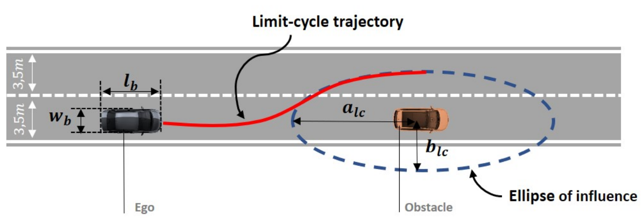


Fig. 1. Ego vehicle, in black, is overtaking the orange obstacle vehicle using the elliptic limit-cycle trajectory.

This ellipse of influence is not fixed and can evolve according to a_{lc} and b_{lc} parameters:

$$\begin{cases} a_{lc} &= l_b/2 + t_s v_r \\ b_{lc} &= w_b + L_{Distance} \end{cases} \quad (2)$$

with l_b the wheelbase of the vehicle, w_b the vehicle track and v_r the relative velocity between the Ego vehicle and the obstacle vehicle. t_s is a safe temporal distance and $L_{Distance}$ represents a minimum lateral safety distance.

B. Dynamic Predicted Inter-Distance Profile (D-PIDP)

Inter-distance profile is the main RA metric and represents the evolution of distance between the Ego and the considered Obstacle. At the initial conditions, if the initial configuration (expected trajectories and speed of each of the considered vehicles) remains unchanged, it is possible to predict the evolution of the inter-distance through a control horizon t_{ch} and define the Upper and Lower Safety Boundary limits (USB and LSB). Moreover, these limits, especially LSB, must not be crossed. An USB crossing means that the obstacle's distance is further away than the prediction expects and there are no more risks of collision. An LSB crossing means that the Obstacle vehicle is closer than the prediction expects and that the dynamic of this obstacle has changed. A critical time, $t_{critical}$ is then observed to determinate the dangerousness degree of this change and to consequently apply an emergency maneuver (cf. Fig. 2) [15].

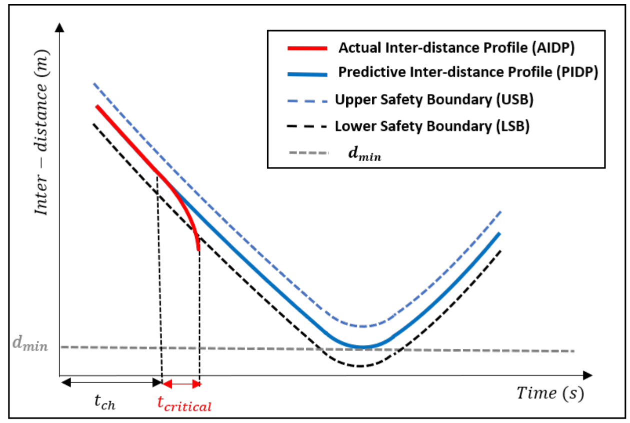


Fig. 2. Crossing between actual inter-distance profile and the lower safety boundary.

C. Time To Collision

Time To Collision (TTC) is the first metric used to make the decision to overtake. It is the time before the collision appears if both vehicles, Ego and Obstacle, keep the same dynamic. TTC allows the adaptation of the distance considering the speed in one computation. The employed TTC formulation is:

$$TTC = \frac{\sqrt{(x_{Ego} - x_{Obs})^2 + (y_{Ego} - y_{Obs})^2}}{|v_{Ego} - v_{Obs}| + \xi} \quad (3)$$

with (x_{Ego}, y_{Ego}) the Ego's position, (x_{Obs}, y_{Obs}) the Obstacle's position, v_{Ego} and v_{Obs} are respectively the Ego's speed and the Obstacle's speed and ξ is non significative constant to avoid the division by 0 when the relative speed is 0.

III. Distance Awareness for Adaptive Velocity Profile (DA-AVP) based on D-PIDP

The aim of this paper is to assess and manage the risk of collision with the surrounding obstacles (mainly the one coming from behind) during the overtaking maneuver, and this while taking into account the new dynamic of the surrounding obstacles and the actual actuation capacity of the Ego-Vehicle (its maximum velocity and acceleration). This is done by using a new metric proposed which is the Distance Awareness for Adaptive Velocity Profile (DA-AVP) based on D-PIDP and including a safety margin while achieving the maneuver.

A. Main assumptions and proposed approach

Once the overtaking decision is taken, i.e., conditions (position and obstacles' dynamics) are favorable to the decision making of an avoidance/overtaking, it is necessary

