Cooperative Maneuver study between Autonomous Cars: Overtaking

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Abstract. This research studies the overtaking maneuver in some representative situations. A simulator using Matlab Simulink connecting its outputs to a Virtual Reality module to show the complete overtaking performance from all points of view has been made. With this useful tool the parameters of the car controllers and decision making systems can be set up, and unforeseen new features of the overtaking maneuver can also be taken into account.

1 Introduction

Overtaking in two way roads is one of the most dangerous maneuvers. Making a mistake while doing this maneuver can lead to terrible accidents. That is why all the efforts to develop driving aids for this operation are one of the main issues of the Intelligent Transport System (from now ITS) area. The starting-point of our research in ITS was developing intelligent controllers for the automatic driving. Now, in order to achieve automated traffic systems in dedicated areas, we have aimed our research in the cooperative driving between several vehicles. The cooperative maneuvers already implemented have been the Adaptive Cruise Control, the Stop & Go driving and the Overtaking without an incoming flow of vehicles [3]. Once the possibility of finding an incoming car in the other lane is included, the risk of a dangerous situation makes the use of a simulator for the early steps of the research mandatory. A cheap and modular simulator has been made using Matlab toolboxes Simulink and Virtual Reality. To ensure a close collaboration between research groups, the decision and control modules are easily interchangeable and allow each group to test their own algorithms effortlessly. Moreover, the Virtual Reality output shows the overtaking evolution from all points of view. The simulator includes the kinematics of the car and a simplified model of its longitudinal and steering system dynamics. This work studies the overtaking maneuver in all possible situations. The goal is to improve the controllers and the decision making systems in real cars, and on top of that, to discover and take into account unforeseen new features of the overtaking maneuvers.

2 Simulator Overlook

The simulator is built on Matlab Simulink and includes the modeled cars with the kinematics and some dynamics. There is a module, the decision making subsystem, which opts for the best behavior in each moment. The fuzzy controller turns a desired behavior into the appropriate orders for the steering wheel, accelerator and brake. And the Virtual Reality output allows us to see the evolution of the maneuver from all points of view. The information used for the modeled

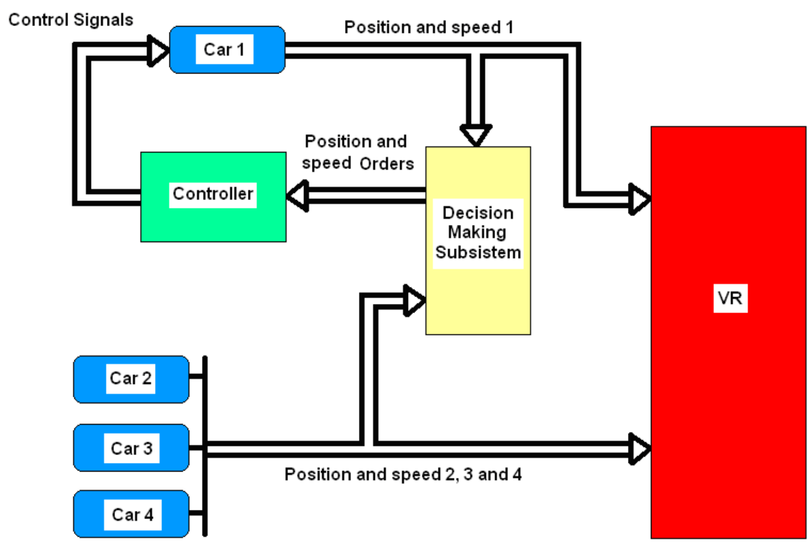

Fig. 1. Main diagram of the overtaking simulator.

cars in the simulator intended to be the same as that available from the real cars of our research. The vehicles have a differential GPS that provides a centimetrical precise position, so the coordinates of the simulated cars are without errors. The vehicles also have a radio-Ethernet connection to share its position, speed and intention with a high degree of reliability, so the simulated active car can decide upon the position, speed and intention of the rest of the cars. A detailed map of the driving zone with the speed limits and the forbidden overtaking zones is also integrated, and that information is simulated by setting the length limits to the endless straight lane road of the simulator. The map information and the data shared by the other vehicles permit a car to determine which vehicles are relevant to the maneuver in progress. In the simulator case all the vehicles are relevant and its information is always available.

