Driving Behavior Prompting Framework for Improving Fuel Efficiency

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***Abstract*—With escalating fuel prices, limited fossil fuel reserves and increasing carbon emissions, significant efforts are being made to decrease fuel consumption in vehicles. While, drivetrain improvements play a major role in improving fuel economy, it has been identified that fuel efficient driving behavior is a viable method for increased fuel efficiency. Thus, if the optimal fuel efficient behavior can be identified, it can be used to increase the fuel efficiency of drivers. However, once the optimal fuel efficient behavior is identified, it has to be presented to the driver, while the vehicle is being driven. Thus, this method of information representation has to be un-obstructive and easy to comprehend. This paper presents a low cost framework and a hardware setup for prompting drivers on fuel efficient behavior. The presented framework includes an information rich, intuitive un-obstructive visualization. The presented method was implemented using low cost, commercial-off-the-shelf hardware and tested on a sample of buses selected from the Idaho National Laboratory (INL) bus fleet. Different types of visual cues were and evaluated by professional drivers for obstructiveness, interpretability and intuitiveness.**

Keywords—Visualization; fuel efficiency; driver prompting; passive driver assistance

I. INTRODUCTION

Vehicle fuel efficiency is a key area of research that is gaining increasing attention. Escalating fuel prices and the need to reduce carbon emissions is a driving factor for increasing fuel efficiency in vehicles [1]-[3]. Furthermore, due to various factors such as the increasing number of vehicles in use, the fuel consumption for the transportation sector is projected to further increase in coming years [1], [4]. In light of this situation, governments around the world are enforcing increasingly strict fuel consumption regulations [2], [5].

One of the most researched methods of achieving better fuel efficiency is by improving the physical design of the vehicle [2], [3]. This entails improvements on specific components of the vehicle such as engine, gearbox, and aerodynamics [2]. Other approaches include weight reduction such as the use of advanced carbon-fiber body-structure components. Such improvements reduce fuel consumption mainly by reducing driving resistance, weight, and achieving efficient energy transition. Furthermore, alternative drivetrain designs with different propulsion technologies are also being investigated as a solution for fuel efficiency problem [3]. However, these methodologies have a long implementation time, high implementation cost, and will not affect the vehicles that are currently on the road [6].

However, it has been demonstrated that the fuel economy in vehicles not only depend on the drivetrain, but also on its operation [7]-[11]. Furthermore, it is clear that the most influential aspect that affects the vehicle performance and operation is the driver.

Thus, it has been shown that more fuel efficient driver behavior can increase the fuel efficiency by about 10-15% [6], [12], [13]. Therefore, some drivers may not be achieving the optimal fuel efficiency of the vehicle [1]. Accordingly, identifying optimal fuel efficient driver behavior and presenting such behavior to drivers may enable significant fuel savings. These methods are known as passive fuel efficiency improvement methods [14]. Because these methods utilize already existing vehicles, and no changes in the configuration of the vehicle is necessary, they are the most cost effective methods of improving fuel efficiency [6], [15]. However, the effectiveness of these methods relies on the willingness of the driver to change behavior as well as how skilled he or she is in applying the relevant behavior given the context of the situation [13].

Passive driver assistance methodologies can be used that prompt the driver while the vehicle is being driven. This can be done using real-time audible, visual or other signals, so that the driver can follow the most fuel efficient behavior [14]. However, in order for the prompts to be effective, they should be: 1) un-obstructive, 2) intuitive and easy to understand, 3) provide the driver with clear and accurate information, 4) take safety into account [6].

This paper presents a framework for prompting drivers with visual cues in real-time, regarding optimal fuel efficient behavior. The framework incorporates data collection, data pre-processing, generation of visual cues and presenting the generated visual cue to the driver. The presented framework utilizes the optimal fuel efficient behavior extraction method presented in [1]. The presented driver prompting framework was implemented using low-cost Commercial-Off-The-Shelf (COTS) hardware. The framework was tested using buses from the INL fleet operations that were in use on a daily basis to carry workers from the town of Idaho Falls to the site, some 50 miles away. Several different types of visual cues developed by the authors were implemented in visual display interfaces and

