Terrain and speed-limit optimized cruise control for heavy road vehicles

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Abstract: Ensuring proper driver behaviour and driving style is an essential and ongoing task for transportation enterprises, including those that operate heavy road vehicle fleets. Aspects and subtasks of this general task range from issues concerning road and vehicular safety, vehicle and cargo security to issues of environmental friendly and economic operation of the fleet. In the paper, one particular facet of the economic operation is addressed, namely the proper choice of momentary speed for heavy road vehicles along a route. One approach to handle this facet is to define fleet-level guidelines and policies concerning the recommended vehicular speed and monitor their enacture regularly. A more promising option in this respect that can be considerably better monitored is the application of semi-automatic and the fully automatic cruise control devices in the vehicles. A method was proposed recently for the longitudinal speed control of heavy land vehicles. The method relies on appropriate brake and traction forces to attain the required velocity. By choosing the vehicle speed in accordance with the mentioned road and traffic characteristics, the number of unnecessary accelerations and brakings, as well as the durations required for carrying these out can be significantly reduced. The control method was designed, modelled and initially tested with a control design tool-set for robust control of the linear parameter variant (LPV) systems. After series of software-in-the-loop simulations carried out in an up-to-date professional vehicle and road simulation environment, an on-the-road testing of the implemented control method is in preparation.

Introduction

Ensuring proper driver behaviour and driving style is an essential and ongoing task for transportation enterprises, including those that operate heavy road vehicle fleets. Aspects and subtasks of this general task range from issues concerning road and vehicular safety, vehicle and cargo security, environmental friendly, and economic operation of the fleet.

Issues of the road and vehicular safety were looked at – in conjunction with heavy road vehicles, such as trucks – in (Fazekas, Z. – Gáspár, P. 2010) and later in (Fazekas, Z. et al. 2012). In the frame of these studies, emergency braking data was collected from vehicular sensors by logging their messages sent over the vehicle's CAN bus. In the data collection, a small fleet of commercial trucks was involved.

The location data for the braking events was obtained from the navigation devices on-board. Apart from the location, the data describing a braking event included a time-stamp, the vehicle speed just before the braking event and the maximum deceleration intended. Issues of vehicle and cargo security were touched upon in (Fazekas, Z. et al. 2011). The authors lay emphasis on truck-related aspects. The low-speed maneuvers and stoppages were looked at in particular. To make the post-trip assessment of the trajectory data easier and faster, a method for rendering route sections to vehicle activity classes was proposed therein. The method computed and used certain spatiotemporal features of the trajectory. The linguistic approach used by the authors to characterize trajectory data took care of the multiple spatial and temporal resolutions. The multi-resolution capability was deemed necessary to recognize different – usual, as well as unusal – vehicle/driver activities.

In the present paper, the third and the fourth of the issues listed above are touched upon. Particularly, a facet of the economic operation of the heavy road vehicles is addressed, which has also environmental relevance. The facet is the proper choice of momentary speed for heavy road vehicles along their routes. One approach to handle this problem is to define fleet-level guide-lines and policies concerning the recommended vehicular speed and monitor their enacture regularly. The recommendations could depend on many aspects of the freight, route and itinerary. These aspects include the terrain characteristics, the actual road type, the speed limits along the route, as well as data on traffic intensity and weather conditions.

Related work

A more promising option in the above respect – that can be considerably better monitored – is the application of semi-automatic and automatic cruise control devices in the vehicles. However, to reach a good compromise between the conflicting objectives associated with the profitable operation of the heavy road vehicles (e.g., between the minimization of the fuel consumption and that of the journey time) as normally dictated by the economy of managing and operating a vehicle fleet, one needs to solve an optimization problem and use its solution in the cruise control device.

Such optimization problems can be solved using various approaches ranging from pragmatic engineering approaches to theoretically sound – but in many cases not quite feasible – mathematical ones. For instance, the implementation of a receding horizon control, and the modelling the terrain and traffic flow with Markov chains are examples of viable engineering solutions with appropriate mathematical basis. For references, see (Németh, B. – Gáspár, P. 2015). A number of cruise control methods are known from the literature that take certain road conditions (e.g., inclinations along the road, changes of the friction coefficient due to various forms of precipitation) into consideration in an explicite quantitative manner when choosing the vehicle velocity. For references see the paper cited above.

