Intermittent Control Properties of Car Following: II. Dynamical Trap Model

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ABSTRACT

A new model for car-following is proposed to capture the found properties in our previous experiments. It is based on the experimental results showing that (i) human behavior in car driving should be categorized as a generalized intermittent control with noise-driven activation of the active phase and (ii) the extended phase space required for modeling human actions in car driving has to comprise four phase variables, namely, the headway distance, the velocity of car, its acceleration, and the car jerk, i.e., the time derivative of the car acceleration.

Categories and Subject Descriptors

J.4 [**Social and Behavioral Sciences**]: psychology; H.1.2 [**User/Machine Systems**]: human factors

General Terms

Theory

Keywords

Human behavior, status quo bias, intermittent control, car-following dynamics, dynamical traps

1. INTRODUCTION

In the last decades a new concept of how human operators stabilizing mechanical systems, called human intermittent control, was developed (e.g., [1]). It considers human operators not to be capable of controlling system dynamics continuously and, as a result, their actions must be a sequence of alternate phases of active and passive behavior, with the switching between these phases being event-driven. Recently, we developed a concept of noise-driven control activation as a more advanced alternative to the conventional threshold-driven activation [2]. In this concept the transition from passive to active phases is probabilistic and reflects human perception and fuzzy evaluation of the current system state before making decision concerning the necessity of correcting the system dynamics. During the passive phase the control is halted and the system moves on its own, broadly speaking, during the passive phase the operator accumulates the information about the system state. The periods of active phase can be regarded as fragments of open-loop control, which is due to the delay in human reaction (e.g., [1]).

Driving a car in following a lead car is a characteristic example of human control, which allows us to suppose that the intermittency of human control should be pronounced in the driver behavior and affect the motion dynamics essentially. Previously [3] we reported the results obtained in our experiments on car-following based on a car driving simulator created using the open source engine TORCS [4]. As the main results we have drawn a conclusion that the human behavior in car driving should be categorized as a generalized intermittent control with noise-driven activation of the active phase. Besides, we have argued for the hypothesis that the car jerk is an individual phase variable required for describing car dynamics.

2. FOUR-VARIABLE MODEL OF CAR-FOLLOWING

In this paper we discuss a mathematical model for car-following that employs the results of the experiments noted above. It is based on the assumption that to describe the driver behavior the extended phase comprising four independent variables is required; this idea was partly elaborated in [5]. A driver is not able to change the car position and its velocity directly; he can only vary the car acceleration by pressing the gas or break pedal. In real driving the car acceleration on its own is an important characteristic of car motion. Therefore, in describing the car dynamics we have to include the car acceleration in the list of the phase variables [6, 7, 8]. However, according to the found characteristics of the jerk distribution [3, 5], *the jerk on its own is also an independent phase variable* or another additional variable combining the headway distance h, the car velocity v, acceleration a, and jerk $j = da/dt$ within a certain relationship should be introduced. In the proposed model using a simplified description of car motion control, this fourth variable is the position θ of an effective pedal combining the gas and break pedals into one control unit.

Namely, the model is specified as follows. The car ahead is assumed to move at a fixed velocity V and the dynamics

IWAIT '15, Oct. 8 – 10, 2015, Aizu-Wakamatsu, Japan.

