Investigating optimal velocity model in urban traffic environment

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Summary. Behaviors of city drivers are investigated in heavy traffic scenarios using automatic differentiation-based parameter fitting. Traffic data are collected via video capturing, and the parameters of the optimal velocity model are identified. Then, time-delay and time-delay-like behavior are introduced into the driver model. These extended models are then fitted to the measurement data, and their success and consistency are evaluated.

Introduction

The drivers' behavior directly affects the evolution of traffic congestion on our roads. Consequently, the development of driver models is an essential topic for traffic management. This study focuses on the identification of driver model parameters. Traffic data are extracted via image processing from videos captured about real traffic. Statistical analysis of the identified parameters are also carried out.

Measurement method and collected data

A simple algorithm is created for analyzing different dynamic situations in traffic through video recordings. In our special approach, the region of interest is selected in the picture, and the background is identified. The perspective distortion is compensated by fitting a plane on suitable reference points. Then, the background is subtracted from each frame. Moving objects are separated with the help of the background image, and bounding boxes are generated (see Fig. 1(a)), which are tracked along the whole video. Using the whole dataset, we calculate the speed of every vehicle through differentiation and filtering of the discrete positions, see Fig. 1(b).

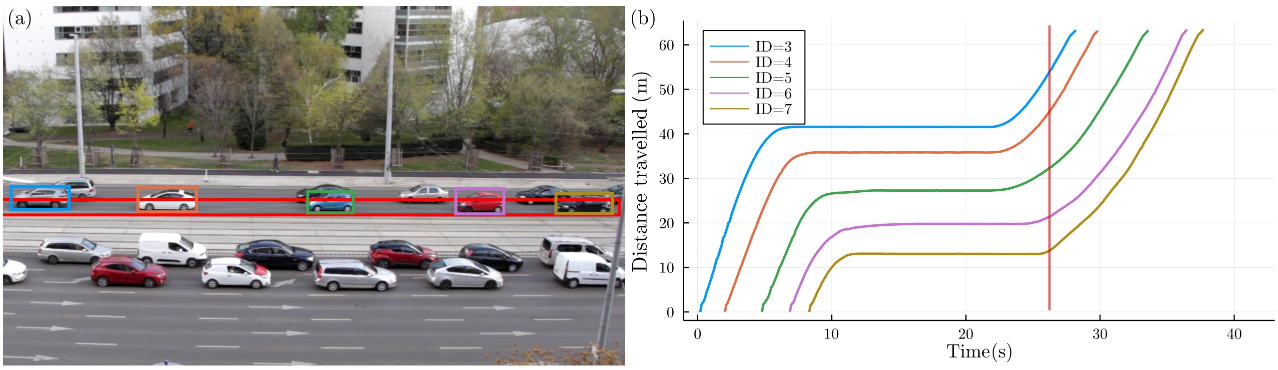

Figure 1: One of the measurements with the processed kinematic data. Panel (a) shows one frame of the captured video with the highlighted region of interest (red rectangle). Bounding box colors are in accordance with the position data in panel (b). The vertical red line refers to the time instant of the presented frame.

Fitting of the optimal velocity model

Throughout our work, we use the optimal velocity model with time-delay [1, 2]. The car following model is depicted in Fig. 2. The position s and speed v of the vehicle are described by

$$\begin{aligned} \dot{s}(t) &= v(t), \\ \dot{v}(t) &= \alpha\big(V(s_1(t-\tau) - s(t-\tau) - l) - v(t-\tau)\big) + \beta\,(v_1(t-\tau) - v(t-\tau))\,, \end{aligned} \tag{1}$$

where the range policy function $V(h)$ returns the desired velocity for a given headway. By subtracting the actual velocity v, we get the difference from the optimal velocity. The parameter α is the gain of this velocity difference. The second term is directly proportional to the speed difference between the vehicle and the leading vehicle. This is fed back with the gain β. In (1), s_1 and v_1 refer to the leading vehicle's position and speed. In Figure 2, the notations are explained visually.

