Eco-Driving Assistance Systems for Commercial Vehicles

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Abstract. In this paper, a novel concept for eco-driving assistance systems for on-road and off-road commercial vehicles is addressed. Aiming at ensuring a trade-off among energy consumption, mission time and optionally driving comfort, an optimization problem is defined and an appropriate solution based on a vehicle model and an environment model is proposed. Furthermore, due to the crucial importance of the visualization and interaction, novel human-centered approaches are presented. The whole concept is evaluated in a lab environment.

1 Introduction

Eco-driving assistance systems promoting a fuel-efficient driving style are a powerful and cost-efficient technology to decrease the fuel consumption as well as the greenhouse gas and pollutant emissions. The potential to reduce the consumption is generally between 15 % and 30 %, depending on the vehicle type and the driving profile [1,2].

However, the available eco-driving assistance systems in cars and on-road commercial vehicles usually use only limited data and simple but limited approaches for visualization and interaction. Furthermore, developments and applications of the economy assistance for off-road commercial vehicles are rarely addressed in the literature. Hence, substantial research to these aspects is required.

A survey of fuel economy driver interfaces for on-road vehicles is given in [3]. A typical example is the estimation and indication of the current and average fuel consumption. For the estimation simplified vehicle models are utilized and enviroment information is not considered. An advanced eco-driving assistance system based on fuzzy rules is proposed in [4]. Eco-driving assistance systems based on dynamic programming (DP) are introduced in [2,5]. However, to account for disturbances, e.g. due to traffic, an online computation of the optimal driving strategy is required. An online computation is, however, not possible with DP due to high computation times.

Eco-driving assistance systems for off-road commercial vehicles are rarely studied. In [6] an optimal operation strategy for a wheel loader is proposed. The optimization problem for a wide range of off-road commercial vehicles is, however, still unsolved.

Furthermore, eco-driving assistance systems are currently often not very intuitive and the suggestions are partly not easy to follow. In this paper innovative eco-driving assistance systems for on-road and off-road commercial vehicles based on novel modeling and optimization methods as well as modern visualization and interaction concepts are presented.

Cornerstone of the eco-diving assistance systems for on-road commercial vehicles is the optimization of the speed profile. Particularly, stochastic modeling and optimization methods with integration of spatial, traffic and sensor data are investigated. The main focus of the eco-diving assistance systems for off-road commercial vehicles is the computation and implementation of a fuel-optimal operation profile.

For transmitting the information to the driver, visual interaction techniques are investigated. With these, the driver is able to efficiently track the optimal profile in compliance with the current traffic situation. Interactive and intuitive user interfaces are developed and evaluated. Camera-based eye and gesture tracking systems are furthermore developed. Aiming at interpreting the attention of the driver, the eye and the hand movements are detected. Merging these both channels shall capture the intention of the driver and thus enhance the usability of the assistance systems. For the communication between the optimization process and the smart interaction devices (e.g. augmented reality glasses, smartphone, smart watch, tablet, etc.) a client-server architecture is developed for a simultaneous use of different devices. A preliminary evaluation is done in a lab environment. Then for real driving an Android-based tablet application is developed and tested.

2 Concept

2.1 Use Cases

On-Road Commercial Vehicles For on-road commercial vehicles the objective of the optimization is to achieve a compromise between energy consumption, trip time and driving comfort. In this scenario, the driver defines the destination and the driving time. Then an energy-optimal speed profile is computed by solving an optimal control problem, where a vehicle model and an environment model using geographic and traffic information, e.g. altitude and distance to the next vehicle, are taken into account. The assistance system visualizes the optimal speed profile and the driver tracks the suggested speed in compliance with the traffic situation. To make the assistance intuitive visual interaction techniques are applied. On the one hand several visualization approaches with virtual reality glasses are investigated in a driving simulator. On the other hand an Android app with Bluetooth communication to the real vehicle is developed and tested.

Off-Road Commercial Vehicles For off-road commercial vehicles the objective of the optimization is to achieve a compromise between energy consumption and cycle time. The operator specifies the task, for example digging. The assistance system then calculates a reference operation profile based on a vehicle model and an environment model, e.g. a fuel-efficient trajectory of the bucket in an excavator. The assistance system then supports the operator in implementing the reference profile.