3 Car Model

The modeled cars that appear on figure 1 are nonlinear single-track models, commonly called bicycle model [2], upgraded by steering wheel/wheel and longitudinal dynamics. The steering wheel/wheel dynamics avoid the instant change

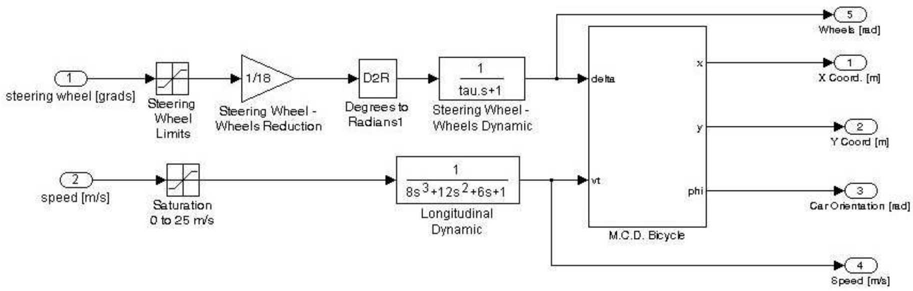

Fig. 2. Expanded view of the car model.

in the wheel angle. It is modeled by equation 1, obtained from experimental results with real cars in [4].

$$G(s) = \frac{1}{\tau s + 1} \tag{1}$$

The longitudinal dynamics avoid the instant change in the car speed. It is modeled by equation 2, obtained also in [4].

$$H(s) = \frac{1}{8s^3 + 12s^2 + 6s + 1} \tag{2}$$

4 Decision Making System

The essence of the decision making system can be explained with figure 3. This module is an automaton where each state is a desired car behavior. The transitions between states depend on processed information of the position, speed, acceleration of the cars involved in the overtaking maneuver. The active car (the overtaking car) position, speed and acceleration are used to compute the time needed to overtake the preceding cars (one or more, depends on the scenario). And the position, speed and acceleration of the incoming car in the left lane (the active car is in the right lane, as continental Europe drives on the right lane) are used to calculate the time to reach the active car. Using this measures the active car can, opt for overtaking or following the preceding car, or, once the overtaking has been started, for aborting the maneuver. The available modes for the active car are: Single navigation, Overtaking, Following the preceding car or

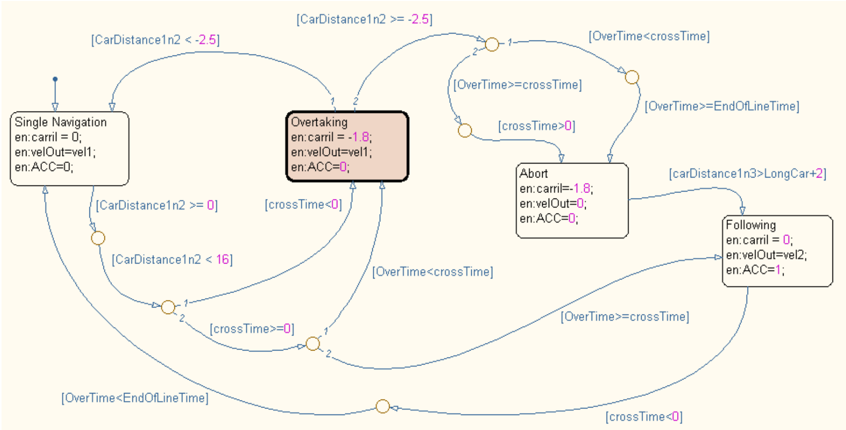

Fig. 3. Simplified Decision Making Flow Chart.