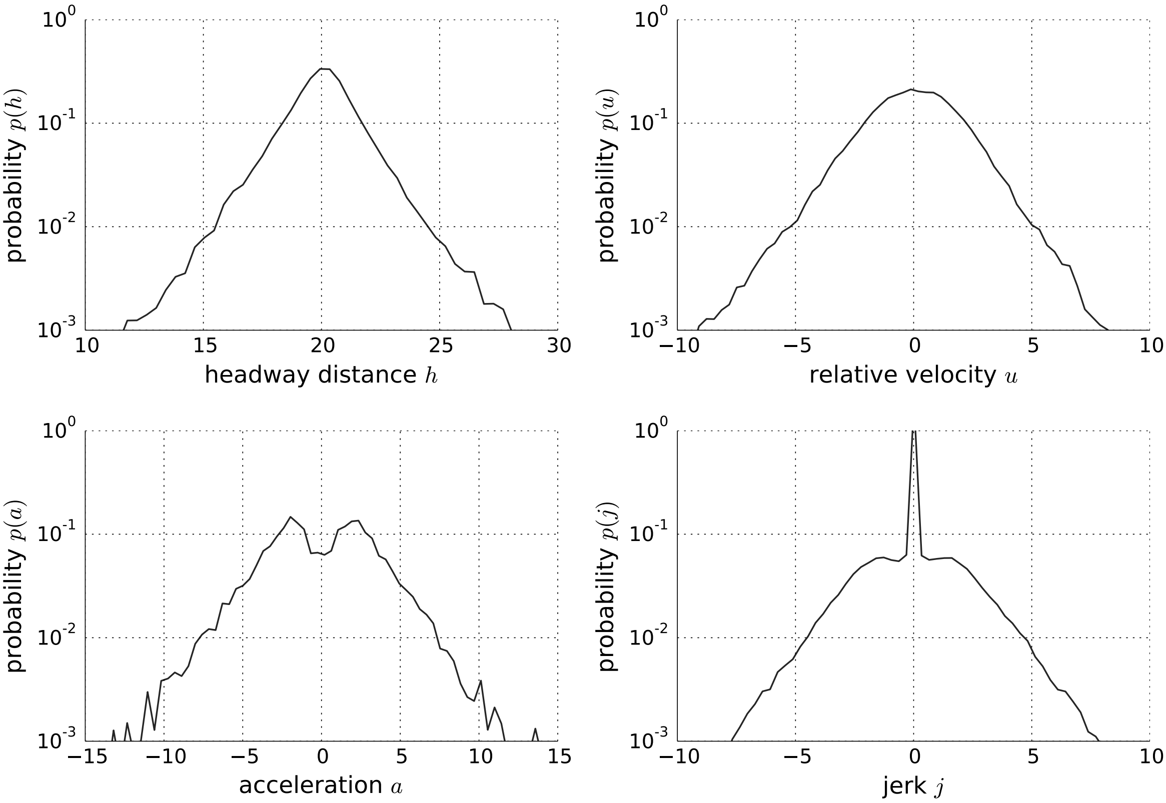

Figure 1: The distributions of the headway distance h, relative velocity $u = v - V$, acceleration a, and the jerk $j \propto (\theta - v)$ obtained by numerical solution of model (1)–(4). In simulation the following values were used, $v_{\mathbf{max}} = 30$ m/s (about 100 km/h), $V = 15$ m/s, $D = 20$ m, $a_{\mathbf{th}} = 0.1$ m/s^2, $\tau_h = \tau_\theta = 0.2$ s, $\tau_v = 1$ s, and $\epsilon = 0.005$ m/s$^{1.5}$. The numerical labels at axes are given in the corresponding units composed of meters and seconds.

of the following car is given by the equations

$$\frac{dh}{dt} = V - v\,, \tag{1}$$

$$\frac{dv}{dt} = a\,, \tag{2}$$

$$\tau_\theta \frac{da}{dt} = \theta - a\,, \tag{3}$$

$$\tau_h \frac{d\theta}{dt} = \Omega\,(a-\theta)\cdot[a_{\mathrm{opt}}(h,v) - a] + \epsilon\xi(t)\,. \tag{4}$$

Equations (1) and (2) are just simple kinematic relations between the variables h, v, and a, equation (3) describes the mechanical properties of the car engine and its response with some delay τ_θ to the position θ of the control unit measured here in units of acceleration. The last equation (4) describes the driver behavior. It combines the basic ideas of noise-driven activation in human intermittent control [2] and the concept of action dynamical traps for systems with inertia [8]. The driver is able to control directly only the position θ of the control unit and the difference $(\theta - a)$ between the desired acceleration θ and the current car acceleration a is the parameter quantifying the difference between his active and passive behavior. The bounded capacity of driver cognition is described in terms of action dynamical traps via the introduction of cofactor

$$\Omega(a-\theta) = \frac{(a-\theta)^2}{(a-\theta)^2 + a_{\mathrm{th}}^2} \tag{5}$$

similar to fuzzy reaction coefficients. Here a_{th} is the driver perception threshold of car acceleration. The ansatz

$$a_{\mathrm{opt}}(h,v) = \frac{1}{\tau_v}\left[v_{\max}\frac{h^2}{h^2+D^2} - v\right] \tag{6}$$

determines the optimal acceleration with which the strictly rational driver with perfect perception would drive the car. This expression inherits the optimal velocity mode widely used in modeling traffic flow (see, e.g.. [9]). Here τ_v is the human response delay time, $v_{\max}$ is the maximal velocity acceptable for safety reasons on a given road without neighboring cars, and D is the characteristic headway distance when drivers consider it necessary to slow their cars down as the headway distance decreases. The last term in equation (4) is the random Langevin force, where $\xi(t)$ is white noise of unit amplitude and ϵ is the Langevin force intensity. The interplay between the fuzzy perception function $\Omega(\theta - a)$ and this Langevin force are two main components of the noise-induced activation model elaborated in [2] for describing human balance of overdamped pendulum. Finally, the difference $[a_{\mathrm{opt}}(h, v) - a]$ quantifies the stimulus for the driver to correct the current state of car motion.

It should be noted that this approach to describing the effects caused by the bounded capacity of human cognition inherits the general formalism developed previously and called the dynamical traps [10, 11, 12, 13]. It assumes that individuals (operators) governing the dynamics of a certain system try to follow an optimal strategy in controlling its motion but fail to do this perfectly because similar strategies are indistinguishable for them. In systems, where the optimal dynamics implies the stability of a certain equilibrium point in the corresponding phase space, the human fuzzy rationality gives rise to some neighborhood of the equilibrium point, the region of dynamical traps, wherein each point is regarded as an equilibrium one by the operator. So, when the system enters this region and while it is located in it, maybe for a long time, the operator control is suspended. In this case the system can leave the dynamical trap region only because of the mismatch between actions which may be treated as some random factor.

