

Model adaptive driver assistance system to increase fuel savings

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Abstract—With increased awareness of environmental protection, volatile resource prizes and rising world trade, energy efficiency has become a focal point in international research. While new vehicle propulsion systems, e.g. battery or fuel cell systems, are still in their early stages, it is already possible to increase fuel saving and reduce costs by applying a fuel efficient driving behaviour. In this paper, a fuel efficiency driver assistance system concept is presented that generates optimal fuel efficient driving guidelines for the driver, who retains full control of the vehicle during the entire process. The optimization is based on an adaptive partial power train model and current measurements available on the CAN-Bus. System identification methods, solely using CAN-Bus data, are proposed to estimate the unknown power train parameters that will enable the model to adapt to a wide range of different vehicles. Based on the adapted model, an optimization routine generates fuel efficient driving guidelines. Aided by the fuel efficient guidelines, the driver is able to adopt a more fuel efficient driving behaviour.

I. INTRODUCTION

Several authors have published solutions in the area of fuel efficient driving. The approaches range from complete vehicle control to passive driver assistance systems. Active approaches include the works of [1] [2] [3]. They are usually manufacturer specific due to the necessity of solid knowledge about the vehicle. Topology height maps and exterior sensors (e.g. radar and camera systems) are used to allow model predictive approaches. In contrast to active approaches, passive driver assistance systems only send audiovisual or other information to the driver so that he or she can follow the proposed guideline to his or her best ability [4]. They do not necessarily rely on complete vehicle models and only concentrate on the present situation. More rudimentary passive systems can be found among satellite navigation devices or smartphone apps which only warn the driver of excessive acceleration and braking based on basic device internal sensors or generate other rudimentary guidelines [5] [6]. The driver assistance system proposed in this paper is a passive system. It is an integral part of a larger fleet management assistance system called EXPERT (EXPERT System for a more Efficient Road Transportation) [7]. The system is primarily designed for freight forwarding companies which want to improve the fuel and cost efficiency of their fleet. The functionality ranges from fleet management support to individual driver assistance. The latter will be the main focus of this paper. Different to model dependent and

therefore often manufacturer specific approaches, EXPERT will be applicable to a great variety of vehicles due to an internal online multivariable adaptive partial power train model, which at the same time takes more vehicle specific characteristics into account than smartphone app approaches [5] [6]. The computations are done in the on-board EXPERT components within every individual vehicle. The adaptive model is then used in an optimization routine that can generate fuel efficient guidelines depending on the current vehicle and the current state. Because no height maps, slope information, object detection, traffic light information, speed limit information or route information is available, the system identification and the fuel efficiency guideline generation is solely based on CAN-Bus data. Fuel efficient route selection is not the topic of this paper, but rather the assistance of the driver during actual driving.

II. EXPERT SYSTEM

The EXPERT system is primarily designed for freight forwarding companies, which want to keep track of their fleet and increase the cost efficiency or rather the fuel efficiency of their drivers. An overview of the system is given in figure 1. From the figure the reader can see that EXPERT is a collaboration of different components. The "EXPERT Information System" is a fleet management system, which resides at the management headquarters and communicates with vehicles within the fleet via the "Green Box". The "Green Box" is the main communication hub of every EXPERT assisted vehicle that enables the communication of all other EXPERT hardware components. It is installed into every vehicle's cabin. A HMI device (e.g. a tablet computer) is assigned to every driver of the fleet. It can be fixed to the dashboard of each vehicle. The HMI device contains the "Driving Efficiency Module" software developed by Fraunhofer IOSB, which will be the main focus of this paper. The module receives information from other EXPERT components via the "EXPERT Co-Pilot" HMI software, which is also integrated into the HMI device. The "Driving Efficiency Module" (see figure 1) consists of an adaptive power train model that serves as state estimation for its counterpart in the real world and an optimization sub-module, which generates fuel efficient driving guidelines for the driver. During operation, the driver retains full control of the vehicle at all times. When the delivery is executed, the driver can unplug the HMI device and start with a new assignment in a different vehicle. There are currently several technical and economic constraints imposed on the EXPERT system. First of all, routes and position dependent velocity limits cannot always be provided by fleet headquarters. Furthermore, it can generally not be