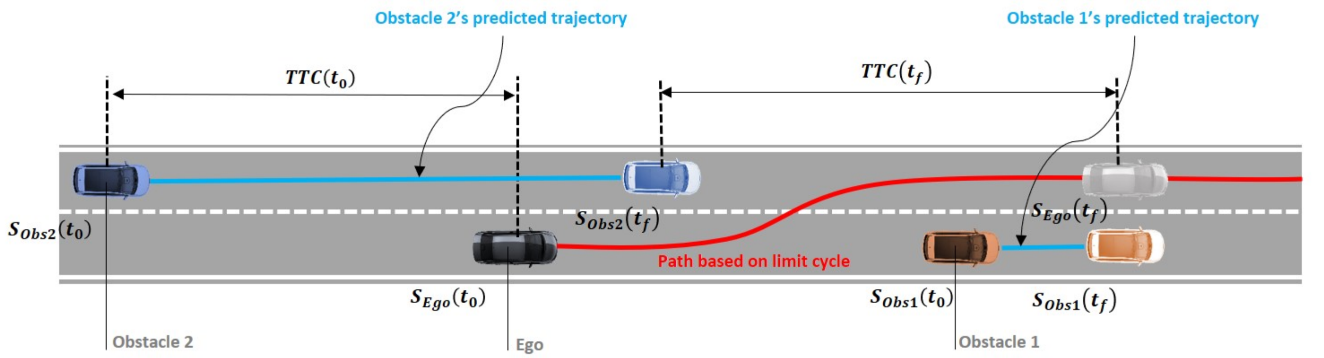


Fig. 3. Scenario used with the positioning of vehicles from t_0 which is the time of avoidance decision-making to t_f which is the end of maneuver time.

to know the feasibility to ensure the safety of this decision by using D-PIDP. The change of the obstacle dynamic can be detected with this metric when the acceleration or deceleration of the obstacle is sufficient to cross the Lower Safety Boundary (LSB). An emergency maneuver is then required with an adapted decision to this situation [16], [19]. But in cases where the acceleration is not sufficient to involve a crossing with LSB threshold during the observed control horizon, the new prediction of the inter-distance is computed without alarming the Ego vehicle that there is a potential collision if the obstacle keep this dynamic during the overtaking maneuver time. In other words, it exists a range of accelerations values untreated that can endanger the Ego vehicle. For the overtaken vehicle (which is Obstacle 1 in Fig. 3), the speed variation is managed by adapting the path based on limit cycle. If this obstacle decelerates, the path is recomputed considering this new dynamic. If the obstacle accelerates, the path is also recomputed but the speed of the Ego vehicle is not adapted and the maneuver can be very long. These two situations are not treated here because there is no situation identified where this obstacle enter in the dangerous zone, under the permitted TTC without Ego vehicle adaptation. A strong deceleration is already well managed by the algorithm in place [15]. However, what can be dangerous and can involve a collision or a non-compliance with safety distances, is the possible rear obstacle vehicle (is given in Fig. 3, with Obstacle 2) at the overtaking decision-making time. D-PIDP allows the detection of a significative dynamic change from this obstacle. The DA-AVP method exposed in this paper proposes to react at less significative changes that represent all accelerations from Obstacle 2 which do not involve an LSB crossing. The path is always adapted to the overtaken vehicle but the speed profile is adapted considering the dynamic of the rear obstacle to prevent a collision or in front of the obstacle by maintaining a safety distance. To focus on this part, let us consider the following assumptions according to Fig. 3:

- The roadway is assumed to be straight and contains two lanes.
- The obstacles trajectories are straight and follow the center of the lane.
- The overtaken obstacle keeps the same speed during all the maneuver and its speed is significantly lower than the Ego vehicle.
- The dynamic change of rear obstacle appears when the overtaking decision is made and this acceleration is an uniformly accelerated rectilinear motion (u.a.r.m).

Maintaining a safety distance with the Obstacle 2 can be performed through a speed profile but the overtaking has to consider some limits that allow us to identify if the maneuver can be safe or no longer possible.

B. Application limits

An overtaking, in the case of this scenario, is considered safe if Ego vehicle can maintain a defined TTC with the Obstacle 2 on Fig. 3. To estimate TTC between Ego and Obstacle 2, if both vehicles are on the same lane, TTC is directly computed, else, if both vehicles are not on the same lane, a projection on the targeted lane of the Ego vehicle is made to compute TTC. It allows the consideration of a more restrictive TTC between vehicles. Initially, the taken decision is based on D-PIDP. If Obstacle 2 does not change its dynamic, the overtaking can be performed safely. If the dynamic of Obstacle 2 changes after the decision-making at t_{event}, it is necessary to certify if the defined TTC will be respected during all the maneuver. First step is to determine the maneuver's time with the actual Ego's speed. The end of the maneuver at t_f, is considered when the position of the Ego vehicle on x axes is positive in the overtaken obstacle's system (when the Ego vehicle is at the end of the Limit-cycle trajectory as shown in Fig. 1). Knowing the maneuver time, it is possible to estimate the position of Obstacle 2 during the maneuver time and its finale position at time t_f and to compute the evolution of TTC during the maneuver (if all dynamics are kept). We are in the case where LSB is not crossed by the Actual Inter-Distance Profile as described in the organizational chart (cf. Fig. 4):

1) First constraint: When all the trajectories of the surrounding obstacles are predicted, the minimal maneuver time t_{fmin} can be determined by applying the maximum acceleration that Ego can provide during the maneuver. Here is the first constraint applied on the Ego's acceleration. If the Ego vehicle can not perform the overtaking by maintaining

TTC with this maximum acceleration, the overtaking is no longer possible.

