Assisting the Drivers by Means of the Constant Time to Collision Criterion

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Abstract

The paper is proposing an Intelligent Speed Advice and Collision Warning interface, based on the Constant Time to Collision Criterion. This criterion is addressing the car fallowing issue and it offers a speed adapted planner for the distance gap between cars. The planner is designed using a computer model of two following cars. This method is able also to support a highway traffic flow management. The interface's decision block is implemented by a fuzzy interpolative controller that is estimating the collision risk, taking into account the traffic intensity.

Keywords: car following, constant time to collision, inverse time to collision, traffic intensity management, fuzzy-interpolative controller.

1 Introduction

The automate driving is enhancing the driving performance and reducing the crash risks, but each step forward in this domain is carefully considered because of the possible impediments (driver distraction, reduced situation awareness, loss of skill, etc.). That is why the direct intervention in driving are restricted for the moment.

Advanced Driver Assistance Systems ADAS are systems to help the driver. When designed with a safe Human-Machine Interface they are able to increase the car's and the traffic' safety [1], [2]. Examples of such systems are: the In-Vehicle Navigation System usually with Global Positioning System GPS and Traffic Message Channel TMC for providing up-to-date traffic information, the Adaptive Cruise Control ACC, the Lane/Road Departure Detection/warning system, the Collision warning system, the Intelligent speed adaptation or intelligent speed advice ISA, the Night Vision, the Adaptive Light Control, the Pedestrian Protection System, the Automatic parking, etc. Other systems emerging in the field are the Autonomous Intelligent Cruise Control AICC and the Collision Avoidance Systems CAS. Some systems also feature Forward Collision Warning Systems FCWS or Collision Mitigation Avoidance System CMAS, which warns the driver and/or provides brake support if there is a high risk of a rear-end collision. These use radar or laser sensors to warn the driver if a vehicle in front - given the speed of both vehicles - gets too close (within the preset headway or braking distance). Some systems can be linked to a car's cruise control system, allowing the vehicle to slow when catching up the vehicle in front and accelerate again to the preset speed when traffic allows. A key problem in this issue is the measurement and the control of the distance gap between two following cars.

In some previous papers [4] [5] we introduced a fuzzy-interpolative distance-gap control method that is using a Constant Time to Collision Planning CTCP, in the sense of the Planning System concept [6]. This approach was also discussed in [7]. The paper is continuing the investigation of CTCP in the analyze of the collision risk with respect to the traffic flow, with applicability in ISA, FCWS, etc.

2 The Time to Collision

Several indicators measure the characteristics of the traffic flow: the Time-to-Collision TTC, the Time-to-Accident TTA, the Post-Encroachment-Time PET, the Deceleration-to-Safety-Time DTS, the Number of Shockwaves, etc. TTC is

L. Magdalena, M. Ojeda-Aciego, J.L. Verdegay (eds): Proceedings of IPMU'08, pp. 946–951
Torremolinos (Málaga), June 22–27, 2008

the time before two following cars (Car2 is following Car1) are colliding, assuming unchanged speeds of both vehicles:

$$TTC = \frac{d}{v_2 - v_1} \qquad (1)$$

TTC is linked to the longitudinal driving task. Negative TTC implies that Car1 drives faster, i.e. there is no danger, while positive TTC is leading to unsafe situations. Starting from TTC one can introduce global indicators such as the Time-to-Collision Distribution or the Cumulative TTC Exposure Times. By assessing TTC values at regular time steps or in continuous time, a TTC trajectory of a vehicle can be determined. Doing this for all vehicles present on a road segment one can determine the frequency of the occurrence of certain TTC values, and by comparing these distributions for different scenarios, one can appreciate the traffic safety [2].

Due to the annulation of its denominator when $v_2 = v_1$, TTC is presenting frequent commutations between $\pm\infty$. That is why TTC is often replaced by the $d(v_1\text{-}v_2)$ trajectory [3]. However, $d(v_1\text{-}v_2)$ is not very suggesting when evaluating the collision risk.

