Behavior Change for Optimal Battery Performance and Aging of Electric Vehicles

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Abstract. To reduce greenhouse gas emissions, fuel efficiency driver interfaces (FEDIs) have been proposed and shown positive results. While FEDIs can be a stopgap, it does not seem to solve the problem in a fundamental way. Electric vehicles can radically decrease greenhouse gas emissions, but they have also brought about another issue, "battery" performance and aging. Research shows that driving style can affect battery performance and aging of electric vehicles. In the present paper, we introduce our multiple approaches to develop persuasive technology for driver behavior modification in electric vehicles. To investigate the effects of driver characteristics and driving style on battery performance and maintenance, we propose a research study using driving simulation data, naturalistic driving data, and driving style questionnaires.

Keywords: battery aging · driving style · electric vehicles · persuasive technology

1 Introduction

Greenhouse gas emissions are getting a more and more critical issue and transportation fuels take up around 30% of them in the US [1]. Fuel efficiency driver interfaces (FEDIs) have been implemented and shown positive effects on fuel efficiency and eco-driving [2]. However, it may not be a fundamental solution. As an alternative, the transportation electrification can tremendously reduce the greenhouse gas emissions. However, here is another barrier to successful transportation electrification: battery for electric vehicles. The battery of electric vehicles usually requires higher cost and has a shorter life span than internal combustion engines. Empirical research has shown that driving behavior or driving style influences the energy consumption and the battery aging [3]. The goal of the present paper is to explore what type of strategies can promote good driving habit so that the driver can effectively and efficiently manage electric vehicles by keeping battery performance and aging optimal. Given that the concept of electric vehicle is still new, a number of approaches can be possible, including education and training, policy and law making, etc. In the present paper we will investigate driving style and driver characteristics and in-vehicle persuasive technology for driver behavior modification.

2 Driving Style and Aggressive Driving

Just as aggressive driving and different driving styles affect fuel efficient driving and road safety, these variables are closely related to battery performance and aging of electric vehicles. Different types of driving style measures have been suggested to predict and analyze different driving behavior and traffic situation. Moreover, a study proposes that individual driver's driving style might even affect autonomous vehicles [4]. Among others, the recently validated multidimensional driving style inventory (MDSI) [5] seems to have more reliable factors than previous ones: angry driving, anxious driving, dissociative driving, distress-reduction driving, and careful driving. Depending on the driving style, the phenomenon may vary and persuasive strategies may need to be differentiated accordingly. Given that aggressive driving is considered a manifestation of anger, the anger response style model [6] can also help tracing the source of aggressive driving. Based on Stemmler, some extreme people can be classified as the "anger-out" style in terms of habitual anger response styles and broad personality dimensions if they consistently show strong index in physiological, behavioral, and experiential anger response. The persuasive technology we will develop can mainly target at this type of population.

3 Hypotheses

(1) Just as aggressive driving degrades fuel efficient driving, aggressive driving will negatively affect battery performance and aging of electric vehicles.
(2) If well-designed, in-vehicle persuasive technologies will educate drivers and help them change their behavior patterns, and eventually form good habit for better battery maintenance.