2) Second constraint: A second constraint is necessary to respect the maximum speed imposed by the highway code. This one can not be transgressed. The acceleration limit is then lowered while considering the initial speed and speed limit and the actual possible t_{fmin} is computed with regards to these constraints. TTC's evolution is then anticipated through speed profile for both vehicles along limit cycle for the Ego vehicle and the straight line for Obstacle 2 between actual time t_i to final maneuver time t_f and allow to know if TTC can be respected with the maximum capacity of the Ego vehicle.

3) Uncertainty on Obstacle 2's acceleration: Another point that must be taken into consideration, is the uncertainty on the Obstacle 2's acceleration. This denotes an additional constraint on the overtaking feasibility by adding an uncertainty on the Obstacle 2's acceleration perception ($\pm Constant\%$ of the acceleration). The most restrictive acceleration, which represents the highest, is then considered to determinate the overtaking feasibility.

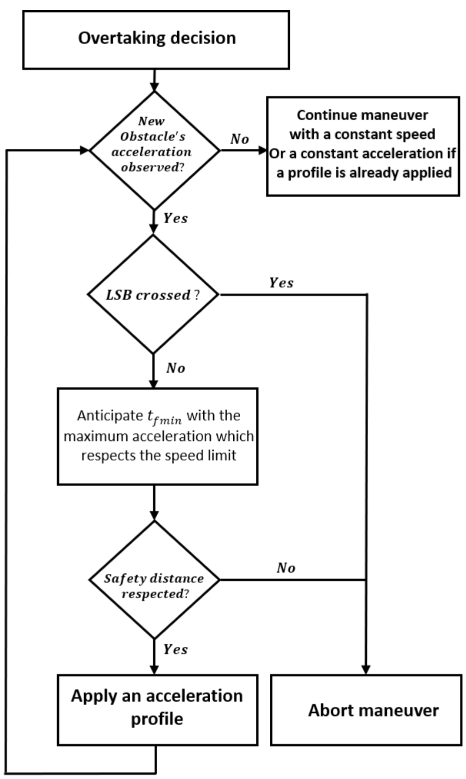


Fig. 4. Organizational chart which represents the method to define the overtaking feasibility.

In cases where these constraints can not be respected, the maneuver is aborted as done in [15]. This approach allows to be more robust in terms of safety insurance, since the Ego vehicle will induces from the beginning a certain safety margin including the perception uncertainties and the possible small modifications in the Obstacle dynamic.

C. Distance Awareness for Adaptive Velocity Profile (DA-AVP)

DA-AVP method brings new insights by adding the TTC information in the inter-distance profile metric. The extreme limit that can not be transgressed during the overtaking maneuver, in previous works [15], [1], is d_{min} (cf. Fig. 2). This limit represents the minimal distance according to the minimal inter-distance in the previous works [16]. While not taking into account the prediction of the Ego vehicle poses, from $S_{Ego}(t_i)$ to $S_{Ego}(t_f)$, which can be determined by computing the curvilinear distance of the overall trajectory according to the solutions of the ELC trajectories differential equation defined in equation (1). Knowing the travel time of the Ego vehicle to accomplish the maneuver, the predicted trajectories of both obstacles and their final positions $S_{Obs1}(t_f)$ and $S_{Obs2}(t_f)$ can be computed according to the assumptions (given in Section III-A). The evolution of the predicted relative speed between Obstacle 2 and Ego vehicle is also known (here it is assumed that the uncertainty on the Obstacle 2's acceleration is applied as described in the previous subsection III-B). The extreme limit can be translated, including TTC, by the following equation:

$$d^i_{safe} = d_{min} + TTC * v^i_r \quad (4)$$

with: TTC the desired time to collision, v^i_r the relative speed between Obstacle 2 and Ego at each time step between t_i and t_f. d_{min}, is the initial extreme limit to manage small relative speeds. In this way, d_{safe} is an indicator that represents the predicted inter-distance needed to respect the TTC during the maneuver if all dynamics are kept by the concerned vehicles.

1) Overtaking decision-making at $t_i = t_0$: According to [14], an overtaking decision is taken when TTC is greater than a defined threshold for all surroundings vehicles. When this condition is favorable to perform an avoidance, Ego vehicle can overtake with a constant speed along the pre-planned trajectory (cf. Fig. 3). This is true as long as obstacles do not change their dynamics.

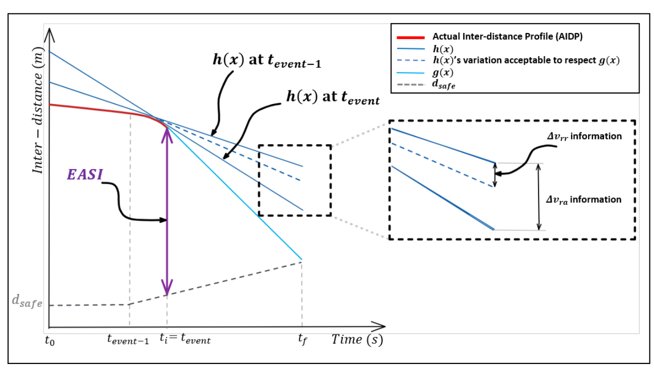


Fig. 5. This figure represents the first situation where $v_r^{i=event} > v_g^{i=event}$ with Δv_{ra} the relative speed variation in one step time without Ego's compensation and Δv_{rr}, the relative speed variation needed at each time step to respect $g(x)$.