2.2 Architecture

The architecture of the eco-driving assistance systems is shown in figure 1. The environment model describes the environment behavior. the states of the environment can be estimated and predicted based on exteroceptive sensors. The database supplies geographic data and the traffic data. The vehicle model describes the vehicle dynamics using data from proprioceptive sensors, which measure the states of the vehicle. The optimization yields an optimal reference state. This is a fuel-efficient speed for on-road commercial vehicles and an energy-saving operation profile for off-road commercial vehicles. Based on the reference, an intuitive assistance is provided. For this purpose, camera-based tracking systems are developed, which detect and estimate the head pose as well as the eye and the hand movements. Finally, the reference is to be tracked by following the suggestions from the eco-driving assistance system. Particularly, the driver can access the priorities of the optimization, for instance more driving comfort.

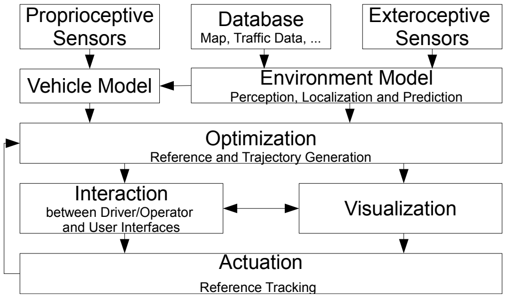


Fig. 1: Architecture of the eco-driving assistance systems

3 Components

3.1 Modeling and Optimization

Modeling the vehicle and the environment dynamics is a key issue for the optimization. The tasks of on-road and off-road commercial vehicles are different, so that the corresponding physical behaviors must be described and handled in different ways. The required trade-off in terms of energy consumption, mission time and driving comfort can be achieved by solving an optimization problem, while physical constraints, for instance the maximum speed, must be satisfied.

Modeling In on-road commercial vehicles the energy from a source, such as a tank, is converted into mechanical energy over the powertrain, which usually comprises a combustion engine and a gearbox. The traction force is then transmitted to the wheels to overcome resistances. such as the rolling friction and the aerodynamic friction.

In the energy-oriented optimization, the ”backward” formulation is frequently used in order to describe the vehicle dynamics with an acceptable complexity and precision. As shown in [7, pp. 39], the energy consumption can be estimated based on a driving profile regardless of the physical causality.

The on-road commerical vehicle model consists of several submodels, which describe the longitudinal dynamics, the behavior of the energy converter, e.g. the combustion engine, and the dynamics of the energy source. Based on geographic information and the measured vehicle states the required mechanical power can be computed. An efficiency map of the converter is then used to describe the relationship between the mechanical and the chemical power. Finally the total energy consumption is computed from an energy source model.

The dynamics of off-road commercial vehicles can also be modeled backwards, since the description of the energy consumption is the core of the optimization. For a given operation profile and spatial informations, the required mechanical power can be estimated, which is supplied by the hydraulic propulsion system. Based on the efficiency map the required hydraulic energy can be computed. Furthermore, for simplicity the converted chemical energy from the combustion engine is calculated by using the corresponding efficiency map. Finally the fuel consumption is determined from an an energy source model.

Optimization The objective related to energy consumption, duty time and driving comfort is expressed as a cost function, which is to be minimized. The physical limitations, e.g. the limits of the engine torque, and the legal requirements, for example the speed limits, are formulated as constraints, which must be satisfied during the optimization. Particularly safety aspects for on-road and off-road commercial vehicles must also be taken into account, respectively.

The environment has a substantial influence on the constraints. The environment is described by the environment model, as shown in figure 1. With the help of GPS data, the vehicle is localized and the corresponding geographic information, such as altitude and curves, can be determined. Further information, for example about the traffic density, can be obtained from database. In addition, the sensors perceive the surrounding, for instance the speed limits set by law, the distance to the preceding vehicle, its speed and the position of obstacles. Based on these inputs, the dynamics of the environment is estimated and predicted, for example the future speed of the preceding vehicle and the switching time of the traffic lights.

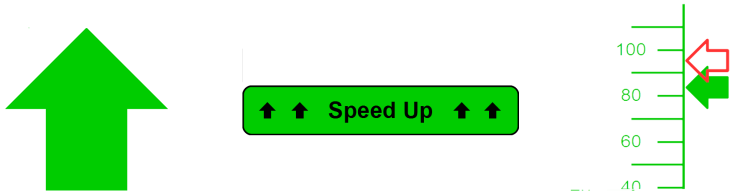
For on-road commercial vehicles an energy-efficient speed is computed, while for off-road ones a fuel-optimal operation profile is generated. Due to the disturbance and the modeling uncertainty the optimization is executed online and the reference values are updated iteratively.

