Context embedded energy efficient driving

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Introduction

Energy efficiency in transportation systems is a long-standing goal. Optimisation approaches are related to vehicle design optimisation, the use of alternative propulsion systems and driving behaviour optimisation.

For many years, engineers have been working on optimising vehicles, but ultimately one limitation for achieving high energy efficiency is driver behaviour. Studies have shown that energy consumption may vary by around 30% depending on the driving behaviour. Increased automation in series production vehicles enables precise control, predictive planning and optimisation of driving behaviour and is a key for achieving the best energy efficiency.

Driving-behaviour-related approaches for improving energy efficiency can be grouped into:

- "eco routing" – for finding energy-optimized routes,
- "using road slope information" – for generating energy-efficient velocity trajectories,
- "traffic light assist" – for planning approaching and passing traffic lights in an energy-efficient way,
- "platooning" – for following other vehicles to decrease air drag resistance, and
- "overtaking" – for overtaking slower vehicles in order to continue driving on an energy-efficient trajectory.

Fig 1. – Approaches to increase driving energy efficiency.

Our current research focuses on an approach to overtaking. Up to now, this topic has not been well covered by the literature. One existing approach considers other traffic participants and optimises the overtaking problem by modifying a previously generated optimal trajectory in order to satisfy the constraints imposed by surrounding traffic. In contrast, the method developed at VIRTUAL VEHICLE incorporates a leading vehicle's motion as a constraint in the original optimal control problem. In this way, the generated trajectory is globally optimal. In addition, the overtaking decision-making itself is part of the optimisation, which allows for the possibility of not overtaking at all.

Optimal control problem

From a mathematical point of view, this problem can be addressed as an optimal control problem with an appropriate cost function to evaluate speed trajectories. The cost function has to reflect the initial requirement of minimal energy consumption. This includes energy used for propulsion and energy used on-board (e.g. infotainment, air conditioning, component temperature management).

A vehicle dynamics model is used to estimate the propulsion force needed to compensate for resistance forces (gravity, air drag, roll resistance) and to provide the required acceleration. When considering only this aspect, energy-efficient behaviour would result in smooth, low-speed driving (almost zero). However, as on-board energy usage is proportional to driving time, slow driving increases overall consumption. The optimal speed trajectory is therefore a balance between these two perspectives.

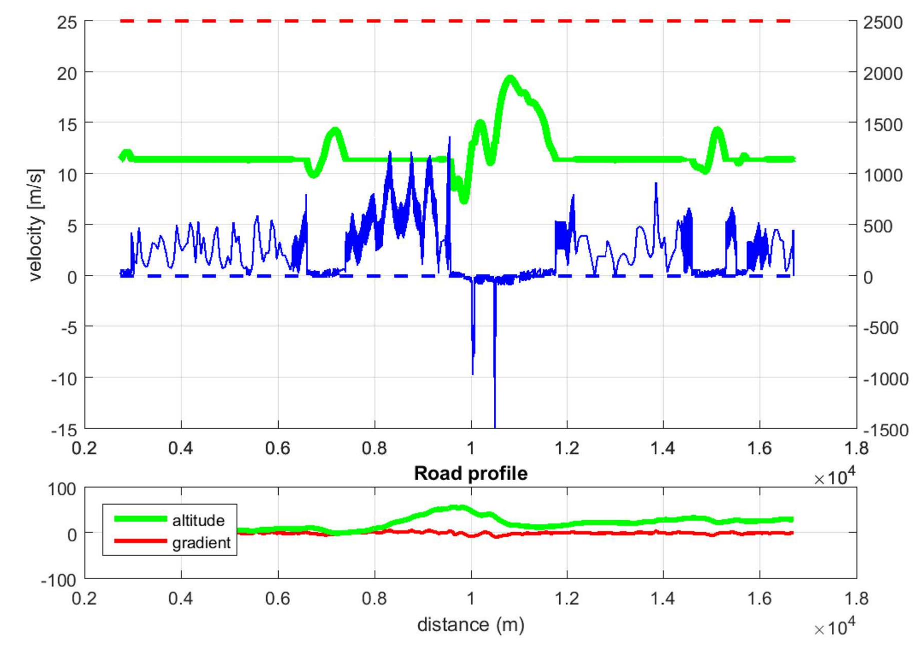

Fig 3. – Optimal speed trajectory generated by using road slope information for predictive planning

$$E_{min} = \min_{T_m} \int_0^T \left(\omega(t)T_m(t) + P_{aux}\right) dt \; .$$

Cost function - **(1)**

$$a = \frac{F_m(t)}{m} - \frac{F_r}{m} \; ,$$

$$F_r = \frac{1}{2}\rho_a c_d A_f v(t)^2 + c_r mg\cos\left(A(s(t))\right) + mg\sin\left(\alpha(s(t))\right) .$$

Vehicle dynamics- **(2)**

In addition, an optimal speed trajectory has to satisfy several constraints. Constraints can be internal and external. Internal constraints arise from system limitations (e.g. maximum acceleration, velocity, torque), while external constraints are caused by the environment (e.g. traffic signs, other traffic participants). The integration of constraints such as collision avoidance is not straightforward, as these constraints depend on the driving trajectory of the controlled vehicle itself.

	Time variant	Time invariant
Space variant	other traffic participants	resting time (e.g. every 2h)
Space invariant	traffic lights	traffic signs (e.g. speed limits), road curvature

Optimal motion planner

To solve this (generally) nonlinear problem under consideration of the time-varying constraints, we developed a motion-planning framework based on dynamic programming (DP). Utilising the advantages of forward and backward DP enables the consideration of constraints on internal states as well as constraints arising from the external environment. Beyond time/space invariant constraints, the approach allows for the consideration of time and space varying constraints as well. Using the predicted movement of other traffic participants, an optimal trajectory without collision is generated. This is used for decision making on possible overtaking manoeuvres.