That is why in a previous paper [5] we introduced the Inverse Time to Collision TTC^{-1}:

$$TTC^{-1} = \frac{v_2 - v_1}{d} \qquad (2)$$

TTC^{-1} is proportional to the collision risk: the higher TTC^{-1} is the higher will be the risk. Negative TTC^{-1}s have the same significance as negative TTCs. The neighborhood of $TTC^{-1} = 0$ is corresponding to the TTC's computing block's saturation for great values, so it is not sensitive. This lack of sensitivity is not an disadvantage in this case, because the two cars' speeds are very close and the collision risk is low. Since the significance of TTC^{-1} is clear, this index can be used as an input variable in more comprehensive decision-making systems, assisting the driver.

The TTC^{-1} universe of discourse can be fuzzyfied with four significant linguistic labels, relevant for the driver's attitude, as in fig. 1:

- *Negative*: any action is permitted;
- *Zero*: preserving the trend is recommended, no interdictions;
- *Positive small*: easy braking recommended;
- *Positive great*: compulsory hard braking.

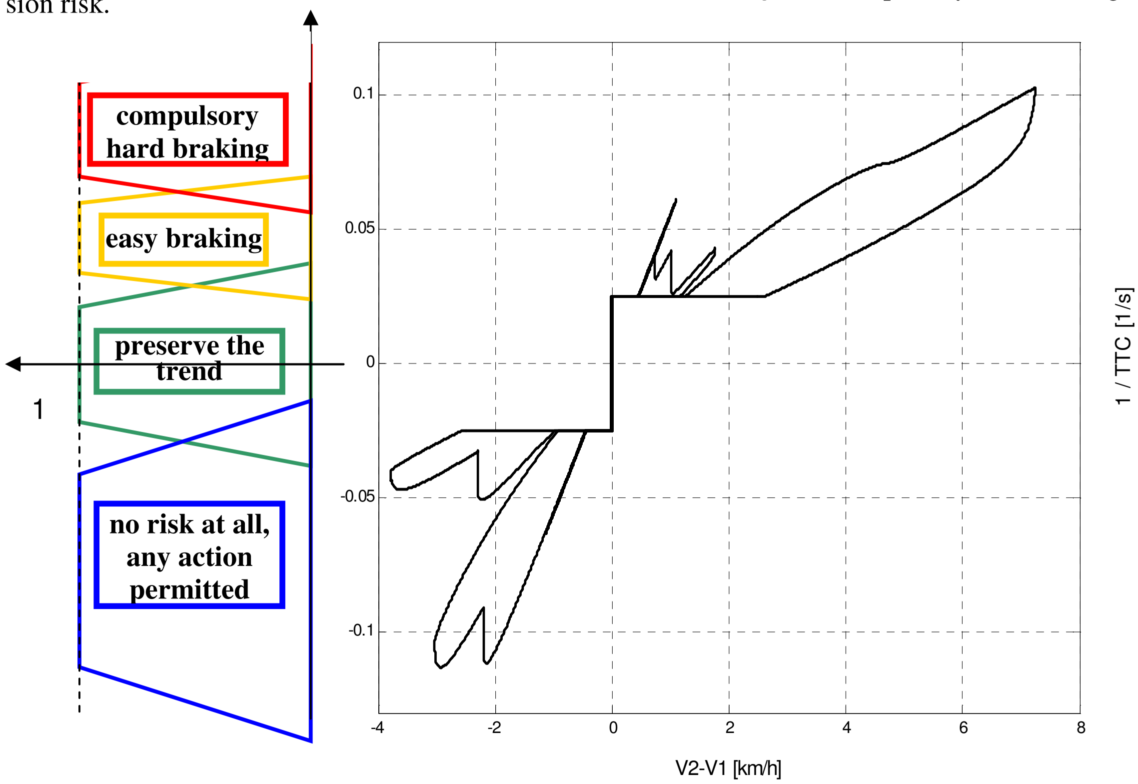


Fig. 1. A $TTC^{-1}(v_2 - v_1)$ trajectory and a corresponding fuzzy partition assisting the driver

The linguistic labels may be symbolized by suggestive colors, in order to assist the driver in a friendly and visual manner: Blue (*Negative*), Green (*Zero*), Yellow (*Positive small*) and Red (*Positive great*)