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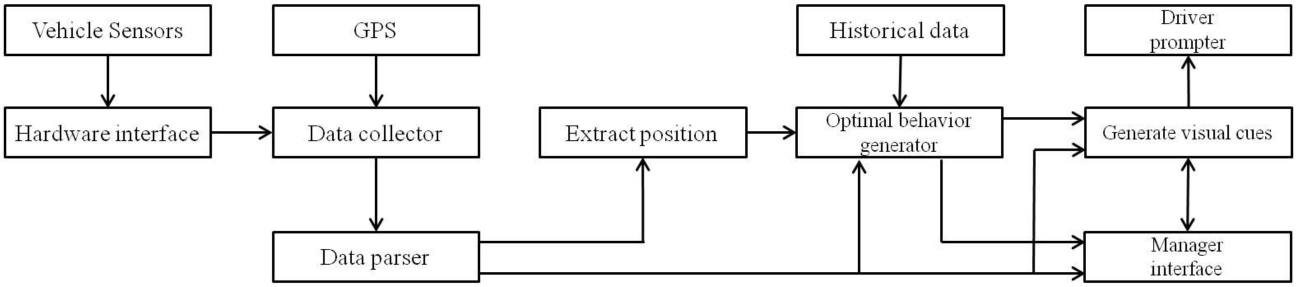


Fig. 1 The overall framework for the driver prompting method

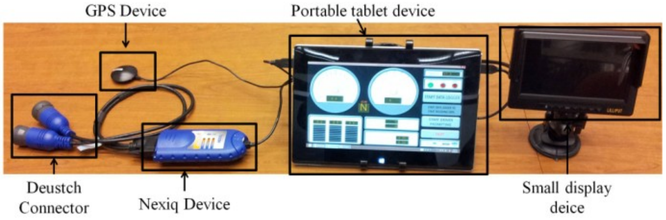


Fig. 2 The hardware implementation of the presented framework

tested and evaluated by professional bus drivers in real-world environments for obstructiveness, interpretability and intuitiveness.

This paper is organized as follows; section II details the presented driver prompting and visualization framework. Details of the specific system implementation are given in Section III. Section IV presents experimental results and finally, section V presents conclusions regarding the project and the potential of achieving fuel efficiency by engaging the driver.

II. PRESENTED FRAMEWORK FOR DRIVER PROMPTING

The overall architecture of the presented framework is depicted in Fig. 1. The overall process can be separated into 3 steps: 1) data collection, 2) data processing, and 3) visualization. Each step is detailed below.

Step 1: Data about the state and the position of the vehicle is collected in this step. All modern vehicles are equipped with sensors throughout the vehicle that gather and feed information to on-board computers that monitor various systems in the vehicle. This sensor information can be collected via industry standard hardware interfaces. GPS is used to record the position of the vehicle. A data parser is used to decode the collected data and extract the speed of the vehicle.

For accurate positioning, a combination of latitude and longitude from the GPS and the speed of the vehicle are used. GPS can be used to accurately measure speed of the vehicle as well, however, this requires high end GPS devices with high accuracy and the speed calculations may suffer if the GPS satellite signal is lost.

Step2: The collected data is processed using the method described in [1]. Using a combination of historical data collected from previous drives over the same route and minimum and maximum speeds allowed, the optimal speed for fuel efficiency for the current position of the vehicle is generated. This optimal speed and the current speed of the vehicle are then used to generate the prompting visualization.

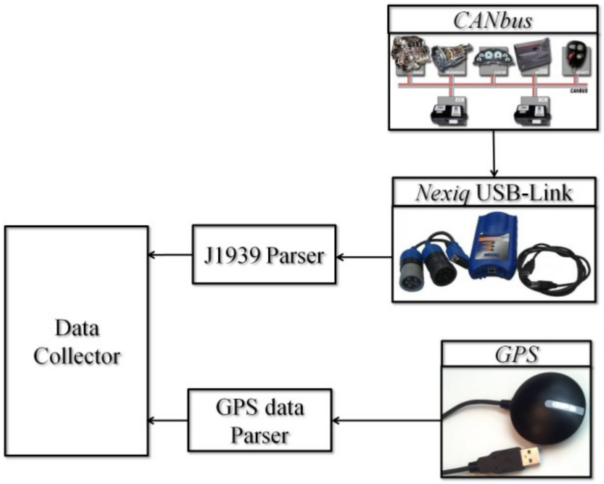


Fig. 3 The implemented data collection and parsing system

Step 3: In this step a prompt is presented to the driver about the optimal fuel efficient behavior for the current state of the vehicle. The prompt is presented as a visualization displayed on a small display device located on the periphery of the dashboard of the vehicle. The difference between the current speed of the vehicle and the generated optimal speed for fuel efficiency is used to generate appropriate visual cues for prompting.