The look-ahead control methods – including the method proposed in (Németh, B. – Gáspár, P. 2016) that was put to work in the simulations presented herein and is described briefly in the next section – assume that some upcoming disturbances (e.g., disturbances over a certain road length) are known in advance. These disturbances include inclinations of the road, speed-limits along the route, intense traffic encountered, etc.

For instance, in the look-ahead control system described in (Hellström, E. et al. 2009), a road-slope database was compiled and used on-board of a truck – in combination with a GPS unit – to extract the road geometry ahead. This information was used for the optimal choice of the vehicle speed with respect to a criterion weighing up journey time against fuel consumption. A dynamic programming algorithm was used for feeding the conventional cruise controller with new set points. On-road experiments were also conducted. The results of these experiments were covered in depth in the cited paper.

Materials and methods

A look-ahead control method was proposed recently in (Németh, B. – Gáspár, P. 2015) and was developed further in (Németh, B. – Gáspár, P. 2016) for the longitudinal speed control of heavy road vehicles. The method relies on appropriate brake and traction forces to attain the required velocity. By choosing the vehicle speed in accordance with the road and traffic characteristics, the number of unnecessary accelerations and brakings, as well as the durations required for carrying these out can be significantly reduced. The control method was designed, modelled and initially tested with a tool-set serving the development of robust control of the linear parameter variant (LPV) systems.

After long series of software-in-the-loop simulations – carried out in an up-to-date professional vehicle and road simulation environment – the on-road testing of the implemented look-ahead control method is in preparation. The on-road test drives will take place in the coming weeks and will be carried out in close cooperation with our industrial partner.

The main modules of the simulation architecture are shown in *Fig. 1.* These are the simulator module appearing at the top of the block diagram, the software module that carries out the map-related calculations is shown below it, while the block representing the mathematical optimization module is placed to the bottom.

Most simulation runs concerned the route marked light gray in *Fig. 2.* It is a section of the main road No. 3 between Gyöngyös and Kápolna in Hungary. Its altitude profile appears in *Fig. 3.*

The sizeable change in the altitude along the road and particularly the rise and the slope close to Gyöngyös ensure that some practical savings can be accomplished, if the truck is driven with care either by a human driver, or controlled in that manner