Emergency overtaking abort. Each behavior has its own outputs like the reference line (imaginary line in the middle of the lane), the desired speed and the activation of the Adaptative Cruise (from now on, ACC) to follow the preceding car. These outputs set the goals for the fuzzy controller. In Single navigation mode, the active car remains in its lane and maintains its desired speed until it is near to the preceding car. In Overtaking mode, the active car establishes the left lane as the reference line and maintains the desired speed as reference speed. Once the preceding car is overtaken the system returns to the Single navigation mode and the right lane becomes the reference line. When the active car can not overtake and must remain in his lane, the system maintain the mode Following the preceding car. In this mode the car is referred to the right lane but the speed is controlled by the fuzzy controller to keep a safety time distance to the preceding car, being enabled the ACC behavior. If the incoming car speeds up when the active car is overtaking, the time measures change. In this case, aborting the maneuver and returning to a safety position are needed. When this happens, the system is set to Emergency overtaking abort mode. In this mode, the reference speed is set to zero to force a hard breaking. Once the active car is behind the car, that has been intended to be overtaken, the systems change to Following the preceding car mode. Its reference line is set to the right and speeds up to adjust its speed to the one of the preceding car.

5 Fuzzy Controller

The decision making system sets the reference line, the desired speed and enables or disables the ACC mode. Then, the fuzzy controller turns those goals into orders for the steering wheel, the accelerator, and the brake. This is done by minimizing the errors in the lateral displacement from the reference line, the orientation (angle), the speed, and the time gap with the preceding car. The fuzzy controller uses the Sugeno [5] method of fuzzy inference. MIN/MAX is used as inference method. In this step, the fuzzy input variables are used to calculate the truth value of the premises. For each rule, all the antecedent variables are computed to get the truth value of the premise, using "Min" as And method and "Max" as Or method. Sugeno-style fuzzy inference uses Product as Implication method and Summation as Aggregation method. Once proper weighting has been assigned to each rule, the implication method is implemented. The consequent variables is reshaped using the product which scales the output fuzzy set. For each output variable the outputs of each rule are summed into a single fuzzy set as aggregation. For Defuzzification it is used the weighted average method to turn the output into a single number. The system state is described by means of this set of input variables:

1. Lateral error: the distance between the center of the back axis of the car and the line of reference (in meters).
2. Angular error: the difference between the car direction and the line of reference direction (in degrees).
3. Speed error: the difference between desired and real speed.
4. Acceleration: the speed variation over time.
5. Time Gap: the distance between the active car and the preceding car measured in seconds.
6. d_timeGap: the increase or decrease of the Time Gap.
7. ACC Signal: A signal that enables or disables the ACC rules.

The actuation over the system is defined by goals for the steering wheel, the accelerator, and the brake. The rules for the accelerator and the steering wheel are shown on figure 4.

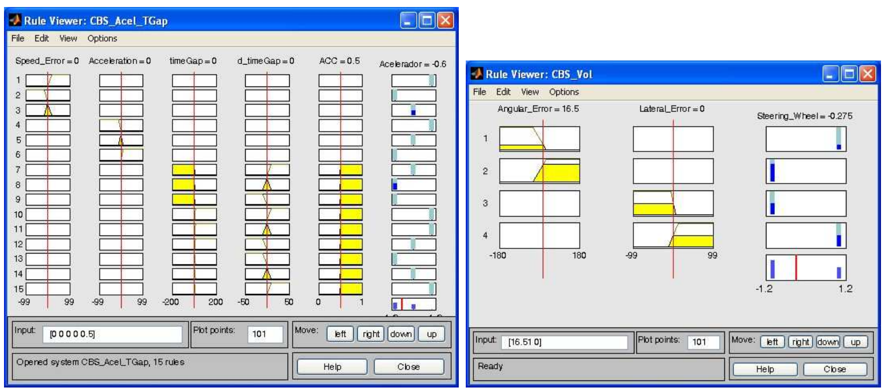

Fig. 4. Fuzzy controller for the accelerator and for the steering wheel.

6 Scenarios

To study the overtaking maneuver four scenarios were selected. The complexity of these scenarios increases from one to the following, reaching the final case which can be as complex as a daily situation.

6.1 Scenario 1: Overtaking in an unlimited straight lane road without incoming vehicles

When the active car is near enough to the preceding car, it evaluates the risks of the overtaking maneuver. As there is no space or time limits, it decides to overtake. The decision module changes the reference line to the left lane and the fuzzy controller starts the maneuver. Once the overtaken car is some distance behind, the active car returns to the right lane. If the speed difference between the active car and the preceding card is big enough, the fuzzy controller only uses the steering wheel. However, if the speeds are similar, the fuzzy controller also uses the accelerator.