In the given paper we actually present a preliminary investigation of this model and its goal is to demonstrate a potential capability of such an approach to describing complex properties of real traffic flow. Figure 1 depicts the results of numerical solution of model (1)–(4) using the characteristic values of the systems parameters employed by other models, at least, being of the same order (cf., e.g., [9]). It should be noted that the distributions obtained by numerical simulation of the developed model and constructed based on the experimental data collected by subjects with experience of driving real cars [3, 5] look rather similar.

3. CONCLUSION

The experiments conducted previously [3, 5] have demonstrated that the behavior of subjects involved into driving virtual cars should be categorized as the generalized intermittent control over mechanical systems. It consists of a sequence of alternate fragments of active and passive phases of driver behavior. The passive phase is characterized by the fact that during the corresponding time interval a driver does not change the position of the gas or break pedal. In this case the jerk plays the role of the parameter controlled directly by the driver and, so, has to be regarded as an independent phase variable determining the car dynamics. It enabled us, keeping in mind also driving real cars, to pose the hypothesis that a sophisticated description of car motion controlled by human actions requires the introduction of four dimensional phase space, where the car position, velocity, acceleration, jerk are the independent variables.

In this paper a new model for the car-following that allows for these features has been proposed. Its numerical simulation has demonstrated that the combination of the concepts of the noise-driven activation in human intermittent control and the action dynamical traps caused by the bounded capacity of human cognition can reproduce, at least, qualitatively the results of the conducted experiments.

4. REFERENCES

[1] Ian D. Loram, Henrik Gollee, Martin Lakie, and Peter J. Gawthrop. Human control of an inverted pendulum: is continuous control necessary? Is intermittent control effective? Is intermittent control physiological? *The Journal of Physiology*, 589(2):307–324, 2011.

[2] Arkady Zgonnikov, Ihor Lubashevsky, Shigeru Kanemoto, Toru Miyazawa, and Takashi Suzuki. To react or not to react? Intrinsic stochasticity of human control in virtual stick balancing. *Journal of The Royal Society Interface*, 11:20140636, 2014.

[3] Hiromasa Ando, Ryoji Yamauchi, Ihor Lubashevsky, and Arkady Zgonnikov. Anomalous Properties of Car Following: I. Driving Simulator Experiments. *this issue*, 2015.

[4] The official site of TORCS. `http://torcs.sourceforge.net/index.php`.

[5] Hiromasa Ando, Ihor Lubashevsky, Arkady Zgonnikov, and Yoshiaki Saito. Statistical Properties of Car Following: Theory and Driving Simulator Experiments. In *Proceedings of the 46th ISCIE International Symposium on Stochastic Systems Theory and Its Applications Kyoto, Nov. 1-2, 2014*, pages 149–155, Kyoto, 2015. Institute of Systems, Control and Information Engineers (ISCIE).

[6] Ihor Lubashevsky, Peter Wagner, and Reinhard Mahnke. Rational-driver approximation in car-following theory. *Physical Review E*, 68(5):056109, 2003.

[7] I. Lubashevsky, P. Wagner, and R. Mahnke. Bounded rational driver models. *The European Physical Journal B-Condensed Matter and Complex Systems*, 32(2):243–247, 2003.

[8] Arkady Zgonnikov and Ihor Lubashevsky. Extended phase space description of human-controlled systems dynamics. *Progress of Theoretical and Experimental Physics*, 2014(3):033J02, 2014.

[9] Martin Treiber and Arne Kesting. *Traffic Flow Dynamics: Data, Models and Simulation*. Springer, Heidelberg, 2012.

[10] I. A. Lubashevsky, V. V. Gafiychuk, and A. V. Demchuk. Anomalous relaxation oscillations due to dynamical traps. *Physica A: Statistical Mechanics and its Applications*, 255(3):406–414, 1998.

[11] I. Lubashevsky, M. Hajimahmoodzadeh, A. Katsnelson, and P. Wagner. Noise-induced phase transition in an oscillatory system with dynamical traps. *The European Physical Journal B-Condensed Matter and Complex Systems*, 36(1):115–118, 2003.

[12] I. Lubashevsky, R. Mahnke, M. Hajimahmoodzadeh, and A. Katsnelson. Long-lived states of oscillator chains with dynamical traps. *The European Physical Journal B-Condensed Matter and Complex Systems*, 44(1):63–70, 2005.

[13] I. Lubashevsky. Dynamical Traps Caused by Fuzzy Rationality as a New Emergence Mechanism. *Advances in Complex Systems*, 15(08):1250045, 2012.