A manager interface was developed and implemented for controlling the visualization presented to the driver and monitoring the state of the vehicle for experimental purposes. However, the full functionality of the presented framework can be retained even without the manager interface.

III. IMPLEMENTATION

As mentioned, the presented driver prompting framework was implemented using low-cost COTS hardware and tested on the INL bus fleet. The INL bus fleet consists of over 80 buses travelling in preset routes [16]. The MCI D-series model D4505 buses were selected for implementing the presented framework. This section details the specifics of the implementation.

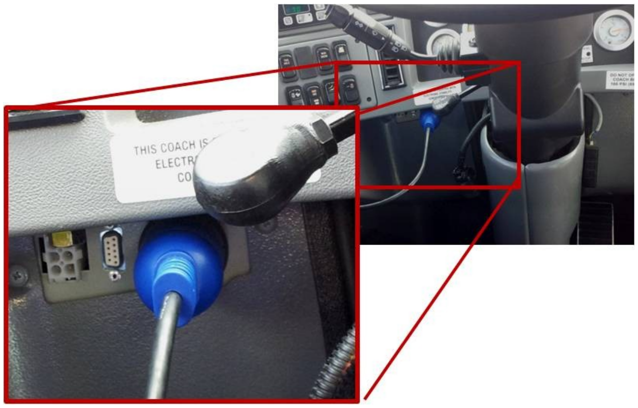
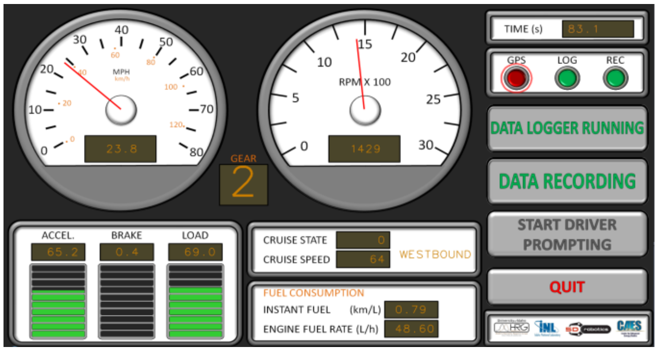


Fig. 4 Deustch connection in MCI D-4505 bus



TIME (s) 83.1
23.8
GEAR 2
1429
ACCEL. 65.2
BRAKE 0.4
LOAD 69.0
CRUISE STATE 0
CRUISE SPEED 64
INSTANT FUEL (km/L) 0.79
ENGINE FUEL RATE (L/h) 48.60

Fig. 5 The GUI of the implemented manager interface

The COTS hardware used and the connectivity is shown in Fig. 2. A small touch-screen tablet device was used for data parsing and processing (see Fig. 2).

A. Data Collection and Parsing

The MCI D4505 bus uses the industry standard CANbus for communication and data transmission between various systems within the bus [17]. Fig. 3 shows the implemented overall data collection and parsing system.

A 6 pin Deustch connection is provided in the bus for interfacing with the CANbus architecture (See Fig. 4). As the interfacing device, the Nexiq^{TM} USB link device was used [18]. The Nexiq^{TM} USB link enables reading raw data sent via the CANbus using a USB connection. However, the raw data passed through the CANbus is encoded in a standard format. In the case of MCI D4505 the J1939 standard is used [19]. Therefore, a J1939 parser was implemented to decode the data into readable format.

As the positioning device, a low cost USB connected GPS device by US Global Sat Inc. was used [20]. Similar to the Nexiq^{TM} device, a separate data parser was implemented for decoding the raw data read from the GPS device.

