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Development of a driving simulator based eco-driving support system

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ABSTRACT

This research developed an eco-driving feedback system based on a driving simulator to support eco-driving training. This support system could provide both dynamic and static feedback to improve drivers' eco-driving behavior. In the process of driving, drivers could get voice prompts (e.g., please avoid accelerating rapidly) once non-eco-driving behavior appeared, and also could see the real-time CO_2 emissions curves. After driving, drivers could receive an eco-driving evaluation report including their fuel consumption rank, potential of fuel saving and driving advice corresponding to their driving behavior. In this support system, five items of non-eco-driving behavior (i.e., quick accelerate, rapid decelerate, engine revolutions at a high level, too fast or unstable speed on freeways and idling for a longer time) were defined and could be detected. To validate this support system's effectiveness in reducing fuel consumption and emissions, 22 participants were recruited and three driving tests were conducted, first without using the support system, then static feedback and then dynamic feedback utilized respectively. A reduction of 5.37% for CO_2 emissions and 5.45% for fuel consumption was obtained. The results indicated that the developed eco-driving support system was an effective training tool to improve drivers' eco-driving behavior in reducing emissions and fuel consumption.

1. Introduction

Eco-driving, the concept of changing driving behavior and vehicle maintenance practices to improve fuel efficiency and reduce greenhouse (GHG) emissions of existing vehicles, has been demonstrated to have a great potential in reducing fuel consumption and emissions (Martin et al., 2012). It has been reported that eco-driving could on average reduce fuel consumption between 5% and 10%, and the reduction percent could even increase to 20–50% for excellent performers (Martin et al., 2012). In addition to less fuel consumption and reduced emissions, eco-driving also offers benefits such as cost saving, greater safety and riding comfort, and less noise pollution (Barth and Boriboonsomsin, 2009). In recent years, many cities in China have seen accelerated levels of pollution and vehicle emissions are major contributors to the deteriorating air quality (Beijing Municipal Statistics Bureau, 2011). The quality of life and the health of general public in these cities were impacted negatively (Zhu et al., 2005). To conserve natural resources, protect our environment, and enhance the wellbeing of the general public, energy conservation and emissions reduction in transportation are of great and immediate importance. Therefore, eco-driving has gained more and more prominence in China and Chinese government has planned to start a campaign to train drivers to drive more economically and environment-friendly (Nie and Zhang, 2014).

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According to previous studies, eco-driving training mainly includes static and dynamic types. A static approach aims at urging drivers to apply general eco-driving techniques after learning through brochures, websites and other information sources. Dynamic eco-driving involves providing direct feedback to the drivers while driving (Martin et al., 2012). As eco-driving has been widely implemented in the European Union, Japan and other developed countries, a number of approaches to driver feedback have been developed (Gonder et al., 2011). These eco-driving feedback methods were generally used to train drivers to improve their eco-driving behavior.

In general, the eco-driving feedback may be carried through three sensory modalities: visual, auditory, and haptic (Azzi et al., 2011). The main types of eco-driving feedback include conventional dashboards, hybrid vehicle dashboards, smart phone applications, offline feedback systems, dedicated aftermarket feedback devices and haptic pedal feedback (Gonder et al., 2011). Using these eco-driving systems and devices, drivers could know their relative levels of driving with respect to fuel consumption and emissions, and gain tips to improve driving skills (Satou et al., 2010). Besides, the results of validation experiments demonstrated that these feedback approaches were effective in saving fuel and reducing emissions to varying degrees (Boriboomsomsin et al., 2011; Martin et al., 2013; Lee et al., 2010).

In addition, the strengths and weaknesses of each type of eco-driving feedback were also compared in previous studies (e.g., Gonder et al., 2011). The dedicated aftermarket feedback devices and haptic pedal feedback were two of the most effective way to support eco-driving, but these two approaches needed installation and setup and also tended to be costly. While, eco-driving on-board devices (e.g., vehicle dashboard, smart phone applications) and offline feedback were usually used to influence driver behavior through visual and auditory feedback, which were easier to apply but might have negative effect on driver attention and performance (Reimer et al., 2006; Wang et al., 2010).

In China, however, eco-driving was just introduced in recent years and this fuel-efficient driving concept is not well known by many drivers. According to a recent survey about drivers' understanding of eco-driving carried out by Beijing Transport Energy and Environment Centre (2013), more than 75% of the drivers did not have a good understanding of what eco-driving is, and around a quarter of the drivers had never heard about eco-driving. Meanwhile, drivers' awareness to buy efficient cars was also extremely low. Furthermore, the limited previous studies in China were focused on analyzing the potential of eco-driving in reducing fuel consumption and emissions, and exploring the effective methods to educate and promote eco-driving and exploring technologies for monitoring vehicle energy usage and emissions. There was no systematic eco-driving training mechanism and the methods to support eco-driving training hardly exist. Although eco-driving feedback system has been widely used in many developed countries (e.g., Ando et al., 2010; Gonder et al., 2011), these systems might not be suited for Chinese drivers due to different engine technologies, driving habits and driver population. Particularly, the overwhelming majority of the licensed drivers in China are not very experienced drivers. To our knowledge, the limited research devoted to develop eco-driving feedback system or devices in China was only concentrated on designing and discussing the concept of eco-driving assistance system (Gui et al., 2013).

Summarizing above, the main objective of this study is to develop a more comprehensive eco-driving system to support drivers training. Different from the single function of the similar product discussed above, the current developed support system could provide both the static evaluation report and dynamic feedback. Moreover, it is more cost-effective than the currently-existing dedicated aftermarket feedback; and much convenient to apply without complicated installation. Besides, as visual and auditory feedback might impact driver attention and performance in the process of driving, the interface of the developed system is designed much more intuitive and easily to understand and operate.

With the obvious benefits in guaranteeing driving safety and the ability to control influencing factors, driving simulator technologies have been widely applied to driving training and also been demonstrated to be very effective (e.g., Muttant et al., 2014; Wang et al., 2010; Zafian et al., 2014). Eco-driving training based on driving simulator can focus on dynamic approaches (Hiraoka et al., 2009). Therefore, this study aims at developing an eco-driving feedback system to support eco-driving training in a driving simulator platform. On one hand, this eco-driving support system could be used to estimate the characteristics of drivers' current driving behavior in fuel consumption and emissions. On the other hand, this support system could help drivers improve their eco-driving behavior. In addition, the study results would lay a foundation for development of vehicle-mounted eco-driving feedback devices.

2. System development

2.1. Objectives of eco-driving support system

To estimate driving behavior with respect to saving fuel and reducing emissions and help drivers learn how to drive more environment-friendly, the eco-driving support system was designed to have two kinds of information feedback: dynamic and static feedback. In the process of driving, this support system mainly provides real-time voice prompts of non-eco-driving behavior and instant CO_2 emissions curves to drivers. After driving, drivers could check their driving record through the eco-driving support system, and they could get pertinent driving advice, fuel consumption rank and the potential of fuel saving. The cycle of eco-driving support system was designed as shown in Fig. 1.

In this support system, five types of non-eco-driving behavior were defined, mainly including quick accelerate, rapid decelerate, engine revolutions at a high level, too fast or unstable speed on freeways and idling for a longer time. The main reason for driving behavior choosing has three parts: (1) these five behaviors are the common rules of eco-driving in