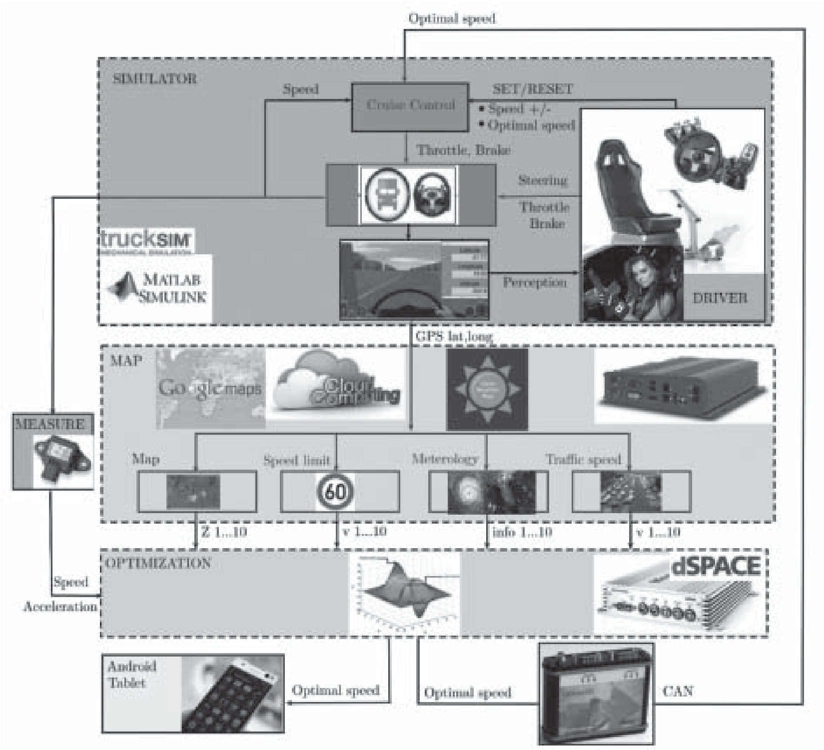

Fig. 1. The software architecture used for the simulations concerning the look-ahead control for trucks

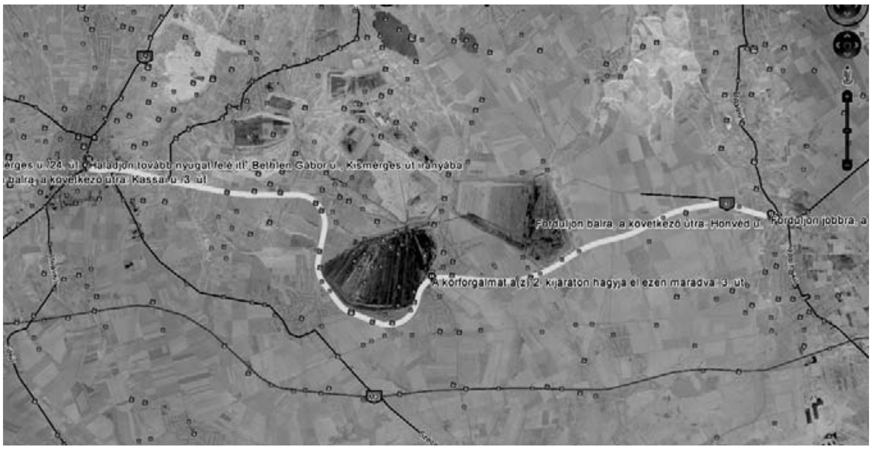

Fig. 1. The software architecture used for the simulations concerning the look-ahead control for trucks

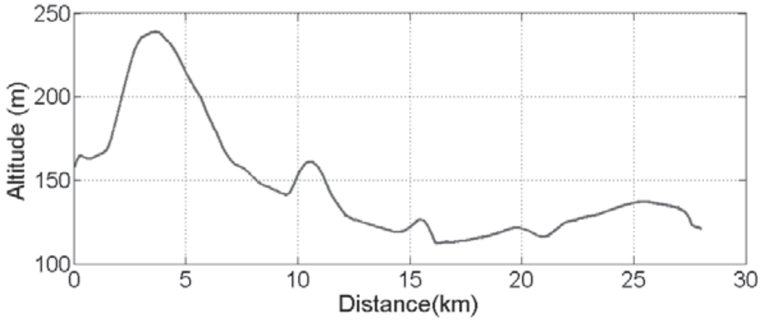

Fig. 3. The altitude profile of the Gyöngyös to Kápolna route

by a cruise control application. A short road segment of the route is displayed quite realistically – even the slopes of the Mátra Mountains show up at some distance in the background – in Fig. 4 by the virtual reality module of the TruckSim simulaton environment. TruckSim is shown as a submodule of simulator module in *Fig. 1*.

During the on-road test, the implemented control method will be physically located and work on-board of a truck. The software architecture designed for the purpose is sketched in *Fig. 5*. The functions implemented within this software architecture are the look-ahead control method, the necessary communication with the vehicle control system, gathering data from the high-precision navigation system, and accessing and displaying a region of the downloaded map.