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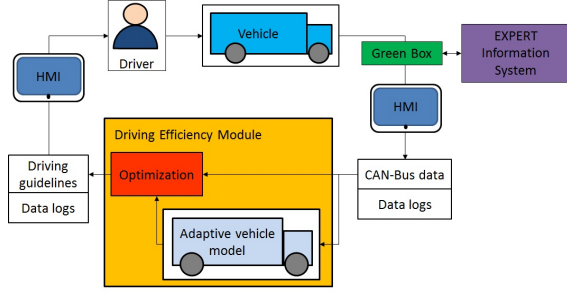


Fig. 1. EXPERT system overview

expected that the vehicles using EXPERT possess advanced object detection sensors like radar or camera systems. This makes velocity dependent guidelines difficult to implement in practice. Precise height maps are usually subject to fees [8] and free of charge height maps have a low resolution [9]. Therefore model predictive strategies [1] [2] are infeasible. The strategies used in the "Driving Efficiency Module" instead, will be explained in the upcoming sections.

III. ADAPTIVE PARTIAL POWER TRAIN MODEL

Due to the complex interaction of internal and external propelling and resistant forces in the different vehicle components, it is necessary to simplify the vehicle to obtain a unified model with a small amount of unknown parameters that can be adapted online and used for a great variety of different vehicles. For the purpose of EXPERT, the proposed power train model (see figure 2) is a static partial model of the vehicle's power train. It only contains an engine and a transmission model. In case of a vehicle with automatic transmission, only the engine is modelled. It is assumed that the vehicle state is quasi stationary, i.e. there are no state changes within a short period of time. Furthermore vehicle internal slip and vehicle internal friction of any kind are neglected, because necessary measurements to estimate internal inertia and friction of the various components are not available. External resistance forces are also neglected. The reason for this type of partial model formulation is that due to the previously stated system constraints, the "Driving Efficiency Module" will not suggest precise velocity or acceleration pedal values to the driver or anticipate his or her behaviour in the future (see section IV for further details). With the given constraints, model predictive approaches or long integration horizons are generally infeasible. If only little or no state integration is allowed, a fully fledged dynamic vehicle model will indeed yield little improvement compared to a static model.

The transmission model is described by the static trans-

mission ratio $i_t(G)$ depending on the currently selected gear level G . It enables the estimation of the current engine speed ω_e depending on the current vehicle velocity v and vice versa. Internal inertia and clutch dynamics are neglected. Thus, measurement samples during gear shifts are not used for estimation. The transmission ratio is the ratio of the input transmission rotation speed $\omega_{t,in}$ and the output transmission rotation speed $\omega_{t,out}$. Note that $\omega_{t,in}$ is assumed to be equivalent to the current engine speed. The CAN-Bus measurements primarily needed for estimation are engine speed and vehicle velocity. Additionally the status of the clutch and gear level is needed to sort out measurements during transient processes. The transmission ratio estimation is given in (1).

$$i_t(G) = \frac{\omega_{t,in}}{\omega_{t,out}} = \frac{\omega_e}{\omega_{t,out}} \quad (1)$$

$\omega_{t,out}$ is calculated from the current vehicle speed v and divided by the wheel radius r_w . If the wheel radius is unknown, it can be set to any positive non-zero value because the relation between vehicle speed and engine speed will still remain the same.

$$v = \omega_{t,out} r_w \quad (2)$$

The online calculated raw ratios are collected for each observed gear level category and saved in a corresponding ring buffer. In each category, the distribution of the ratios is estimated. If the standard deviation decreases below a certain threshold (in our case 10% of the highest observed value has been chosen), the raw ratio collection for the gear level is deemed as trustworthy. The ratio of this gear level category is then estimated as the median of the hitherto saved data. The estimation is updated every second. If the internal ring buffers are full, the new estimation update is set to the average of the current estimation and the previous estimation.