3 The Constant Time to Collision

The central issue in cars' safety is to impose an appropriate distance between cars, d_i. The AICC is imposing a particular polynomial $d_i(v_2)$ law:

$$d_i(v_2) = z_0 + z_1 \cdot v_2 + z_2 \cdot v_2^2 = \\ =3 + z_1 \cdot v_2 + 0.01 \cdot v_2^2 \quad (3)$$

Several settings are recommended, for example $z_1 = 0.8s$ or $z_1 = 0.6s$. Two objections can be drawn against this polynomial $d_i(v_2)$ law:

- no adaptation to the traffic intensity is offered: if (3) is tuned for the highest possible traffic, when the traffic is decreasing, the following cars will continue to maintain the same short distance-gaps between them;

- z_1 and z_2 are artificially introduced parameters, they have no significance for humans - highway operators or drivers - and they are not linked to the physical features of the system.

A step forward is to use TCC in the Car2 control with the purpose to *stabilize* TTC. The *Constant Time to Collision* CTTC criterion is bringing two obvious advantages:

- a constant collision risk for each vehicle involved (following and followed vehicles);

- the possibility to control the traffic flow on extended road sections, if each vehicle will follow the TTC that is currently recommended by the Traffic Management Center [14]: long TTC means *low traffic flow* and *higher safety* while short TTC means *high traffic flow* and *higher risk*.

The on-line TTC control is impossible because of the evolution of v_2-v_1, so CTTC must be implemented off-line, with the help of $d_i(v_2)$ mappings (fig. 2). The CTTC implementation by $d_i(v_2)$ distance-gap planners is possible because *a distance gap planner using* TTC *will produce* CTTC. We studied this method by computer simulations, using a Matlab-Simulink model of the tandem Car1-Car2, introduced in other previous papers [3], [4], [5], [9], [13].

Since the design of the planners is performed with the help of functional models of the cars, accurate knowledge about the specific behavior and parameters of each car (traction and braking forces, weight, aerodynamic coefficient, etc.) can be taken into account, which is not possible to the simplified and leveling analytic model (3).

The application of this method is imposing to car manufacturers to provide each type of automobile with a computer model.

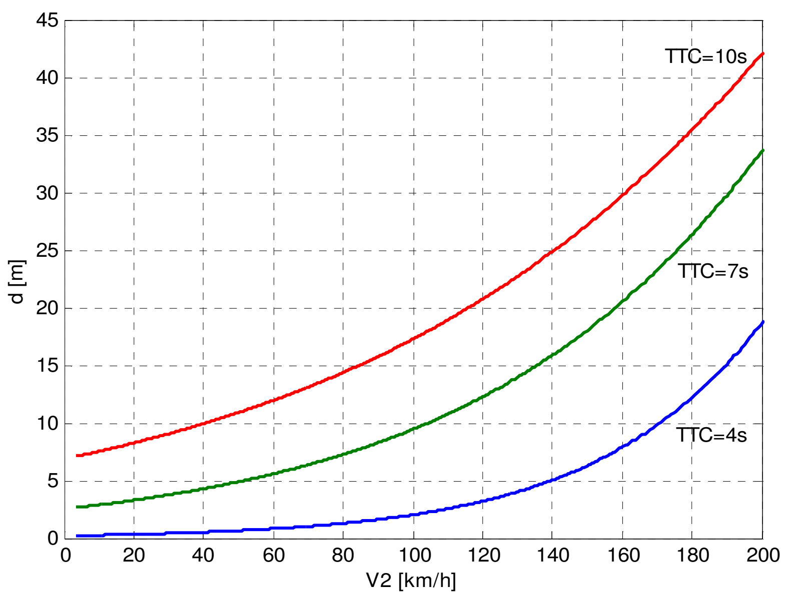


Fig. 2. The recorded $d_i(v_2)$ mappings for three different TTC

The distance-gap planners are build as follows. The simulation scenario consists in braking Car1 until the car is immobilized, starting from a high initial speed. A TTC controller is driving the Car2 traction/braking force such way that during the whole simulation TTC is stabilized to a desired constant value. The continuous braking allow us to avoid the v_2-v_1=0 case. We will use the recorded d mapping as the desired $d_i(v_2)$ planner for the given TTC. The figure 2 planners are build for three TTC values: 4s, 7s and 10s. These planners can be easily implemented with the help of the look-up tables with linear interpolation.