3.2 Visualization

From the user’s perspective, the visualization of the optimization results is one of the key components. Therefore, an efficient and intuitive user interface is needed. For highest flexibility, we decided to use augmented reality glasses for visualizing the data.

Three different visualizations have been developed for displaying the optimization results, which are shown in figure 2. Each visualization can be shown vision-fix (i.e. always on the same place on the screen of the AR glasses, regardless of the view direction), or vision-dependent with help of a marker which is detected by the in-built camera of the AR glasses. Based on the marker position, a three-dimensional coordinate system is generated as long as the marker is visible to the camera. The visualization is fix at the same place related to the coordinate system. If the marker is getting lost (e.g. because of moving the head 90 degrees to the side), the integrated gyroscope as well as the accelerometer are used to estimate the position of the visualization.

The visualization has to transport two important facts: the need for increasing / decreasing speed as well as the difference of the target speed and current speed. Therefore, we used two retinal variables defined by Bertin [8], namely color and size.



(a) Arrow visualization (b) Bar visualization (c) Scale visualization

Fig. 2: Different Visualizations

The arrow visualization (figure 2a) shows a green arrow pointing upwards if the current speed is too low and a red arrow pointing downwards if the current speed is too high according to the target speed provided by the optimization process. The size of the arrows directly relates to the difference of the current speed to the target speed, a larger difference means a larger arrow and vice versa. If the current speed fits to the target speed, the arrow completely disappears. The bar visualization (figure 2b) makes use of the width of the screen and simply shows a green or a red bar only at the bottom of the screen to minimize the distraction. Again, these bars disappear when driving at the recommended speed. The scale visualization (figure 2c) shows the most information, beside the need for increasing or decreasing speed and the difference of current and target speed the visualization provides the exact speed as numbers. Like a primary-flight-display in an aircraft, a speed band is visualized, where the current speed as well as the target speed are indicated by small markers.

The implementation is based on a client-server architecture. The system reads the current and the target speed simultaneously from the server and adapts the visualization if needed. The update frequency is set to 25 Hz, resulting in a smooth visualization.

3.3 Interaction

An overview of the driver interaction is provided in figure 3. The driver's attention monitoring and gesture interaction modules are discussed in details in this section.

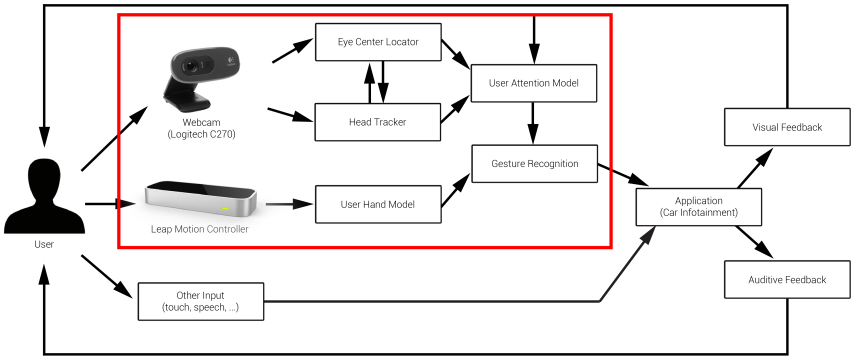


Fig. 3: Overview of driver attention monitoring and gesture interaction modules.

Head and eye-tracking User independance is an important criterion for use in driver attention monitoring. We decided to implement an approach by Vanelti et al. [9], which is combining an optical flow based head pose estimation with an isophote based eye center locator. The approach by Valenti et al. makes use of a cylinder model based head tracking method proposed by Xiao et al. [10]. After the model has been initialized in a frontal position to the camera, the head is tracked using optical flow and the pose recovered in case of inaccuracies based on dynamic templates. Using the estimated head model, the eye regions are extracted and unwarped to a normalized frontal view. On these normalized eye images, eye center location is performed using an isophote curvature based method proposed by Valenti et al. [11]. The result of both, the head tracking and the eye center location, are then used as corrective measure for each other to improve overall accuracy and reduce drift. In a final step, the known eye displacement vectors from their respective resting position are used to construct a calibrated mapping and therefore estimate the user's gaze. Given a reliable eye location and head pose in 3-D one can basically calculate the users gaze and field of view.