The engine model is described by an engine torque map and a fuel consumption rate map. The fuel consumption rate map is defined as a polynomial of low degree (e.g. first or second degree). It depends on engine torque T_e and engine speed ω_e [10]. The equation is stated in (3). The polynomial coefficients are estimated using equality constrained least squares. The equality constraints enforce the expectation that if either engine torque or engine speed is zero, the fuel consumption rate is also zero. The estimation primarily requires fuel consumption rate $\frac{dV_{fuel}}{dt}$, engine speed ω_e and engine torque information T_e from the CAN-Bus. Additionally, status information about clutch and gear level G are needed, because measurements during the transient gear shift process are not regarded.

$$\frac{dV_{fuel}}{dt} = a_0 + a_1 T_e + a_2 \omega_e + \dots + a_M T_e^N \omega_e^N \quad (3)$$

The engine torque map is dependent on the acceleration pedal position u and engine speed ω_e [11]. It is initially described by a polynomial of low order if only little CAN-Bus data is available. This case typically arises if the "Driving Efficiency Module" is confronted with a new vehicle. As large data

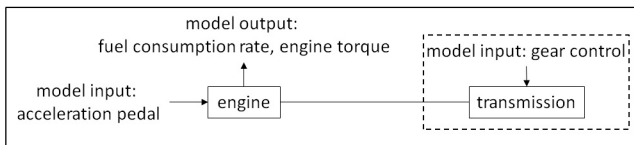


Fig. 2. Partial power train formulation

sets become available, e.g. collected over several hours, the characteristic map changes to a three segment spline $S(u, \omega_e)$ approximation. The segments are divided at certain acceleration pedal values, where significant changes in appearance are expected (e.g. at $u = 20\%$ and $u = 80\%$). Thus, the spline segments can use different types of polynomials to account for local engine torque map characteristics. The spline estimation is partitioned into three steps. Before the estimation can begin, a histogram test is performed to discard outliers. After the histogram test, a parabola shaped full load curve is estimated using engine torque and engine speed data for which $u > 80\%$. From the full load curve's only maximum, the torque maximizing engine speed $\omega_{e,m}$ can be retrieved. Finally, the spline coefficients are estimated using equality constrained least squares that takes the common spline intersection equality constraints into account [12]. The different polynomials are developed at different operation points: $\omega_{e,m}$, $u_h = 100\%$ and $u_m = 50\%$. All these methods support the reliability of the engine torque map and allow a reliable interpolation behaviour within the observed data scope. The three polynomials of the spline are given in equations (4) to (6). The spline is stated in (7). The estimation requires acceleration pedal position, engine speed and engine torque information from the CAN-Bus.

$$P_1(u, \omega_e) = b_0 u^2 \quad (4)$$

$$P_2(u, \omega_e) = c_0 + c_1(u - u_m) + c_2(\omega_e - \omega_{e,m}) + \dots + c_{15}(u - u_m)^3(\omega_e - \omega_{e,m})^3 \quad (5)$$

$$P_3(u, \omega_e) = d_0 + d_1(u - u_h)^4 + d_2(\omega_e - \omega_{e,m})^2 + d_3(u - u_h)^4(\omega_e - \omega_{e,m})^2 \quad (6)$$

$$T_e = S(u, \omega_e) = \begin{cases} P_1(u, \omega_e), & u < 20\% \\ P_2(u, \omega_e), & 20\% \leq u \leq 80\% \\ P_3(u, \omega_e), & u > 80\% \end{cases} \quad (7)$$

The estimation of the engine model is deemed as trustworthy when the internal ring buffers are filled. In the current system the buffers are set to a capacity of 30 minutes of valid data. The estimation is updated every second. If the ring buffers are full, the new estimation update is set to the average of the current estimation and the previous estimation. The parameters of the partial power train model components change little over time. Thus, it is beneficial to save parts of the estimation for future journeys. Otherwise, the system has to wait for the completion of the vehicle adaptation at the beginning of every new system start. Since the designated HMI devices (see figure 1) are smartphone devices or tablets, which are not designed to handle huge amounts of historic data in real time, only the currently estimated ratios are planned to be stored on the device in the final system for later use. By calculating the average of the historic parameter estimates and the current estimates, the model adaptation is able to improve over time.

IV. OPTIMIZATION AND FUEL EFFICIENCY GUIDELINE GENERATION

The optimized fuel efficiency guidelines for the driver are calculated from the partial power train model and the current CAN-Bus data. The optimization uses gain maximization and cost minimization, which penalize unfavourable driving behaviour. In this paper, an unfavourable driving behaviour is regarded as a driving behaviour that leads to overall high fuel consumption and high attrition to the vehicle. Naturally, not driving at all is the best way to accomplish both goals. But at the same time, excessive deviation from the driver's wishes is also unwanted, which includes punctual delivery. All these aspects can be highly contradictory to each other. Thus, the goal is to find an optimal trade-off. Due to stated system constraints, the "Driving Efficiency Module" does not propose a precise set velocity to the driver, but a maximum tolerable acceleration pedal position (comparable to the approach in [4]) that should not be exceeded and two specific gear levels in case of a manual transmission.