Once the position of the vehicle is extracted using GPS, the actual position is recalculated for further accuracy using the speed of the bus read from the Nexiq^{TM} device, and the latitude and longitude of the road.

TABLE I

DETAILS OF THE IMPLEMENTED VIEWS

View	Color		Other visual cues	
	Speed up	Slow down	Speed up	Slow down
View 1	Green	Red	-	-
View 2	-	-	Arrow up	Arrow down
View 3	Green	Red	Arrow up	Arrow down
View 4	-	-	Speedometer dial	Speedometer dial
View 5	Green	Red	Speedometer dial	Speedometer dial

B. Generating Visual Cues and Driver Prompting

The optimal behavior extraction method for fuel efficiency using historical data, presented in [1] was used to generate an optimal speed profile for a given route.

Using the extracted position and optimal speed profile, the optimal fuel efficient speed for the bus is first calculated. A visual cue is then generated that is proportional to the difference between the current speed of the bus and the calculated optimal speed for fuel efficiency.

For presenting the driver with the generated visual cue, a small, self powered, mountable display was used. The display used was a 7 inch HD (1280X720), high brightness (450cd/m^2) display with an inbuilt rechargeable battery (See Fig. 2). A suction mount was used to mount the display on to dashboard of the bus so that the display was in the periphery of the driver vision, without obstructing the instruments or the road view. Furthermore, the screen can be moved according to driver preference. As a check on the mounting of the device, the drivers were polled and the consensus among them was that the display was in a useful and acceptable placement.

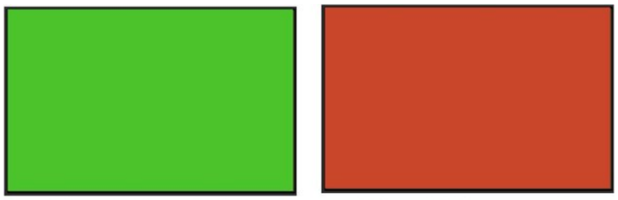
C. Manager Interface

A software-based manager interface was implemented for the purposes of this experiment. The manager interface was used by the experimenters while on board the bus and consists of a display for the overall state of the bus and tools for controlling the visual cues presented to the driver.

The manager interface was implemented on a small hand-held, touch-screen tablet device for easy operation. Fig. 5 shows the implemented graphical user interface for the manager interface. The experimenters maintained a seated position behind the bus drivers, and y the drivers were not aware of which cues/prompts would be selected.

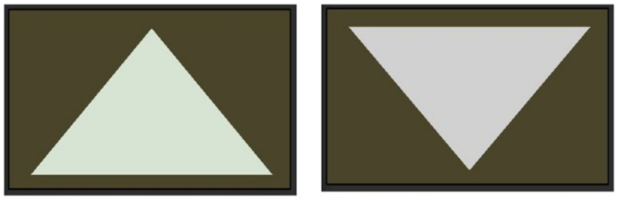
IV. EXPERIMENTAL RESULTS

As mentioned, the visual cues were generated according to the current speed of the bus and the optimal fuel efficient behavior extracted from the bus. Using these two values, 5 different types of views with different visual cues were implemented. The implemented views are shown in Fig. 6. Table I briefly describes the visual cues used in each view.



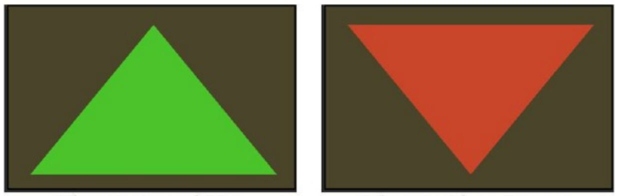
View 1 (Speed-Up) View 1 (Slow-Down)

(a)



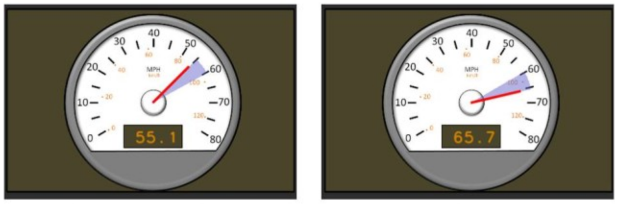
View 2 (Speed-Up) View 2 (Slow-Down)

