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A new psychological methodology for modeling real-time car following maneuvers

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ABSTRACT

In this paper a new structure of car following is proposed, and the psychological point of view is investigated in it. In general, most car following models have been investigated from the physical point of view, but in this paper, it is shown that in order to find a more realistic model for car following, not only does the physical point of view have to be considered, but also this model has to be investigated from psychological and control-engineering points of views too. In the rest of the paper, the psychological point of view in the proposed structure for the car following model is investigated in detail. In order to do this, some scenarios are designed with the aim of investigating drivers' behavior; then, these scenarios are applied to 65 different drivers using different simulators. By analyzing the data gathered from the scenarios, the related parameters of the proposed model are estimated, and the distributions of the values of the parameters are shown. In the end, some suggestions for investigating the control-engineering point of view in the proposed car following structure in this study are presented. The results of this research are of great importance in applying car following models in different driving simulators and also in every research where there is a need for a more realistic car following model.

1. Introduction

Driving simulators as effective devices in educational and research realms of transportation have become extremely popular. In the field of research, the investigation of following aspects can be mentioned: (1) Human–Machine Interface (Weir, 2010), (2) studying drivers behavior such as the impacts of perceptual treatment (Auberlet et al., 2012, 2010), visual attention (Konstantopoulos et al., 2010), gender differences (Yeung and von Hippel, 2008), or age differences (Gelau et al., 2011; Devlin et al., 2012; Chan et al., 2010) on driving performance, and (3) the impacts of environmental conditions on driver's performance such as differences of night and day (Garay-Vega et al., 2007), climate effects (Konstantopoulos et al., 2010; Saffarian et al., 2012), and roads (Dunn and Williamson, 2012). In addition, training derivers through driving simulators, because of being fast, simple, and cost-effective, has become common in different driving training branches like street crossing (Dommes and Cavallo, 2012), driving skill and style (de Groot et al., 2012), and speed attention (Roenker et al., 2003). In driving simulators, the driver interacts with the virtual environment using the simulator hardware. Meanwhile, realistic and real-time modeling of virtual vehicles, as one of the most important elements of the graphical environment, requires a great deal of attention (Demir and Çavuşoğlu, 2012). One of the most important and practical models in this field is the car following model. Not only does this model control the process of following the leader car by the follower (Khodayari et al., 2011; Brackstone and McDonald, 1999a,b), it, also, plays a crucial role in other driving maneuvers such as lane change (Jin, 2010; Lv et al., 2011), and overtaking (Tang et al., 2007; Jamison and McCartney, 2009) too. A lot of researches have been done in the field of car following model. Car following models, in general, are divided into two linear (Farhi, 2012) and non-linear groups (Li and Ouyang, 2011a,b; Li et al., 2012). Zheng et al. (2012) classified the car following models in a more detailed manner in the following categories: stimulus-response (Gazis et al., 1961), safety-distance (Gipps, 1981), Newell (Newell, 2002; Ahn et al., 2004), optimal velocity (Bando et al., 1995; Peng et al., 2011; Davis, 2003), and cellular automata (Schadschneider, 2006). Nevertheless, another category called visual angle (Jin et al., 2011; Yousif and Al-Obaedi, 2011) should be added to the various categories of the car following model. Most of the other car following models are, indeed, modified samples of one of the mentioned categories. For instance, Tang et al. (2011) added the concept of road side memorial to the previous car following models.

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Real-time simulation of "reality" is one of the most important concerns in the area of driving simulation and other areas of virtual reality. Although the above-mentioned models have been extensively used in traffic simulators, they still have some limitations to be adopted in a driving simulator because there are some concerns whether or not the current car following models are real (Hancock, 1999). Generally, the car following model could be investigated from physical, control engineering, and psychological points of views (Brackstone and McDonald, 1999a). No effective effort has been made to combine these three points of views and present a general model. It can be observed that the philosophy related to most of the car following models has been, firstly, estimating a model from driver's response using simple physical views, and secondly, calibrating this model using the available actual information. In fact, among the three available points of views, the physical view has been paid attention more although the importance of psychological and control engineering views can never be overlooked when it comes to creating a real model. As a drawback of the physical model, in most of them, it is assumed that the performance of the driver is completely rational, and he can perfectly identify the distance, acceleration, headway, and the other factors. Nonetheless, there is little evidence in psychological papers to prove that the driver performs rationally (Jin et al., 2011; Ranney, 1999). Moreover, as the second drawback of the physical model, it could be mentioned that in physical models the sensitivity is assumed to be a constant number although this assumption is not correct either.