The maximum tolerable pedal position $u_{max,opt}$ is a trade-off between torque maximization and fuel consumption rate. A higher torque or lower fuel consumption rate can be defined as a gain, while a higher fuel consumption rate or lower torque can be defined as a loss or a negative gain. The goal is to maximize the overall gain. In order to define a gain term, it is necessary to define a reference. For the maximum pedal optimization, the reference torque is defined as $T_{e,ref}(t) = T_e(u = 100\%, \omega_e(t))$. The reference fuel consumption rate is defined as $\frac{dV_{fuel,ref}(t)}{dt} = \frac{dV_{fuel}(T_{e,ref}(t), \omega_e(t))}{dt}$, i.e. the possible maximum values for the current engine speed $\omega_e(t)$. The positive and negative gains in torque and fuel consumption rate depend on the current reference values and the selection of the pedal position u . They are described by:

$$\Gamma_{torque}(t) = \frac{T_e(u, \omega_e(t)) - T_{e,ref}(t)}{T_{e,ref}(t)} \quad (8)$$

$$\Gamma_{fuel}(t) = -\frac{dV_{fuel}(T_e(u, \omega_e(t)), \omega_e(t)) - dV_{fuel,ref}(t)}{dV_{fuel,ref}(t)} \quad (9)$$

An additional regularization term is used to penalize possible oscillations in the optimal solution. The weighting λ_u is a design parameter:

$$\Gamma_s(t, t-1) = -\lambda_u |u - u_{max,opt}(t-1)| \quad (10)$$

The overall gain function for the current time-stamp t is therefore:

$$\Gamma_u(t) = \Gamma_{torque}(t) + \Gamma_{fuel}(t) + \Gamma_s(t, t-1) \quad (11)$$

The maximum tolerable pedal position $u_{max,opt}(t)$ is the acceleration pedal position of all feasible pedal positions $\mathcal{U} = \{u | 0\% \leq u \leq 100\%\}$ that maximizes $\Gamma_u(t)$:

$$u_{max,opt}(t) = \max_{u \in \mathcal{U}} \Gamma_u(t) \quad (12)$$

In case of a manual transmission, two specific gear levels are proposed to the driver in addition to $u_{max,opt}(t)$. The first gear level proposal $G_{opt}(t)$ is a trade-off between fuel

consumption and torque maximization, designed for regular driving and acceleration. The second gear level proposal $G_{brake}(t)$ maximizes the braking torque of the engine and is only needed if the driver wants to reduce speed through coasting. It is assumed that the driver can distinguish between the two cases. The estimation of $G_{opt}(t)$ is conducted in two steps. In the first step, two other gear candidates $G_{eco}(t)$ and $G_{torque}(t)$ are calculated. $G_{eco}(t)$ is the gear level among all feasible gears \mathcal{G} that minimizes the fuel consumption rate. It is suitable for low torque demand situations (e.g. maintaining speed on flat terrain). Possible engine speed candidates can be estimated using equations (1)(2):

$$G_{eco}(t) = \min_{G \in \mathcal{G}} \frac{dV_{fuel}(u(t), \omega_e(G, v(t)))}{dt} \quad (13)$$

$G_{torque}(t)$ is the gear level that favours torque maximization, suitable during acceleration and hill climbing. In this case the selected gear should move the engine speed close to $\omega_{e,m}$ (see section III):

$$G_{torque}(t) = \max_{G \in \mathcal{G}} T_e(u(t), \omega_e(G, v(t))) \quad (14)$$