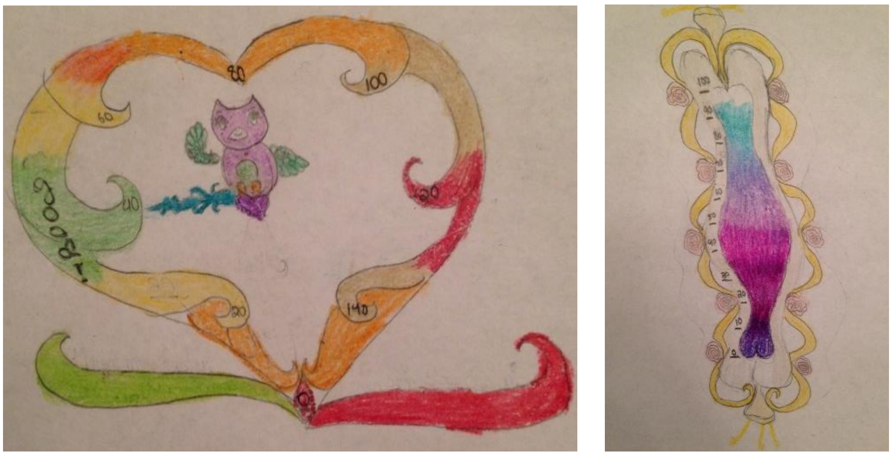
4 Approaches

To illustrate, let's consider the wireless recharging lanes on the highway. Drivers need to keep a constant speed to effectively recharge their car on that lane. However, drivers might respond to the wireless recharging lanes very differently, depending on their driving style and characteristics or traffic circumstances. This different interaction pattern will specifically influence battery performance and aging.
(1) To deal with aggressive driving, we can focus on either "*aggressiveness*" or "*driving*". We have conducted research on emotion detection and intervention. To estimate driver affective states, we have developed a real-time facial detection system [7] and used neurophysiological equipment (e.g., ECG, fNIRS, respiration, etc.) [8, 9]. Further, we have conducted research on mitigation technologies based on a robust emotion regulation model [10]. Another approach would be intervening directly with driving performance rather than touching driver emotion or angry state. The present paper mainly deals with this second approach to promote good habit in driving, regardless of their emotional states.

(2) Again, we can approach this problem, using two different strategies in terms of intervention timing: *Real-time displays* vs. *analysis and interpretation afterwards* [11]. Real-time displays can be more effective because they can provide just-in-time feedback. However, the real-time display can be another source of distraction if it requires driver attention. Feedback after driving can provide more detailed information, but the drivers might not exactly remember how they have driven. It is also hard to force them to remain in the car to see that analysis. Combining both methods would be another solution.

(3) For the real-time displays, we can provide *guidelines* (e.g., optimal speed on the wireless charging lane) if drivers are not familiar with the concept or we can provide *reinforcement* once the drivers are accustomed to how to do (e.g., commending when doing a good job).

(4) A number of *visual displays* can be utilized for providing guidance (e.g., coloring an appropriate speed area in the speedometer) [12] or feedback (e.g., the power level increases as recharging progresses) (Fig. 1). *Auditory displays* can also be used for similar purposes. Continuous sonification can provide guidance sounds and/or drivers' performance [13]. Speech feedback can be used to reinforce drivers' performance. *Tactile feedback* can also be an alternative in a limited form.



(a) **(b)**

Fig. 1. Conceptual sketch of visual displays for (a) guidance for the optimal speed zone for recharging and (b) feedback for the battery level.

(5) We can also think about other ideas rather than traditional displays, such as *gamification* or an *intelligent tutor* for behavior modification. In terms of promoting engagement or providing incentive, these methods could be more effective than the traditional ones. Again, if aggressive driving is a decisive factor, we can attempt to mitigate aggressive driving by regulating drivers' emotional state or distract them from the emotional source. With any approach, the goal should be forming new long-term habit that can result in optimal battery performance and aging as well as road safety.

5 Research Plans

We will design different types of in-vehicle persuasive technologies – in terms of intervention timing, display modalities, guidance vs. reinforcement, or other strategies, etc. – and conduct successive experiments with these alternative technologies in the driving simulator. Then we will compare the simulation data with naturalistic driving data, and also correlate them with driving style questionnaire data.

From an engineering point of view, each in-vehicle persuasive technology will be translated to specific driving cycles, which can then be used to simulate how an electric vehicle will perform under such requirements. For this, we will use the software developed [14], which allows to automatically simulate any driving cycle, and study the dynamic battery performance, and evaluate and quantify the capacity fade in those conditions. With this, it will be able to quantify the battery aging to specific driving behaviors, and also quantify how each pervasive measure actively improves it.

6 Conclusion

Now, we see electric vehicles on the road, but they are still fairly new and not much empirical research has been conducted on them. We will investigate the effects of driving behavior pattern and driver characteristics on battery performance and aging of electric vehicles. In addition to drivers' behavior with the wireless recharging lanes, their interaction pattern with the electrical grid at company or home might specifically influence battery performance and aging, too. We plan to collect naturalistic driving behavior data in real world and compare them with individual driver's behavior in the driving simulator, and also simulate the collective driving cycle to deepen our understanding of their behavior and its effects on battery aging.

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