6.2 Scenario 2: Overtaking in an unlimited straight lane road with incoming vehicles

When the car is near enough to the preceding car, it evaluates the risks of the overtaking maneuver. As there is an incoming car, the decision subsystem must calculate if there is enough time to overtake. If there is time enough it overtakes like in scenario 1.If not, then it must follow the preceding vehicle until the incoming car passes. To follow the preceding car, the fuzzy controller must maintain a certain distance measured in time. In the simulation, the car

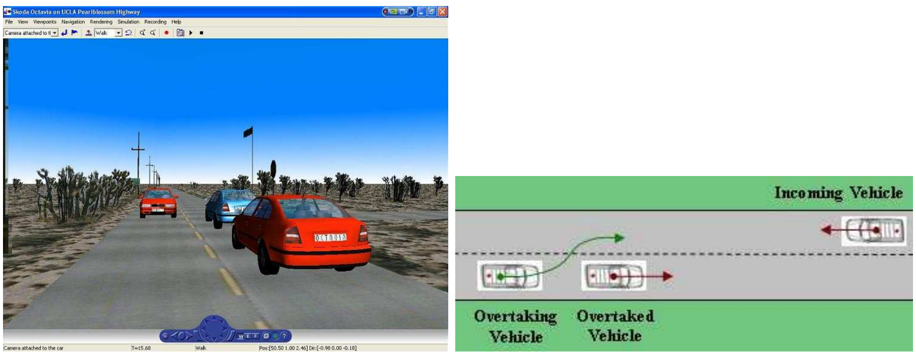

Fig. 5. Virtual Reality output for scenario 2, and scenario 2 diagram. Car models are from Ismar VR Company, and virtual environment is from UCLA.

changes its behavior from single navigation mode to Overtaking mode. When the incoming vehicle speeds up the evaluation of danger turns from a safe to an unsafe situation, and the car returns to the right lane and starts following the previous car. This emergency abort while overtaking, including the hard breaking, is a very interesting case of study. And knowing its limits and solutions is one of the main purposes of this work. A key issue of this simulation is the time margin left. This margin is recalculated constantly. If the incoming car speeds up, and the margin is not enough to finalize the overtaking maneuver, then the maneuver is aborted. Only the simplest abortion maneuver is considered here, that is, hard breaking and returning to the right lane. There are other possibilities to consider when, time is running out for the active car, such as accelerating, especially if the overtaking maneuver is in very advanced stage; then much is still to be discussed.

6.3 Scenario 3: Overtaking with space limitations and incoming vehicles

As there are an incoming car, and a space limit (forbidden overtaking zones), the decision subsystem must calculate the minimum of the two time limits: the time to overtake before the incoming car passes and the time to reach the forbidden overtaking zone. Once this calculation has been completed, the maneuvers are like scenario 2.

6.4 Scenario 4: Overtaking with space limitations, incoming vehicles and several cars in the same driving lane

The preceding cars in the same lane are considered a platoon. So the overtaking maneuver is considered for all of them. Not one by one. For the calculations of the time constrains the head and the tail of the platoon are considered. Once included this time constraint, the maneuvers are like scenario 3. In this scenario, the probability that time is run out before finalizing the overtaking maneuver is higher. Then, different options are open to discussion: accelerating to finalize, docking in the platoon (in which position?) and breaking to follow the platoon.

6.5 Conclusions

The simulator helps in tuning the real car controllers. The knowledge acquired by tuning the simulator can be very useful with real cars. Also helps choosing the decision making subsystem rules and constrains. The real car dimension becomes relevant. The car is not longer being represented like a point and a vector but it is seen and handled like a 3 dimensional object. It is also a useful tool to investigate the reduction of the time spent in the overtaking, the increase of the safety when overtaking, and the alternatives in an overtaking abort. Using the simulator, unexpected dangerous situations can be discovered while modifying the cars speeds and positions. Also relatively complex situations can be seen while playing with the simulation parameters.

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