In a second step, a cost list or cost set $\mathcal{C}_{GG}(t)$ is defined for $G_{eco}(t)$, $G_{torque}(t)$ and all intermediate gear levels between them. It is assumed that the driver expresses the wish for acceleration through the acceleration pedal. If the current pedal is completely pressed down, maximum torque is probably demanded and $G_{torque}(t)$ should be chosen. If the pedal is completely released, the driver is probably coasting and $G_{eco}(t)$ should be chosen. Between these two definite cases, the intermediate gear levels are chosen dependent on the current pedal position $u(t)$. To accomplish this, the elements $\mathcal{C}_{GG,i}(t)$ of $\mathcal{C}_{GG}(t)$ are set between 0% to 100% with a linear progression from the lowest to the highest element. Each element is related to one possible gear level between $G_{eco}(t)$ and $G_{torque}(t)$. By taking the absolute difference of each cost element and the current pedal position $u(t)$ denoted in [%], the element that refers to the optimal gear is marked as the smallest absolute difference. Finally, a temporal regularization term $C_{dG}(t, t-1)$ is added if a feasible gear candidate G differs from the previous optimal gear to avoid possible oscillations in the optimal solution. t_{shift} is the time stamp of the previous change in the G_{opt} solution. λ_G is a weighting that describes the length of the time period, in which a change in G_{opt} is regarded as early (e.g. 2 seconds). This yields the overall cost set $\mathcal{C}_G(t)$:

$$\mathcal{C}_G(t) = |\mathcal{C}_{GG}(t) - u(t)| + \begin{cases} 0, & G = G_{opt}(t-1) \\ C_{dG}(t, t-1), & otherwise \end{cases} \quad (15)$$

$$C_{dG}(t, t-1) = \frac{\lambda_G}{|t - t_{shift}|} \quad (16)$$

The optimal gear choice should ideally not lead to an engine speed that is below the fuel cut-off engine speed $\omega_{e,cut}$ or above the long-time sustainable maximum engine speed $\omega_{e,max}$. The thresholds $\omega_{e,cut}$ and $\omega_{e,max}$ can be estimated from the collected CAN-Bus data. The effect of a gear

change on the engine speed can be estimated using the estimated transmission model (1) and the current velocity $v(t)$. Those gear levels that comply with the engine speed thresholds constitute the feasible set \mathcal{G} . The choice of G_{opt} can then be described by:

$$i_{opt} = \min_{i \in \mathcal{G}} \mathcal{C}_G(t) \quad (17)$$

$$G_{opt}(t) = G_{i_{opt}} \in \mathcal{G} \quad (18)$$

The second gear proposal G_{brake} is chosen as the lowest feasible gear level that does not violate the previously stated constraints.

$$G_{brake}(t) = \min_{G \in \mathcal{G}} \mathcal{G} \quad (19)$$

Transient conditions during gear shifts are separately detected that overrule the new gear proposals and instead maintain the previously viable optimal gear choice. Apart from the previously discussed primary guidelines, the driver will be additionally notified to switch off the engine during idling phases and to coast instead of braking if the brake pedal is pressed.

In autonomously controlled systems [1] [2], different optimization variables can be jointly calculated and applied. In the case of EXPERT, it is uncertain if the driver will apply both guidelines at the same time. The maximum tolerable pedal position is indeed only an upper threshold. Thus, the pedal optimization and the gear choice optimization are separately performed. The optimization can be solved with a direct discrete search in real time on a tablet computer device. Although direct searches are usually inefficient, consider that if the pedal discretization is set to 1% and the manual transmission has 5 gears, the estimated model is only executed 105 times during a single optimization. Thus, the fuel efficiency guidelines and the model adaptation can be easily updated every second. It is assumed that the driver cannot react to higher update rates. Furthermore, direct searches have the benefit of finding the global maximum or minimum of a gain or cost function, if discretization is sufficiently subtle. It is noted here that there are other characteristic maps that can be used to generate fuel efficiency guidelines, e.g. efficiency maps. The estimation of these maps has turned out to be challenging on the available test data taken from a real world test drive because the automatic transmission of the test vehicle mostly stayed within a confined operation area.

V. RESULTS

In this chapter the authors present results based on real world CAN-Bus data and simulated environment. The available CAN-Bus data are records of a truck delivery that stretches over six hours. This data is used to evaluate the performance of model adaptation. The simulation framework is inspired by the works of [13] [10].

The transmission ratio estimation result is shown in figure 3 (top). It has as many as 12 gear levels because the transmission is an automatic transmission. A red interpolation curve shows the smooth and gradual decline of the ratio levels. Using the estimated gear ratios, the engine speed can

be estimated depending on the vehicle speed and selected gear. The result on a random sequence is displayed in figure 3 (bottom), which shows that the estimated engine speed can mostly follow the engine speed measurement with slightly stronger deviations during gear shifts, because the transmission model is static. The mean average error (MAE) over the entire available test data is 18rpm. The scope of the collected data is between 0rpm and 2100rpm.