2) Needed elements to determinate the overtaking feasibility: When a dynamic change of Obstacle 2 is observed with a constant acceleration, some elements are required to determine if the current configuration involve a non compliance with the defined safety distance (4) :

- $h(x) = v_r^i.x + b$ with $h(x)$ the tangent at the current inter-distance profile (cf. Fig. 5), x the inter-distance and $\dot{h}(x) = v_r^i$ the instantaneous relative speed between both vehicles.
- $g(x) = v_g^i x + b$ with $g(x)$ a straight line passing through the actual inter-distance and d_{safe}^f with $\dot{g}(x) = v_g^i$ the minimum instantaneous relative speed needed to respect d_{safe}^f and x the inter-distance (cf. Fig. 5).

At this time, two situations can appear consequently to the acceleration of Obstacle 2 (cf. Fig. 6). If $v_r^{i=event} > v_g^{i=event}$, it means that the instantaneous relative speed between $t_{event-1}$ and t_{event} is not sufficient to involve a crossing between $h(x)$ and d_{safe} before t_f. However, the relative speed evolved with time and it is necessary to verify if this relative speed evolution does not involve a crossing verifying $v_r^f > v_g^i$. If $v_r^{i=event} < v_g^{i=event}$, it means that the instantaneous relative speed due to the Obstacle 2's acceleration is sufficient to involve a crossing between $h(x)$ and d_{safe} before t_f. If the Ego vehicle keep its dynamic, the chosen TTC will not be respected during the overtaking maneuver.

3) Acceleration determination case 1: For the first situation, where $v_r^{i=event} > v_g^{i=event}$ is true, to know if the safe temporal distance is respected, it is needed to determined v_r^f, which represents the instantaneous relative speed at t_f if both vehicles' dynamics are kept. Obstacle 2's acceleration, with Ego vehicle's constant speed at t_{event}, involve a constant relative speed evolution Δv_{ra} at each time step. We are able to find the final relative speed:

$$v_r^f = v_r^i + \Delta v_{ra} * n \tag{5}$$

with v_r^i the instantaneous relative speed at present time t_i and n, the number of time step between t_i and t_f. If there is no crossing between the predicted $h(x)$ and d_{safe}, it means that the TTC will be respected and the Ego vehicle can perfom the overtaking at its initial constant speed. Otherwise, a new relative speed evolution Δv_{rr}, that repect $v_r^f \geq v_g^i$, need to be computed:

$$\Delta v_{rr} = \frac{v_g^i - v_r^i}{n} \tag{6}$$

The difference of Δv_r, defined previously, represents the Ego vehicle's effort to maintain TTC during the maneuver. This compensation of relative speed, v_{rc}^i, can be translated in acceleration that the Ego vehicle must provide between t_i and t_f:

$$a_{ego}^i = \frac{v_{rc}^i}{t_f - t_i} \tag{7}$$

4) Acceleration determination case 2: In the other situation, where $v_r^{i=event} \leq v_g^{i=event}$, the minimal safety distance d_{safe} will not be respected if dynamics of both vehicles are kept. It is also known that the gap can be compensated with the maximum Ego's acceleration which respects the maximum authorized speed. In that case, the $v_r^f \geq v_g^i$ must be respected. The same principle is used as for the first situation but Δv_{rr} is added to the relative speed evolution, Δv_{ra} to compensate the gap plus the evolution of the relative speed.

5) Safety distance convergence: As shown previously, the acceleration is computed at each time step to respect the current d_{safe} between t_i and t_f. The relative speed which respects instantaneously $v_r^f \geq v_g^i$ is described in the following equation and according to Fig. 5:

$$a_{ego}^i = \frac{v_{rc}^i}{t} \tag{8}$$

with t represents one time step. But during this time step, the acceleration applied has the effect to reduce the maneuver time t_f and to lower the minimal safety distance based on TTC, d_{safe}, due to the relative speed reduction. To have a smooth acceleration this relative speed is compensated during t_i and t_f (7). A loopback is then needed to verify if this new Ego's dynamic allows to say if d_{safe} is still respected and add, if necessary, the new computed acceleration to the precedent one to not lose the relative speed already compensated. The acceleration added each time step is then more and more lesser than the precedent until the prediction of the relative speed involves $v_r^f \geq v_g^i$. This loopback is also needed in order to observe a new dynamic change from Obstacle 2 but only the case of an u.a.r.m is treated in this paper. The deduced acceleration, which must be provided at each time step, allows to converge locally the inter-distance towards the current minimal safety distance. The loopback allows to stay above the minimal safety distance in the entire overtaking.

