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Research on Markov property analysis of driving cycles and its application

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ABSTRACT

The Markov property of driving cycles was discussed by making a thorough description of their essential characteristics. The Markov chain, a useful tool for designing and expressing driving cycles, has been increasingly used in the field of driving cycles in recent years. Although the Markov property of driving cycles left unproved, some researchers have taken it for granted that it is appropriate to design driving cycle with Markov chain. In our research, the vehicle dynamics model and the car-following model were used to establish the two-dimensional Markov state transition model. On the other hand, the driving data from the city of Changchun were collected to analyze how states (in Markov theory) correlation changes with the increase of time intervals. After the Markov property had been proven, the theory of ergodicity was applied to reveal the relationship between velocity-acceleration joint probability distribution (VA Probability) and state transition matrix. Finally, the application of Markov property was also discussed briefly. This research will lay a theoretical foundation for designing driving cycles and ECO driving (Economical and Ecological).

Introduction

Driving cycles have a wide range of applications in both transportation and automotive field. Driving cycles can represent the operating condition of a certain region or a certain vehicle type. It is the important index for emission measuring also the basic data for vehicle design. It also serves as an important simulation input to improve the performance of in-use vehicles. Designing driving cycles is the abstraction and sublimation of large amount of driving data. Although there are many methods for designing driving cycles, the cognition about its essential characteristic is not very clear.

The method of optimization is usually applied to construct driving cycles because the essential characteristic hasn't been revealed clearly. Designing ideas of optimization mainly based on clustering and combination algorithm of micro-trips (Bata et al., 1994; Andre, 1996; Liu et al., 2008; Shi et al., 2009a, 2009b), which just disassembles the velocity information in space, and ignores the essential characteristic. Although it can meet the demand of engineering, the algorithm is complicated and time-consuming. Furthermore it can't fit the dynamometer test which needs long time information. There is no doubt that it is more reasonable to design driving cycle by following its essential characteristics. Generally, driving cycles are considered as a stochastic process, which include the orthogonal increment process, the independent increment process, the Markov process, the normal process and so on. This paper presents a full validation that vehicle driving cycles are Markov process.

In recent years, many scholars have applied the Markov chain to designing driving cycles, but the argumentation of its theoretical support was omitted (Bishop et al., 2012). In 2002, Lin (2002), Lin and Niemeier (2003) from University of

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California, presented a method of constructing driving cycle with Markov chain in her doctoral thesis in which driving patterns such as acceleration, deceleration, idling are defined as states in Markov process. However the author didn't offer a reasonable explanation on the state defined method. Whether it is appropriate to define states in such long time scale still needs to be substantiated. Tazelaar et al. (2009) from Holland considered driving cycle as stochastic processes and traffic condition as random (white) noise. Auto-regressive and moving average (ARMA) model was proposed to generate driving cycles. Both statistical and spectral analysis were used for comparing generated driving cycles with original driving cycles. The Markov model adopted by Gong et al. (2011, 2010) contained both velocity and acceleration information. The state defined by Gong was based on the every second velocity and acceleration information, which is different from Lin Jie's work. The driving cycle designed by Gong matched the statistics of the original data set perfectly. Liu et al. (2012) also used Markov chain to design driving cycles in different cities.

The Markov property of driving cycle has also been skillfully applied to the field of Hybrid Electrical Vehicle. Kolmanovsky et al. (2002) proposed an innovative approach based on stochastic dynamic programming (SDP) to develop optimal operating policies for automotive power train systems. The driving cycle in this situation is performed not for a pre-determined but in a stochastic, "average" sense over a class of trajectories generating from an underlying Markov chain. Lin et al. (2004) employed the optimal control strategy for power management of HEV. The power demand from the driver was modeled as a random Markov process, and the prediction of demand power can be calculated from the transition probability. Although all these outcomes illustrate that the Markov chain method is more effective, the demonstration of its essential characteristic can't be omitted.

Overall, Markov chain has been widely accepted as the most accurate model of driving cycle. However, Markov property of driving cycle, its basic attribute, hasn't been proved up to now. Commonly, driving cycles are always expressed by velocity and time sequence, but the expression with two-dimensional information, i.e. velocity and acceleration can better reflect actual driving characteristics. Consequently, velocity and acceleration information is employed in this study to analyze its essential characteristics and reveal the Markov property of driving cycle.

The Markov property analysis of driving cycles

In this chapter, the wavelet theory is applied to analysis the different frequency components of driving data. The results show that both high and low frequency signals are important components of driving cycles. This conclusion is further used in Markov property analysis in the next step. Dynamic models and car-following theory were all used to build up state transition equation on small time scales. The data analysis in the last part proved that only under the condition of small time interval, does certain probability state transfer exist between the current state and the next one.

Dynamics analysis

Wavelet analysis

The wavelet analysis can benefit the careful observation of signals. In this study, wavelet theory is applied to analyzing the components of velocity and decomposing driving cycle information into several signals with different frequency. Take the driving cycle of Changchun for example, using the wavelet of db1 performed 3-level wavelet decomposition. One series of approximate signal (low-frequency) and 3 series of detail signals (high-frequency) can be got. Merge the 3 detail signals into one, and the result can be shown as Fig. 1.

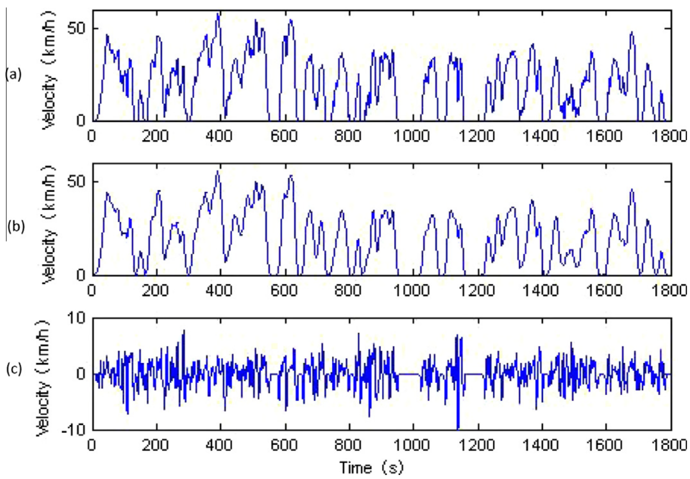

Fig. 1. Wavelet decomposition of Changchun data. (a) The Driving Cycle of Changchun. (b) Approximate signal. (c) Detail signal (3 level all added).