The estimation result of the engine torque map is displayed

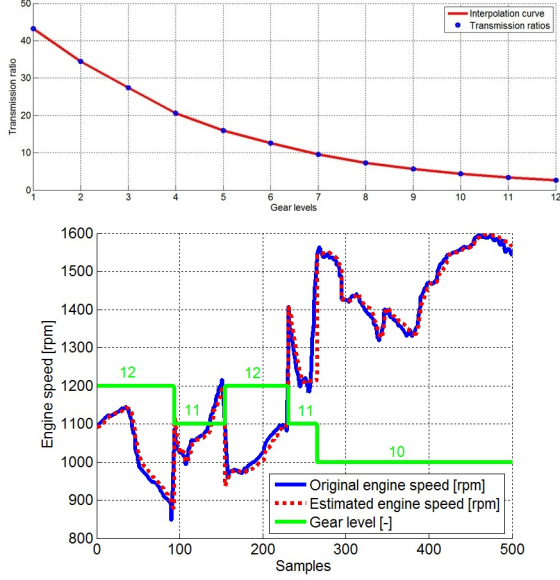


Fig. 3. Transmission ratio estimation (best viewed in color): Estimated transmission ratios (top), Estimated engine speed (bottom)

in figure 4 (top). The measurement points which remain after the histogram outlier test are illustrated as red circles. Note that the engine torque provided by the CAN-Bus is the torque directly generated by the cylinders according to SAE J1939 specification [14]. It is therefore never negative. The three segment spline is fitted to the measurement points and shows stable interpolation behaviour. The spline equality constraints have been imposed on eight different support points along the acceleration pedal positions of 20% and 80%. Several outliers from the original measurement collection could not be discarded. But compared to the main measurement point concentration they are only few in numbers. Using the estimated torque map, the engine torque can be estimated. An example is given in figure 4 (bottom). The estimated engine torque qualitatively follows the recorded engine torque signal, but deviations of more than 10% can occur because the engine map is static and is composed of polynomials of low degree in order to avoid instabilities. The mean average error (MAE) over the entire available test data is 70Nm. The scope of the collected data is between 0Nm and 2250Nm.

The estimation result of the fuel consumption rate map is displayed in figure 5 (top). The original measurement points are illustrated as red circles. A polynomial of third degree is fitted to the measurement points. It shows good interpolation behaviour. Using the estimated fuel consumption rate map,

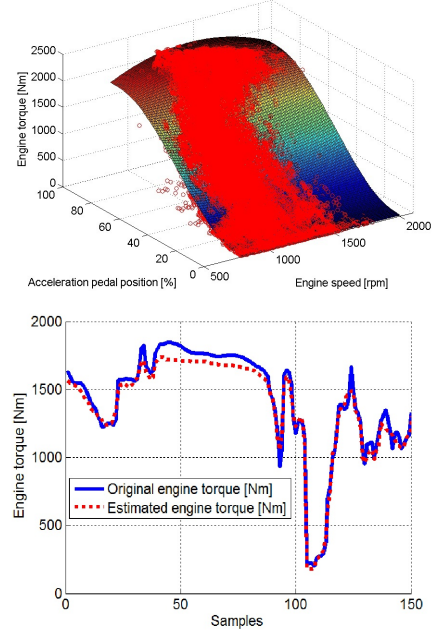


Fig. 4. Estimated engine torque (best viewed in color): Estimated engine torque map (top), Estimated engine torque compared with CAN-Bus data (bottom)

the fuel consumption rate can be estimated. An example is given in figure 5 (bottom). The estimated fuel consumption rate qualitatively follows the fuel consumption rate measurement. Deviations of more than 10% can occur because the fuel consumption rate map is a static polynomial of third degree. The mean average error (MAE) over the entire available test data is $0.7351 \frac{l}{h}$. The scope of the collected data is between $0 \frac{l}{h}$ and $95 \frac{l}{h}$. Note that in the illustration, the extrapolation reaches beyond the full load capacity of the engine. Within the optimization, the full load constraint is implicitly ascertained by the torque map.