Considering all of the mentioned problems, most researchers are agreed that the general model of car following is like Eq. (1) (Brackstone and McDonald, 1999a).

$$response = sensitivity \times stimulus \tag{1}$$

From control engineering point of view, Eq. (1) can be expressed as illustrated in Fig. 1. In this figure, physical and perceptual information enters the P(s) box as the behavioral box of the driver and is analyzed in it; then, its output appears as stimulus. Stimulus enters into the G(s) box as the driver's sensitivity, and the G(s) output is the desired response which appears in three types: gas, brake, and steering-angle. Finally, the driver makes the three gas, brake, and steering-angle outputs convergent to the desired value by the closed-loop F(s) controller. We believe that P(s), and G(s) should be investigated from psychological and control engineering points of views to achieve a model more complete and compatible with reality. In this paper, specifically, the P(s) box is discussed. The chosen view in this paper is the psychological view. Psychological views of car following were first presented by Van Winsum (1999), but after him, not enough effort has been put to improve them.

2. Material

2.1. Preferred Time Headway (TH) of individuals

There is evidence that drivers adapt their Time Headway (*TH*) with the lead car based on their abilities in controlling cars (Van Winsum and Heino, 1996). Since the *TH* represents the time available to the driver to adjust the acceleration of his car when the lead car brakes, the relation between the Preferred Time Headway (TH_p) and different people's braking performance can be investigated. In addition, although Brackstone et al. (2009) reported that there was no meaningful relation between the velocity of the car and the *TH* chosen by individuals, the results presented in that paper show that the relation between the car velocity and the TH_p could be summarized in some categories.

2.2. TH adjustment

As long as the *TH* to the lead car is more than the TH_p, the driver is not exposed to the process of car following. Therefore, he drives freely at his desired velocity. Nevertheless, when his *TH* to the lead car is less than the TH_p, it is assumed that even if there was no possibility of collision, he would experience an internal sense of being unsafe which would make him reduce his speed to gain his desired *TH*. Naturally, if there is a possibility of collision, proportionate to that possibility, the sense of being unsafe increases, resulting in a more intense reaction by the driver. As a result, two main reasons create and increase drivers' stimulus: (1) the error of the ratio of the *TH* to the TH_p ($\varepsilon_{TH} = 1 - \frac{TH}{TH_p}$), and (2) the estimated time to collision by the driver, TTC_e, (Van Winsum and Heino, 1996). If the stimulus created by the ε_{TH} and TTC_e are denoted by $S_{\varepsilon_{TH}}$ and S_{TTC_e} accordingly, the final stimulus of the driver is obtained from Eq. (2).

$$S_T = \max\{S_{\varepsilon_{TH}}, S_{TTC_e}\} \tag{2}$$

We get the maximum stimulus between ε_{TH} and TTC_e because reaction to the maximum stimulus, in a car-following maneuver, is a safe reaction.

2.3. Time to collision and its estimation with respect to driver perception

Although in a computer program the exact value of the *TTC* can accurately be calculated with relative velocity, relative acceleration, and the distance between the two cars, individuals' prediction of *TTC*, i.e. TTC_e, is different from its exact value. Kiefer et al. (2006) did a thorough research on this subject. In that research, the relationship between the exact *TTC* and TTC_e is extracted at different velocities and relative velocities. But, considering the fact that most car following maneuvers to which drivers are exposed are either constant- or variable-acceleration, are the results presented by Kiefer et al. (2006) correct in every situation? In order to answer this question, it has to be mentioned that although researches on acceleration perception by individuals have proved that people can sense acceleration with the aim of the information retinas provide them with (Capelli et al., 2010), there is no strong evidence to prove that this information is processed by individuals to estimate the *TTC* better. This means that researchers still assert that estimating the *TTC* with constant relative velocity is the best choice which can be used for modeling human's behavior in estimating the *TTC* (Moliner, 2003; Bootsma and Craig, 2003). Therefore, assuming that results of Kiefer's research are correct in every situation, in order to use these results, drivers' perception of relative velocity has to be investigated.

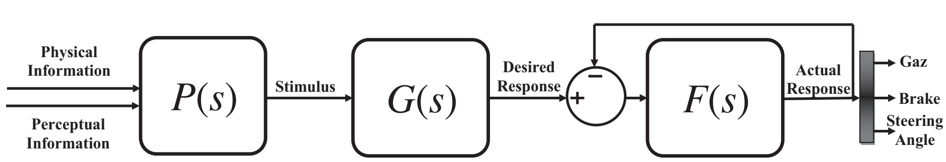

Fig. 1. The general structure of the proposed car following model.