The use of the planning technique is essentially facilitating the task of the distance controller, that is actually driving the traction/braking force of a real car during the cruise regime, as shown in fig. 3. Very simple fuzzy-interpolative PD controllers or even linear controllers can such way cope with the car following task [4].

4 A Fuzzy Interpolative Estimator of the Collision Risk

As we have shown, after simple manipulations, TTC can help us to build useful tools, able to assist the drivers and the traffic management:

- TTC^{-1}, an index of the collision risk, that can assists the driver in a friendly manner, when taking decisions on the longitudinal driving.

- a CTTC distance gap planner that is generating the optimal distance-gap between cars, adapted to the speed and to the technical characteristics of the following car.

- a TTC value imposed by the Traffic Management Centers in order to control the traffic intensity, such way that the collision risk is uniformly distributed over all the cars.

Using these tools, we can design a sensitive and nuanced driver's assisting interface, able to estimate risks and to recommend the right actions that are maximizing the driving safety. The idea is simply to adapt the TTC^{-1} fuzzyfication of fig. 1 to the TTC values that are imposed by the highway administration. Our goal is to obtain a two input fuzzy-interpolative controller, capable to infer the collision risk, in accordance to the traffic intensity.

We use a two input fuzzy-interpolative controller. The family of the fuzzy-interpolative controllers is presented in some previous papers [8], [9], etc. The inputs are the next:

1) TTC^{-1} (the on-line value measured by Car 2), with four linguistic labels: *negative*, *zero*, *medium* and *great*, as presented in fig. 4a.

2) TTC (the values imposed by the highway administration), with three linguistic labels: *small* for high traffic, *medium* for usual traffic and *great* for low traffic.

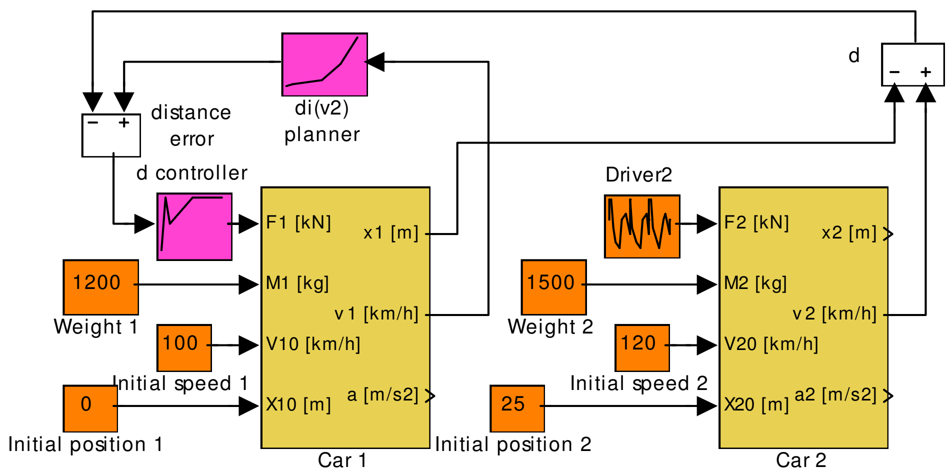
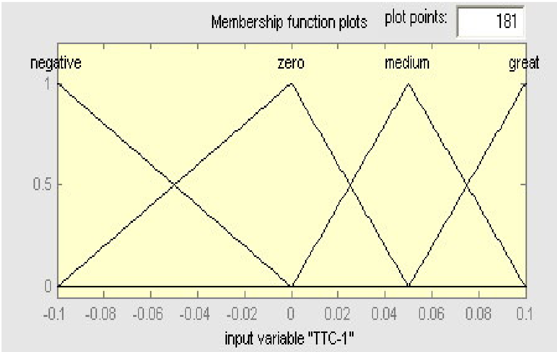
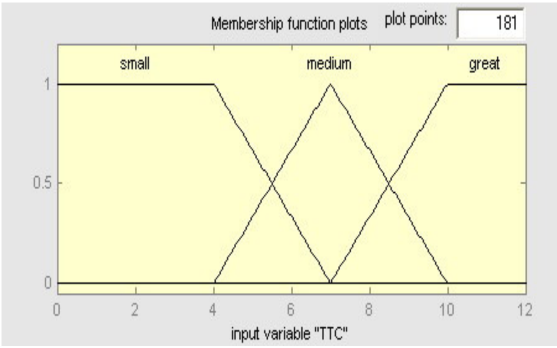