The effect of the application of the fuel efficiency guidelines has been evaluated within a Matlab/Simulink simulated environment with a simulated inexperienced driver. An example is shown in figure 6. The simulated vehicle has a mass of 4000kg and 5 gear levels. The road topology has a length of 1800m with two hills (5° , 2.5°). The vehicle starts at $60 \frac{km}{h}$ and gear level 3. The desired travelling speed is $80 \frac{km}{h}$. In this example, fuel savings of 10.3% could be achieved by the EXPERT assisted driver compared to the inexperienced driver. The inexperienced driver shifts heuristically according to the current vehicle speed ($10 \frac{km}{h}$, $30 \frac{km}{h}$, $50 \frac{km}{h}$, $70 \frac{km}{h}$) and accelerates aggressively. Furthermore, the EXPERT assisted driver had a 5% shorter trip time, largely because the inexperienced driver often accelerates while the highest gear is selected that does not always lead to the maximum engine torque.

VI. CONCLUSIONS

In this paper, the authors have presented the "Driving Efficiency Module", which is used in the EXPERT system

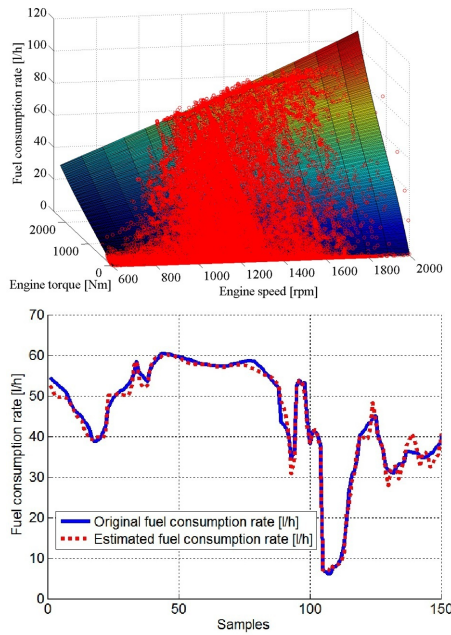


Fig. 5. Estimated fuel rate (best viewed in color): Estimated fuel rate map (top), Estimated fuel rate compared with CAN-Bus data (bottom)

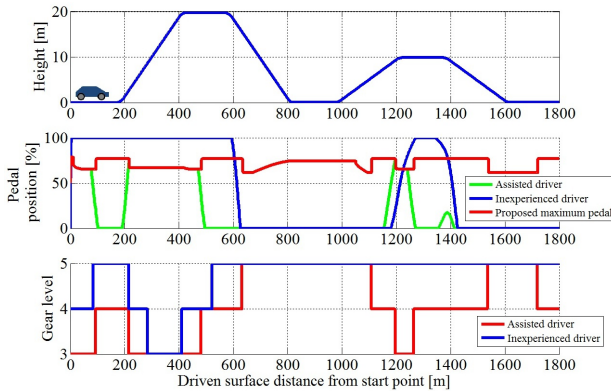


Fig. 6. Effect of fuel efficiency (best viewed in color): Topology (top), Acceleration pedal position (center), Gear change (bottom)

that has also been briefly introduced. One of the main goals of EXPERT is to provide the driver with an assistance system through the "Driving Efficiency Module". It monitors the driver's driving behaviour and generates fuel efficiency guidelines to improve fuel economic driving. An online adaptive partial power train model has been presented that can adapt to different vehicles through CAN-Bus data based system identification techniques. The fuel efficiency guidelines primarily consist of a currently sensible maximum acceleration pedal position that should not be exceeded and two gear level proposals in case of a vehicle with manual transmission. The guidelines are obtained from the maximization of a gain function and the minimization of a cost function based on the estimated partial power train model and current CAN-Bus data. This optimization strategy only requires CAN-Bus data and no knowledge of

the environment or object detection. Simulations have shown that significant fuel savings can be achieved compared to a driver with little experience in fuel efficiency driving. Future works include the improvement of the simulation framework to give a better estimate of the system's potentials. A driving simulator based on open source software is currently under development to investigate the response and the acceptance of real drivers towards EXPERT. With additional CAN-Bus data records from different drivers and vehicles, it may be possible to estimate other types of characteristic maps (e.g. efficiency maps) that lead to a simpler and more precise optimization. Should advanced information about the environment become available in the future, a model predictive approach would become feasible and the formulation of an adaptive dynamic vehicle model would be of great assistance. The "Driving Efficiency Module" has been implemented in an Java/Android environment and will be installed into several test vehicles. Upcoming field tests incorporating 30 different trucks and different drivers will be conducted over several months to evaluate the performance of EXPERT.

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