IV. Simulation results

The simulation results have been performed on Matlab/Simulink. A two lanes highway has been created to focus on the overtaking maneuver with two obstacles vehicles as shown in Fig. 3. The adaptative cruise control of the Obstacle 2 has been disabled to highlight the proposed strategy. This strategy is not based on the Obstacle 2's deceleration during the insertion but on the Ego's capacity to do this insertion by maintaining TTC (See Simulation Video: https://www.youtube.com/watch?v=ouVE6Z5r-7A). To better show the efficiency of this approach, lets expose one scenario with the original algorithm proposed in the previous works (called nominal experimentation) and the same scenario with the algorithm proposed in this paper where both are compared. In both cases, the initial speed of the Ego vehicle is $30m/s$, Obstacle 1's speed is $18m/s$ and Obstacle 2's speed is $31m/s$. The Obstacle 2 will accelerate $0.4s$ after the decision-making of the overtaking with $1.5m/s^2$ $\pm 10\%$ (where $\pm 10\%$ represents a safety margin if an uncertainty

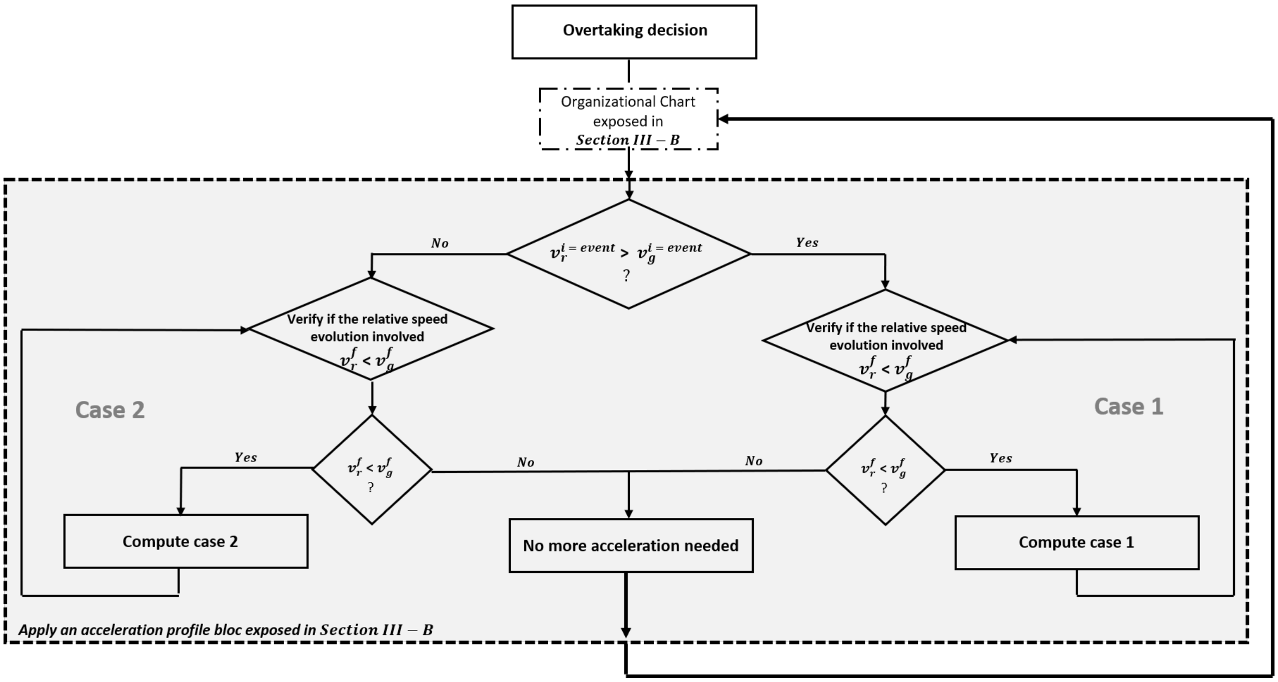


Fig. 6. Organizational chart which represents the acceleration strategy.

acceleration is taken into account). The time step used in these simulations is $0.05s$.

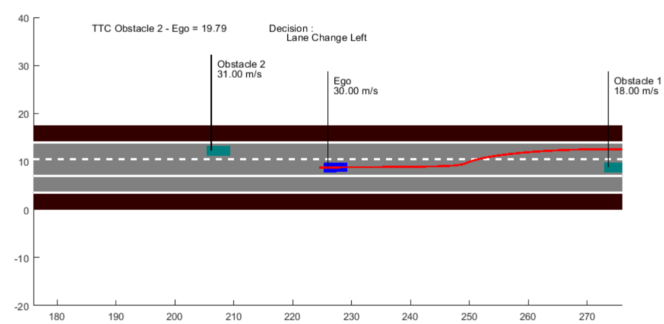
As shown in Fig. 7, at this moment of the scenario, the Obstacle 2 did not accelerate yet. The prediction of tangent at the actual inter-distance profile $h(x)$ will not cross d_{safe} and the Ego vehicle can do the overtaking at a constant speed safely.