Gesture Interaction The user hand model is the basis of the gesture recognition component. It delivers all parameters necessary to determine the hand's position in 3D space and therefore follow its movements and recognize abstract gestures. We chose to use the *Leap Motion*[1]. The provided software tracks the user's hand and calculates the parameters of a sophisticated hand model provided via the API. The hand model consists of several bone and finger models from which the complete hand can be reconstructed (see figure 4c). It also recognizes basic gestures, including swipe, circle, pinch, stretch, point, and click gestures. The gaze estimation and gesture recognition modules can be used for interaction with different systems in the car like for example the radio control, climate control, trip information, and optimization system. The gaze estimation gives a context for gestures. From the gestures that could be recognized by the leap motion and can be useful in the car are swiping left/right, and circle gestures. Swip-

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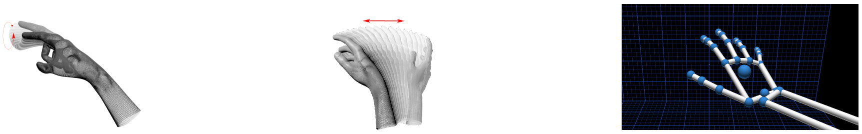
[1] https://www.leapmotion.com/product

ing left is illustrated in figure 4b. Swiping gestures can be used to move the selection left/right, in changing the radio channel, and in changing the optimization parameters. Circle gestures in counter-clockwise direction is drawing a circle with the pointing finger as illustrated in figure 4a. The circle gestures can be used in increasing/decreasing the volume of the radio, and in controlling trip information as the trip time.



(a) Circle gesture (b) Swipe gesture (c) Leap motion visualizer

Fig. 4: Illustration of Leap Motion gestures[2] and visualization

4 Demonstrator and Evaluation

4.1 Simulator Design

The driving simulator consists of a dashboard and center console from a Jaguar model, two power seats, a steering wheel, three foot pedals, surround speakers, a LCD touch screen, and a projector, arranged on a moveable platform (see Figure 5). The steering wheel, foot pedals, and projector are connected to a computer running the driving simulation software OpenDS. The power seats, speakers, and LCD screen are connected to a small computer mounted below the dashboard, which is running a CAN bus emulator connected to the seats and a Java based infotainment server system that can be accessed via a HTML interface (also displayed full screen on the LCD screen). The simulator's overall realism may therefore be classified as of medium *physical* and *functional fidelity*, as defined by Stanton et al. [12].

As additions for the prototype system, a Logitech C270 webcam was placed on the dashboard facing the driver to capture the video for the optical attention monitoring component and the leap motion device was placed on the center console between the driver and front passenger seat (see figure 5). Furthermore, to provide an additional input zone except for the touch screen, an android phone was placed above the touch screen to function as a temperature control unit). This control did not react to touch input but was connected to the prototype system via wireless LAN to listen for gesture events. To simulate a head-up display the Epson Moverio BT-200 smart classes are used. These Android-based smart glasses use see-through over glass and each lens has its own display. The prototype has been developed based on the MetaioSDK[3] for tracking the viewing direction of the user and showing the content of the visualization at the right place. figure 5 shows on the right row the views through the augmented reality glasses

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[2] https://developer.leapmotion.com/documentation/javascript/api/Leap.SwipeGesture.html

[3] www.metaio.de

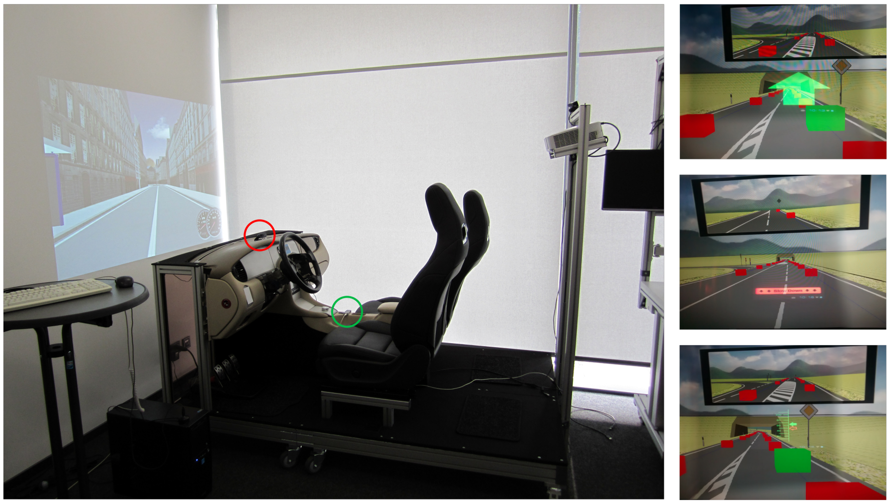


Fig. 5: Driving simulator. Red circle: Logitech C270 webcam. Green circle: Leap motion. On the right: Arrow, bar and scale visualizations in the virtual reality glasses.