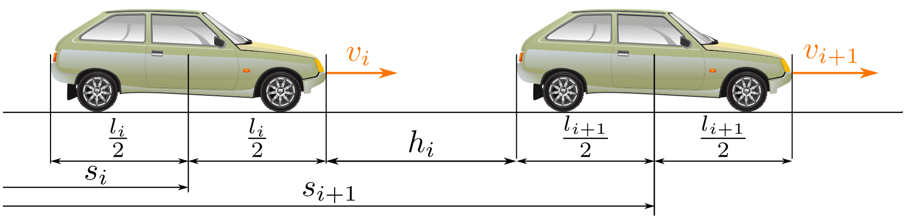

Figure 2: Car following model with the definitions of positions, speeds, and headway.

We fit the parameters α and β by numerically solving system (1), and then we compare the results to the measurements. We minimize the mean square error by utilizing techniques used in machine learning, i.e., automatic differentiation combined with gradient-based optimizer algorithms.

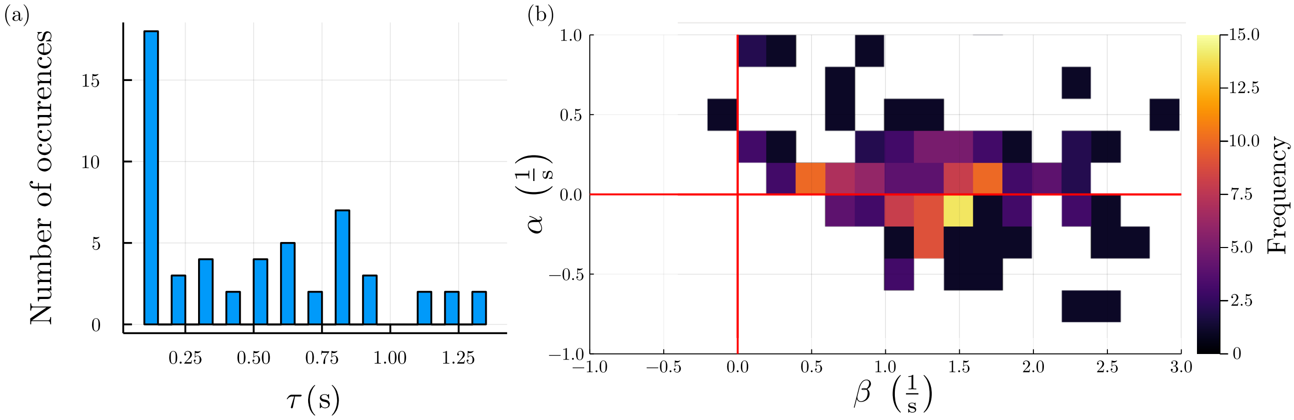

Figure 3: Parameter distributions for the identified systems following the fitting of (1). In panel (a), the identified time delays are shown. These delays are expected to correlate with the reaction and actuation delay of the drivers. Panel (b) shows the distribution for the gains α and β.

Figure 3 shows the results of the parameter fitting. Based on panel (a), the identified delays seem unrealistic since most of the values are below 0.25 s, even though this should contain the human reaction and the actuation delay as well. This suggests that human drivers may predict traffic flow not only based on the vehicle in front of them (i.e., looking at more vehicles ahead). Panel (b) shows an interesting distribution: parameter β has a more significant effect compared to α in most cases. Namely, α is close to zero; in many cases, it is even a small negative value, which is physically meaningless. This means that humans pay attention to the velocity difference and are relatively insensitive to the distance between the two vehicles in the case of heavy urban traffic.

Conclusions

Based on our measurements and investigation, it can be concluded that the optimal velocity model is unsuitable for describing human driving behavior in heavy urban traffic. However, humans seem to have a velocity-matching behavior in this environment. In the optimal velocity model, the acceleration is a linear function of the velocity difference, but this does not describe human behavior well, so investigating the connection between the acceleration and the velocity difference is the aim of our future research.

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