A. Nominal experimentation

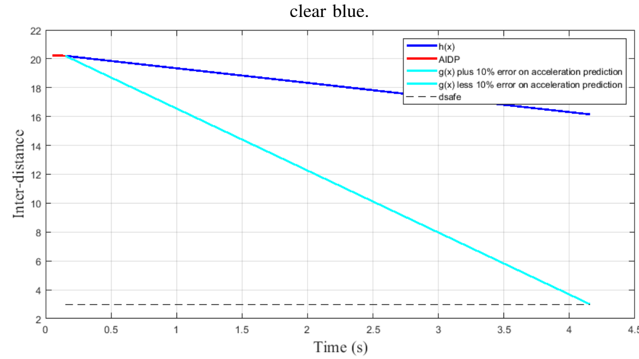
At this moment of the scenario (cf. Fig. 8), the Obstacle 2 has accelerated and $h(x)$ clearly cross d_{safe}. It means that the minimal temporal distance will not be respected during the overtaking. This overtaking can not be performed safely at a constant speed.

B. Simulation results with the proposed algorithm

The same scenario with the proposed algorithm applied (cf. Fig. 9). The TTC which must be respected to consider a safe overtaking is $2s$, and we consider that the maximum Ego's acceleration at this speed is $3m/s^2$. Here, the minimal safety distance is respected due to the Ego's acceleration. When the Obstacle 2 accelerates, Ego reacts by anticipation with a smooth acceleration as shown in Fig. 10. When it is certain that $h(x)$ evolution will not cross d_{safe}, the Ego vehicle keeps the last acceleration until the end of the maneuver. It is implied that the obstacle vehicle has to decelerate and not accelerate indefinitely. The proposed algorithm assures minimal safety distance during the overtaking by applying an acceleration but, when the overtaking is considered finished, the Ego vehicle stops its acceleration and keeps a constant speed. The relative speed reduction during the maneuver allows the Obstacle vehicle to decelerate less than if the Ego had not reduced the relative speed. According to [8],

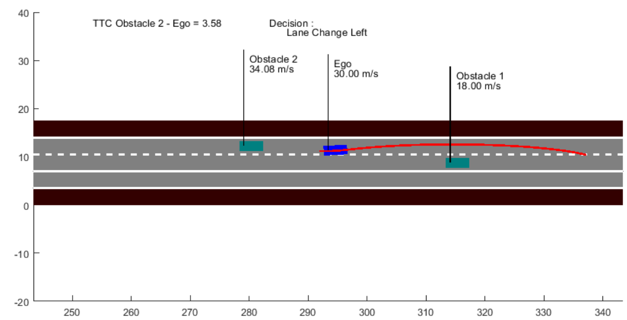


(a) Scenario's view on Matlab with the Ego vehicle in dark blue and 2 obstacles in clear blue.

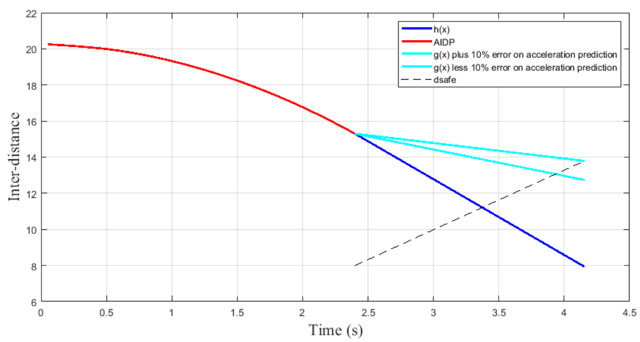


(b) Inter-distance profile with d_{safe} that must be respected

Fig. 7. Initial scenario at the moment where the overtaking decision is taken

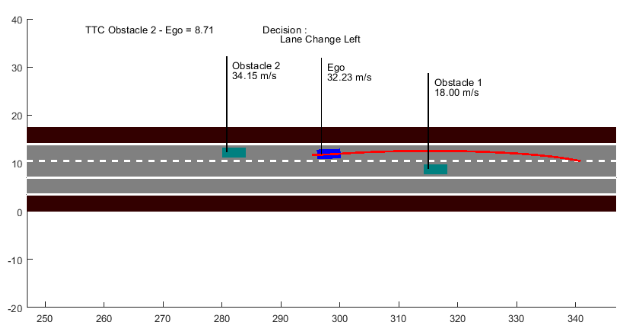


(a) Scenario's view on Matlab where Obstacle 2 has accelerated

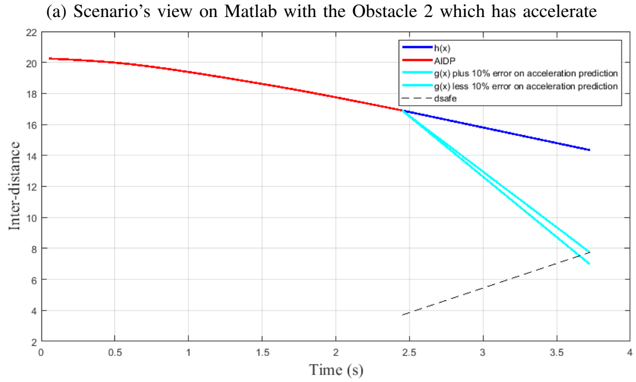


(b) Inter-distance profile with h(x) which is crossing d_{safe}

Fig. 8. Scenario during the overtaking with Ego at constant speed.