(b)



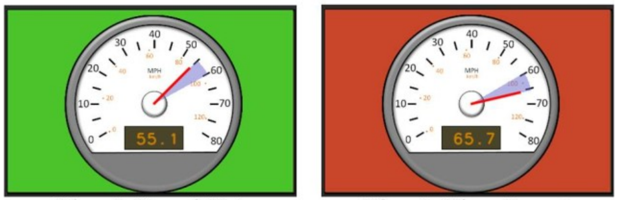
View 3 (Speed-Up) View 3 (Slow-Down)

(c)



View 4 (Speed-Up) View 4 (Slow-Down)

(d)



View 5 (Speed-Up) View 5 (Slow-Down)

(e)

Fig. 6 Different types of visual cues tested

Fig. 6 (a) depicts view 1 where, the color of the screen is changed according to the difference in the optimal speed and the current speed of the bus. If the current speed of the bus is higher than the optimal speed, the screen color is changed to red, and the intensity of the color is proportional to the difference in the speeds. Similarly, if the current speed is lower than the optimal speed the color is changed to green. If the current speed is equal to the optimal speed, then the screen is left blank. No data on exact speed is presented.

Fig. 6 (b) depicts view 2. This view shows an arrow pointing upwards or downwards depending on whether the current speed is lower or higher than the optimal speed. The transparency of the arrow is proportional to the difference of speeds.

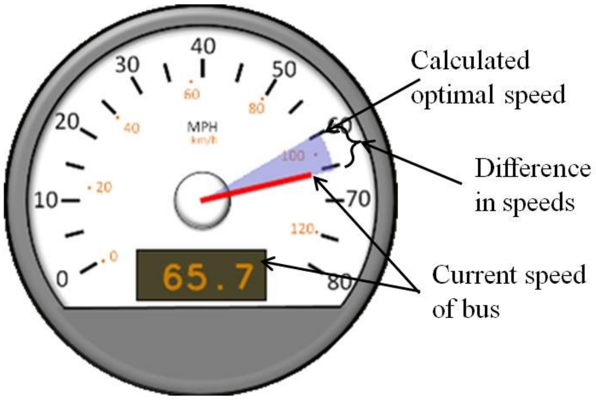


Fig. 7 Speedometer dial based visual cue used for View 4 and 5

View 3 was a combination of view 1 and view 2, where an arrow is displayed similar to view 2 and the color of the arrow is changed similar to the view 1. View 3 is shown in Fig. 6 (c).

Fig. 6 (d) depicts view 4. In this view a speedometer dial that is similar to the dial of the bus is displayed. The current speed of the bus is shown using a red needle and a digital display. The difference between the current speed and the optimal speed is depicted as a triangular wedge overlaid on the dial (See Fig. 7). Thus as the difference between current speed and the optimal speed is reduced the size of the wedge is also reduced. Furthermore, the transparency of the triangular wedge is proportional to the difference in the two speeds.

TABLE II

AVERAGED RESULTS OF THE EVALUATION OF DIFFERENT VIEWS BY PROFESSIONAL DRIVERS (1-WORST, 10-BEST)

View	Obstructiveness	Intuitiveness	Understandability	Overall
View 1	8.2	3.6	2.4	3.3
View 2	8.1	4	2.4	3.8
View 3	8.3	4.2	5.8	5.3
View 4	8.6	8.2	7.9	8.3
View 5	8.6	8.4	9.1	9

Finally, a view combining view 4 and view 1 was implemented as view 5 (Fig. 6 (e)). This view consists of the speedometer dial in view 4, while the background color is changed similar to view 1. This display contains representation of actual speed, desired speed via wedge location and size, and a background containing color coding for desired driver response.