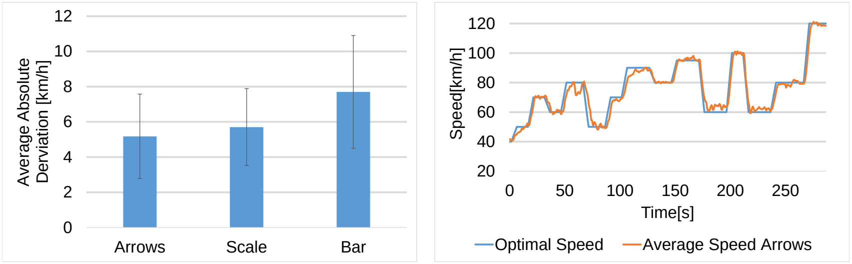
on the OpenDS. Due to the fact that the display of the AR-glasses is very small, it was not possible to position the visualization outside of the center of the driver's view.

4.2 Preliminary Evaluation

The overall system was preliminary evaluated with 16 participants in the age of 19 - 28 years. Each participant tested every visualization for 5 minutes, so the total driving time was 15 minutes. To reduce the influence of learning effects, the order of the visualizations were changed for each participant. The participants were asked to drive on a predefined track with the optimal speed. The difference of the current driving speed to the target speed was recorded twice a second to check which visualization works best. Afterwards, all participants had to fill out a questionnaire for collecting feedback in terms of user satisfaction.

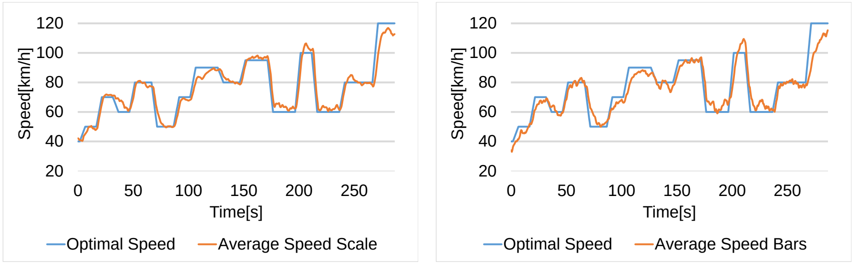
The feedback in general is that 9 out of 16 participants (56%) can imagine using a head-up or head-mounted display with additional information for driving assistance. The charts in figure 6 show the results of the preliminary study. Figure 6a shows that the average deviation when driving with the arrows, scale, and bar visualization is 5.17 km/h, 5.4 km/h and 7.6 km/h, respectively. Comparing the current speed to the target speed (see figure 6b, 6c and 6d), one can observe that the participants could reach the target speed faster and more stable while using the arrow visualization.

Considering the perception of the visualizations, none of the participants had difficulties to see and understand the different versions of the speed recommendation. The subjective feedback shows that the distraction level is perceived very individually so that there is no final statement. But we can already say the chance of lower distraction and thus, safer driving is given by using the bar visualization or arrow visualization po-



(a) Average absolut deviation in km/h

(b) Arrow Visualization



(c) Scale Visualization

(d) Bar Visualization

Fig. 6: Results.

tentially. Nevertheless, the user's satisfaction of the scale visualization is still as high as of the arrow visualization. However, the scale visualization is mostly rated either very helpful or not helpful at all, resulting in a very high standard deviation. All together, 7 out of 16 participants (44 %) chose the arrow visualization or the scale visualization as their favorite, whereas only 2 participants prefer the bar visualization.

5 Conclusions and Future Work

In this paper, we presented a an innovative eco-driving assistance system for both on-road and off-road commercial vehicles. The system is based on novel modeling and optimization techniques. Driver-independent interaction techniques are applied in interacting with the car and the eco-driving assistance system. Optimization results are visualized on head-mounted display in a smart glasses. On-road scenarios where investigated in-lab using a driving simulator. Various visualization techniques for speed optimization were evaluated. For future work, we would like to investigate our system on off-road commercial vehicles.

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