(a) Scenario's view on Matlab with the Obstacle 2 which has accelerate



(b) Inter-distance profile with h(x) that respect d_{safe}

Fig. 9. Scenario during the overtaking with the proposed algorithm.

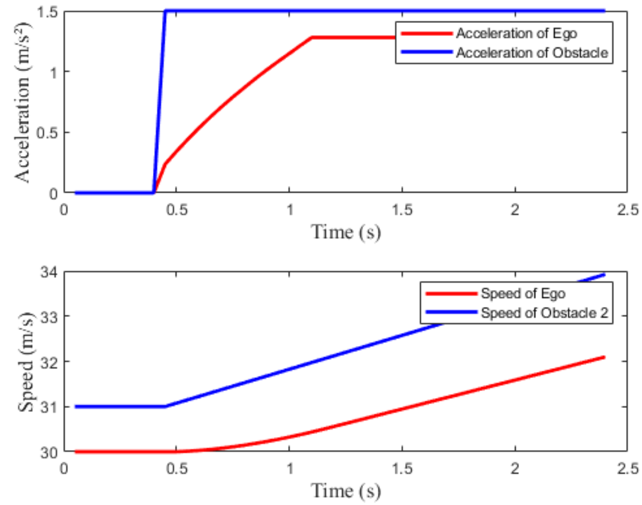


Fig. 10. Acceleration and speed of the Ego and Obstacle vehicles during the maneuver.

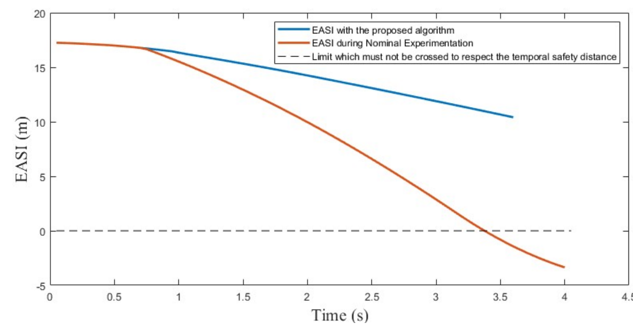


Fig. 11. Evolution of the Adapted Safety Inter-distance during the scenario with the algorithm proposed in previous works and with the proposed algorithm.

this overtaking can be considered as safe and polite. The Evolution of the Adapted Safety Inter-distance (EASI) shows the efficiency of this approach and it is defined as follow:

$$EASI(t) = AIDP^i(t) - d^i_{safe}(t) \tag{9}$$

with $AIDP$ the current inter-distance and d^i_{safe} the current safety distance (cf. Fig. 5). In Fig. 11 there is two cases presented. The scenario with no Ego compensation involves a crossing d_{safe} which represents that the safety distance is not respected during the overtaking maneuver. With the proposed algorithm, the adapted compensation allows us to stay above the limit and assure the safety of the overtaking with a safety margin.

It is important to note that the proposed algorithm is generic and works even with a dynamic change of Obstacle 1 (cf. Fig. 3) acceleration/deceleration and with multiple changes from Obstacle 2 during the maneuver. But, for the efficiency and simplicity of explanation, only standard situations involving 3 vehicles are shown in this section.

V. Conclusion and Prospects

This paper proposes a new Distance Awareness for Adaptative Velocity Profile (DA-AVP) method to improve the safety and the feasibility of an overtaking maneuver based on Dynamic Predicted Inter-Distance Profile (D-PIDP) by applying an acceleration profile computed online on the preplanned path. The aim of this paper is to ensure the feasibility of the overtaking of the Ego's capacity to maintain a safety distance with others obstacles by including constraints on the Ego acceleration/speed and by including a safety margin which represents the uncertain acceleration of Obstacle 2. If the constraints can not be respected, the maneuver must be aborted [15]. This is why a link with the decision-making part has to be done, i.e., the overtaking decision-making has to be taken on the capacity of the Ego vehicle to create this minimal safety temporal distance but not only on the current TTC. The proposed algorithm has been performed on Matlab and compared to the initial algorithm [16], and highlights the efficiency of this approach to maintain a safety distance called Evolution of the Adapted Safety Inter-distance (EASI). This has been done on a two lanes highway but, it will be the topic for future works, this method can be considered to do an insertion between two obstacles with an implementation on real vehicles available in the laboratory.

Acknowledgment

This work has been sponsored by Sherpa Engineering and ANRT (Conventions Industrielles de Formation par la Recherche). This work received also the support of the french government, through the CPER RITMEA, Hauts-de-France region.

References

[1] Iberraken Dimia, Adouane Lounis and Denis Dieumet. Multi-level Bayesian decision-making for safe and flexible autonomous navigation in highway environment. *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Oct 2018, Madrid, Spain

[2] Adouane Lounis. (2016). Reactive versus cognitive vehicle navigation based on optimal local and global PELC. *Robotics and Autonomous Systems*. 88. doi: 10.1016/j.robot.2016.11.006.