These views were evaluated by 10 different professional INL bus drivers on a 10 mile route. Fig. 8 shows the implemented system on a bus evaluated by the drivers. The drivers evaluated the views based on their obstructiveness, interpretability, intuitiveness, ease of understanding, and overall preference. Each driver gave the views for each of the

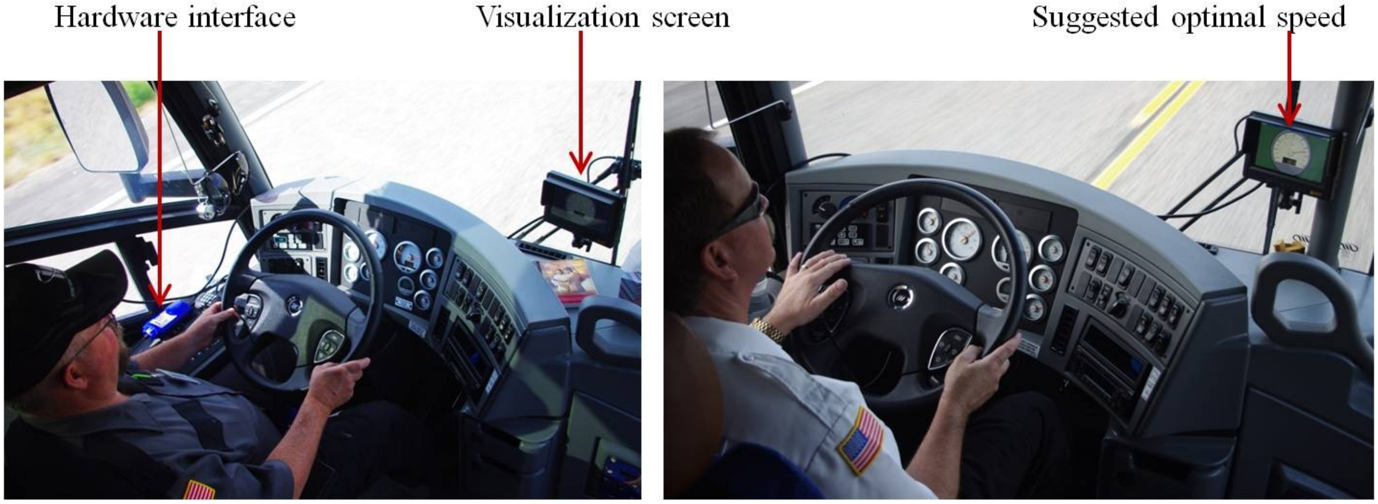


Fig. 8 The presented framework and visual cues evaluated by professional bus drivers

metrics a score of 1-10 where 1 is the worst. The averaged results of the scores are shown in Table II.

The basic colored view (view 1) was the most poorly rated because of the low interpretability. With this presentation method, the drivers knew how to slow down or speed up, but not to what extent. Views 4 and 5 scored the highest overall, as the drivers preferred the familiarity of the speedometer dial and knowledge of how close they were to the optimal speed indicated by the size of the "pie wedge" portion of the display. View 5 was the more preferred because of additional colored background.

V. CONCLUSIONS

The need for safety and fuel efficiency has been established and is of growing importance worldwide. Although, fuel efficiency varies with both the vehicle and the driver, it is easy to overlook the potential contribution to efficiency that drivers can make. In fact, our quick survey concludes that suggestions on driver efficiency tend to be along the lines of selecting the proper grade gasoline and oil, the proper periodicity for tune ups and maintenance, checking auto emissions and looking for signs of oil seepage. In contrast to some of these approaches, this paper presented a novel framework for prompting professional drivers on fuel efficient driving behavior based on the current state of the vehicle. The presented framework included a full hardware setup and a low-cost, information rich, un-obstructive, intuitive visualization for presenting drivers with visual cues for fuel efficient driving behavior.

The presented framework was implemented using low cost COTS hardware and tested on the Idaho National Laboratory (INL) bus fleet. Several different types of visual cues were implemented and were evaluated by professional bus drivers on obstructiveness, interpretability and intuitiveness. In the case of the perceived usefulness of these displays for efficiency feedback, a more information rich display was preferred among bus drivers.

Near term future works entails further testing the usability of the presented method in the real-world by analyzing empirical data for efficiency determined from routes driven with and without efficiency prompting to the driver preference data collected in this study. These data are expected in Spring 2014. Furthermore, in the longer term, the presented system will be tested for safety in adverse conditions in a controlled environment. Collecting further data on longer bus routes and evaluating the fuel efficiency gains achieved by the presented framework will also be performed.

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