Results

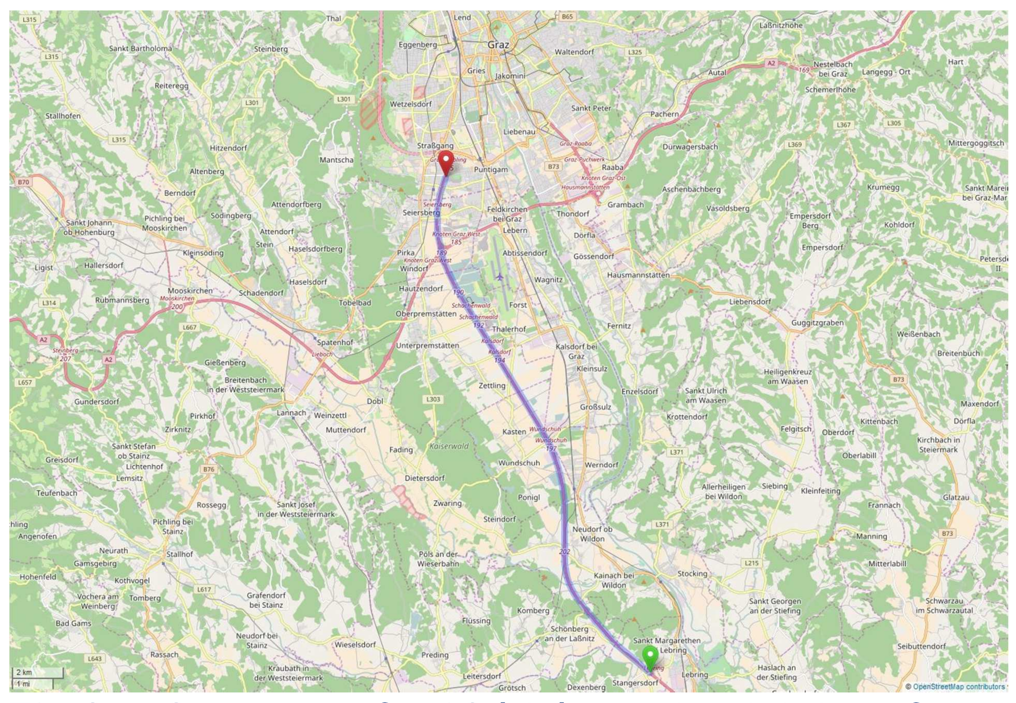

Fig 2. – Segment of a A9 highway in vicinity of Graz used in simulation.© OpenStreetMap.

Initial simulation results show that considering other traffic participants is important when planning energy optimal driving. Even on a simple setup, the proposed driving strategy uses 2.5% less energy compared to existing optimal overtaking approaches.

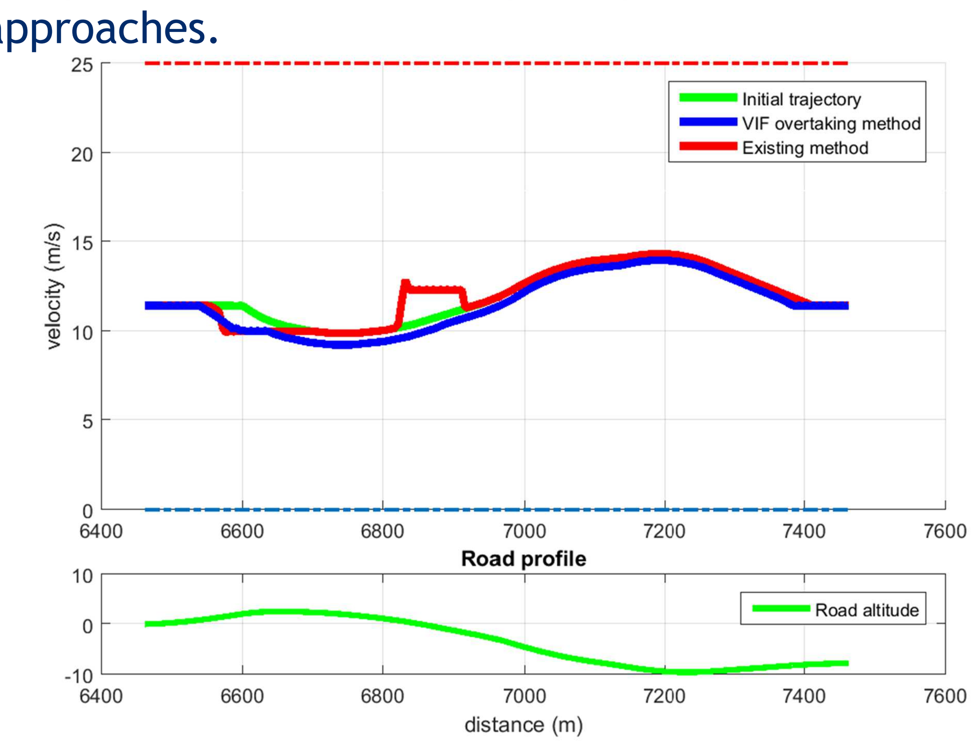

Fig 4. – Comparision of VIF-developed overtaking approach vs existing approach

Simulation results from different scenarios are used to make preliminary conclusions on overtaking decision-making. The results obtained support some the preliminary conclusion that in many cases it may be more energy efficient to overtake on horizontal road segments than on a road segments with a slope. The results also support the conclusion that it is not always best to overtake other vehicles, even though the desired velocity in the unconstrained problem is higher than that of the leading vehicle. Depending on the speed difference between the ego vehicle and the other vehicles, in some cases it is better to slow down and follow.

Acknowledgments

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