Fig. 3. A car following system with distance controller and $d_i(v_2)$ planner



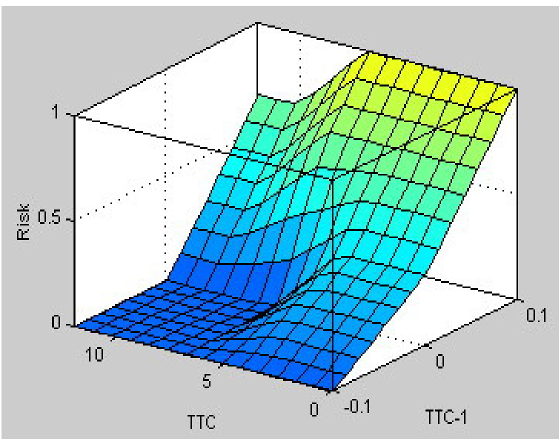
a) The fuzzy variable TTC^{-1}



b) The fuzzy variable TTC

1. If (TTC-1 is negative) then (Risk is zero) (1)
2. If (TTC-1 is zero) and (TTC is small) then (Risk is low) (1)
3. If (TTC-1 is zero) and (TTC is medium) then (Risk is zero) (1)
4. If (TTC-1 is zero) and (TTC is great) then (Risk is zero) (1)
5. If (TTC-1 is medium) and (TTC is small) then (Risk is medium) (1)
6. If (TTC-1 is medium) and (TTC is medium) then (Risk is medium) (1)
7. If (TTC-1 is medium) and (TTC is great) then (Risk is low) (1)
8. If (TTC-1 is great) and (TTC is small) then (Risk is high) (1)
9. If (TTC-1 is great) and (TTC is medium) then (Risk is high) (1)
10. If (TTC-1 is great) and (TTC is great) then (Risk is medium) (1)

c) The rule base



d) The control surface

Fig. 4. The MATLAB Risk fuzzy controller

We will consider the three values from fig. 2: 4s for *small*, 7s for *medium* and 10s for *great*. The variable is presented in fig. 4b.

The output Risk has four singletons: 0 for *zero*, 0.(3) for *low*, 0.(6) for *medium* and 1 for *high*. The rule base is presented in fig. 4c while the resulting control surface in fig. 4d.

The MATLAB implementation using the Fuzzy Inference System FIS is presented in fig. 4c, but the most interesting version is the interpolative one, using the equivalent look-up table.

$$\begin{cases} \text{row } (TTC^{-1}): & [-0.1\ 0\ 0.05\ 0.1] \\ \text{column (TTC)}: & [4\ 7\ 10] \\ \text{output (Risk)}: & [0\ 0\ 0;\ 0.(3)\ 0\ 0; \\ & 0.(6)\ 0.(6)\ 0.(3);\ 1\ 1\ 0.(6)] \end{cases} \quad (4)$$

This controller is only a minimal illustrative version. A final setting of the control rules should rely on a psychological study of the drivers' perceptions of the safe distance between cars, in different traffic intensity conditions.

Conclusions

The Time to Collision index TTC was used in previous papers for determining the optimal distance-gap between following cars and for the highway traffic management. Its inverse TTC^{-1} was used for estimating the collision risk. The two variables are now aggregated into a fuzzy-interpolative controller that is estimating the collision risk, with respect to the traffic's intensity. This controller is conceived as part of a friendly linguistic Intelligent Speed Advice and Collision Warning interface.

Besides the simplicity and the advantageous interpolative implementation, all the proposed Time To Collision based tools have a common feature: they are embedding precise knowledge about the technical data of the automobiles on which they are installed, thanks to the functional computer model that stands behind their design. This adaptive capability is promising to contribute to the improvement of the future highway traffic, that is presenting so many elements of uncertainty.

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