Fig. 4. A short segment of the route displayed with the virtual reality module of the TruckSim simulation environment

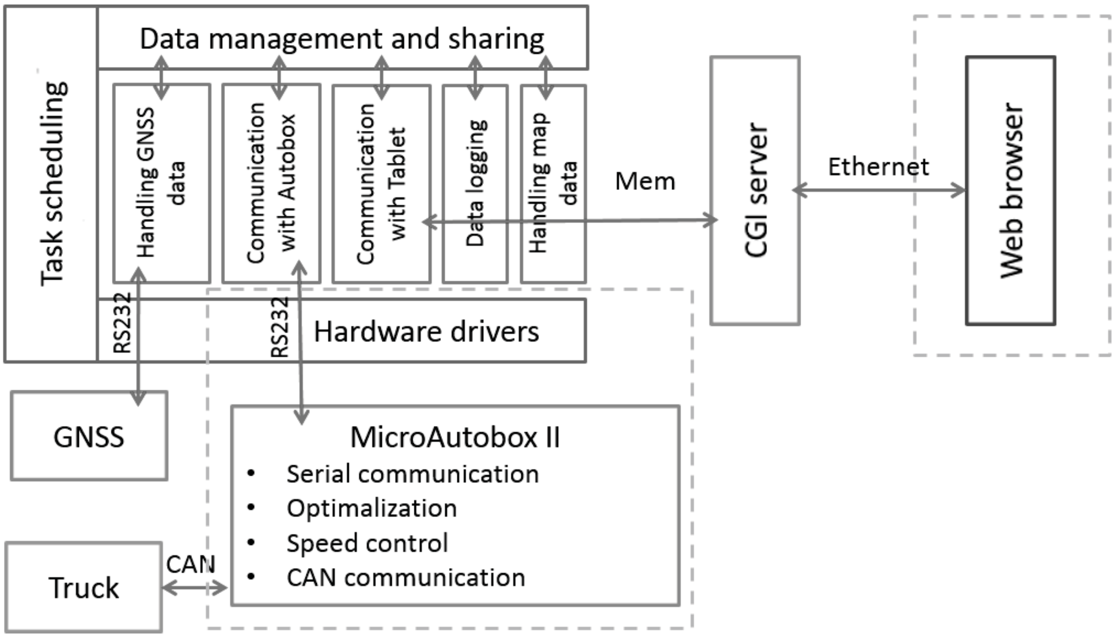

Fig. 5. The software architecture implemented for the on-road experiments

Results

The primary purpose of the simulations in the context of the cruise control is to gain information about the truck’s responses – in the present case mostly in time domain – to certain control inputs. For instance, transient signals, settling times, time-lag are normally calculated and analysed by the control engineers to improve the control method. In the look-ahead control method used herein – see its mechanical and mathematical formulation in (Németh, B. – Gáspár, P. 2016) – for the simulations, there are several important parameters to be tuned for a satisfactory control performance.

The different settings of these parameters result in quite different vehicular behaviours and in very different environmental and economic costs. These parameters include the performance weighting parameter R_1, which effects – among other characteristics of the speed profile – the overshoots (e.g., when a speed limit sign is encountered), the number n of equidistant discrtete spatial points – along the route ahead – which are taken into consideration in the speed optimization, and *L*, which is the actual look-ahead distance. In regards of the different control scenarios and parameter settings, a number of simulation-based experiments were carried out and reported in research articles, see e.g., Mihály, A.–Gáspár, P. 2016, Mihály, A. et al. 2013 and Németh, B.–Gáspár, P. 2016.

The simulation results presented herein concern the look-ahead distance *L* is being varied in the simulation runs, while – initially and most of the simulated time – $R_1 = 0.5$. The latter parameter is modified only briefly to ensure that the speed limits are heeded to. *L/n* , i.e. the distance between consecutive look-ahead points – is kept constant 100 meters throughout the experiment. The following speed limits apply along the route: 50 km/h (0 – 2 km), 70 km/h (2 – 16 km) and 40 km/h (16 – 28 km). These speed limits were obtained from the Open Street Map road database and were checked against the data collected during earlier traffic sign data collection trips in the area (Fazekas Z. et al. 2017). In *Fig. 6*, the truck velocities derived for different look-ahead distances *L* are shown for the route indicated in *Fig. 2*. The times required to cover the route in case of various *L* look-ahead distances are given diagrammatically in *Fig. 7*, while *Fig. 8* presents the truck’s total fuel consumption for different *L*’s.