[3] Dixit Shilp, Fallah Saber, Montanaro Umberto, Dianati Mehrdad, Stevens Alan, Mccullough Francis and Mouzakitis Alexandros. (2018). Trajectory planning and tracking for autonomous overtaking: State-of-the-art and future prospects. *Annual Reviews in Control.* 45. doi: 10.1016/j.arcontrol.2018.02.001.

[4] Gim Suhyeon, Adouane Lounis, Lee Sukhan and Derutin Jean-Pierre. (2017). Clothoids composition method for smooth path generation of car-like vehicle navigation. *Journal of Intelligent and Robotic Systems (JIRS)*

[5] Gim Suhyeon, Lee Sukhan and Adouane Lounis. (2020). Safe and Efficient Lane Change Maneuver for Obstacle Avoidance Inspired from Human Driving Pattern, Accepted. *IEEE Transactions on Intelligent Transportation Systems (T-ITS)*

[6] Zhang Bo, Zhang Jianwei, Liu Yang, Guo Konghui and Ding Haitao. (2021). Planning flexible and smooth paths for lane-changing manoeuvres of autonomous vehicles. *IET Intelligent Transport Systems.* doi: 10.1049/itr2.12014.

[7] Suhyeon Gim. Flexible and Smooth Trajectory Generation based on Parametric Clothoids for Nonholonomic Car-like Vehicles. Automatic. Ph.D. Sung Kyun Kwan university (South Korea) / Université Clermont Auvergne (France), (2017).

[8] Wang Chang, Sun Qinyu, Li Zhen and Zhang Hongjia. Human-Like Lane Change Decision Model for Autonomous Vehicles that Considers the Risk Perception of Drivers in Mixed Traffic. *Sensors (Basel).* 2020 Apr 16;20(8):2259. doi: 10.3390/s20082259. PMID: 32316210; PMCID: PMC7218893.

[9] Noh Samyeul and An Kyounghwan, "Risk assessment for automatic lane change maneuvers on highways," *2017 IEEE International Conference on Robotics and Automation (ICRA)*, Singapore, 2017, pp. 247-254, doi: 10.1109/ICRA.2017.7989031.

[10] Li Ye, Wang Hao, Wang Wei, Liu Shanwen and Xiang Yun. (2016). Reducing the risk of rear-end collisions with infrastructure-to-vehicle (I2V) integration of variable speed limit control and adaptive cruise control system. *Traffic injury prevention.* 17. doi: 10.1080/15389588.2015.1121384.

[11] Rahman Md Sharikur and Abdel-Aty Mohamed. (2017). Longitudinal safety evaluation of connected vehicles' platooning on expressways. *Accident Analysis Prevention*. 117. doi: 10.1016/j.aap.2017.12.012.

[12] Easa Said and Diachuk Maksym. (2020). Optimal Speed Plan for the Overtaking of Autonomous Vehicles on Two-Lane Highways. *Infrastructures*. 5. 44. doi: 10.3390/infrastructures5050044.

[13] Yang Minming, Wang Xuesong and Quddus Mohammed. (2019). Examining lane change gap acceptance, duration and impact using naturalistic driving data. *Transportation Research Part C: Emerging Technologies*. 104. 317-331. doi: 10.1016/j.trc.2019.05.024.

[14] Huan Shih-Ting, Lin Yu-Chen and Lin Chun-Liang., "Design and Implementation of Intelligent Overtaking System Using Model Predictive Control," *2020 International Automatic Control Conference (CACS)*, Hsinchu, Taiwan, 2020, pp. 1-6, doi: 10.1109/CACS50047.2020.9289754.

[15] Iberraken Dimia, Adouane Lounis and Denis Dieumet. (2018). Safe Autonomous Overtaking Maneuver based on Inter-Vehicular Distance Prediction and Multi-Level Bayesian Decision-Making. Conference Record - *IEEE Conference on Intelligent Transportation Systems*. doi: 10.1109/ITSC.2018.8569401. Hawai, USA.

[16] Iberraken Dimia. Safe Trajectories and Sequential Bayesian Decision-Making Architecture for Reliable Autonomous Vehicle Navigation. *Automatic.* Université Clermont Auvergne, 2020.

[17] Adouane Lounis, Benzerrouk Ahmed and Martinet Philippe. Mobile Robot Navigation in Cluttered Environment using Reactive Elliptic Trajectories. *18th IFAC World Congress*, Sep 2011, Milano, Italy.

[18] Vilca Jose-Miguel, Adouane Lounis and Mezouar Youcef. (2013). Reactive navigation of mobile robot using elliptic trajectories andeffective on-line obstacle detection. *In Gyroscopy and Navigation Journal.* 4. doi: 10.1134/S2075108713010094.

[19] Iberraken Dimia, Adouane Lounis and Denis Dieumet. (2019). Reliable Risk Management for Autonomous Vehicles based on Sequential Bayesian Decision Networks and Dynamic Inter-Vehicular Assessment. *IEEE 2019 IEEE Intelligent Vehicles Symposium (IV'19)*