In the simulation runs, the speed profiles were not perfect, e.g., a few over-shoots over the actual legal speed limit can be identified in *Fig. 6*. These occurred due to the parameter setting used in the simulation. Nevertheless, these settings and the tested method of the temporary modification of the performance weighting parameter R1 gave us considerable insight on how to choose the aforementioned parameters for the on-road test and what kind of adaptation via parameter R_1 can be achieved.

For the purpose of on-road testing several other safety functions will be implemented and actively used, e.g., too large abrupt increase/decrease of vehicle speed will not be allowed.

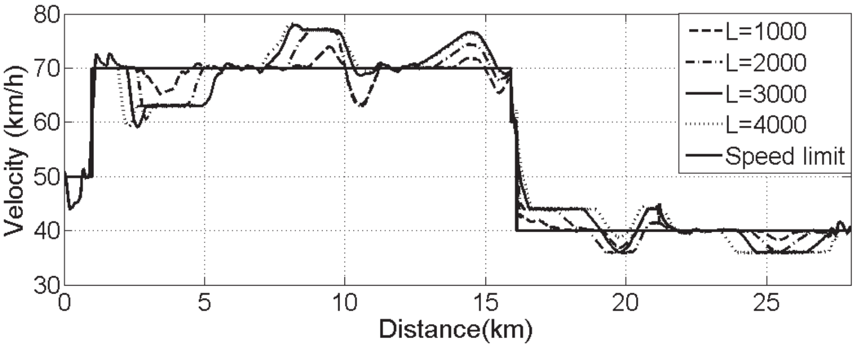

Fig. 6. The speed profile computed for the Gyöngyös - Kápolna route for different control look-ahead distances

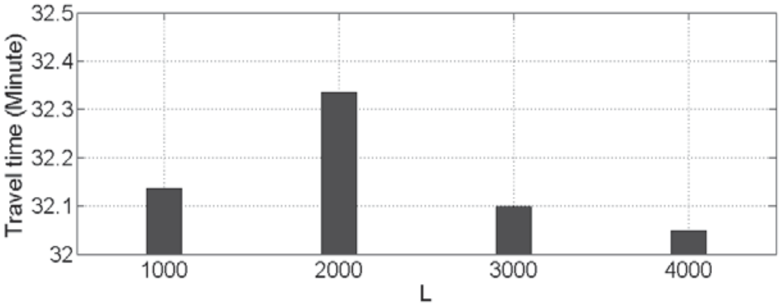

Fig. 7. The time required to cover the route in case of various L look-ahead distances used in the look-ahead cruise control

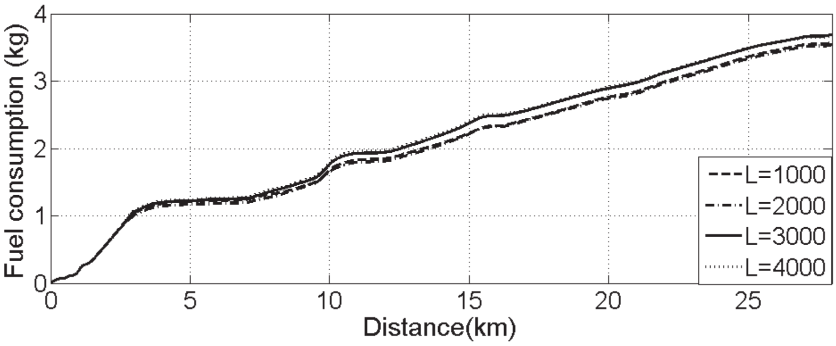

Fig. 8. According to the simulations, the total fuel consumption for the route varies with the parameter L

Conclusions

A look-ahead cruise control method was proposed recently for heavy road vehicles. The method was designed, modelled and initially tested with a control design tool-set for robust control of the linear parameter variant systems. After a long series of software-in-the-loop simulations, an on-road testing of the method is in a final stage of preparation. Some of the tasks associated with turning a truck simulation into a real experiment were pointed out.

Acknowledgements

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