VEHICLE CONTROL USING PREVIEW INFORMATION

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Abstract: The background and the aim of the project,"Vechicle control by using preview information - 'Look Ahead'" , are discussed. The project is raised to explore the possibilities of reduction of fuel consumption and improvements in comfort and safety for heavy vehicles. In particular research will focus on improvements that can be made, in actual and future control systems, with knowledge of the road ahead. This paper describes the project and reports on initial findings as well as related research.

1. INTRODUCTION

Telematics together with on-board vehicle control systems provide a great potential to improve traffic safety and reduce costs. Future navigation systems may not only be used to guide the vehicle the best route, but information from the system may also be used to drive the vehicle through a given route in a safe and cost-efficient way.

Global Positioning Systems (GPS), road information (maps) and other future telematics technologies will provide data to vehicles that can be used to estimate information about the road and driving conditions ahead. The information, e.g., horizontal and vertical curves, speed limits and traffic congestions, can be used to not only inform the driver but also to enhance the automatic control of several systems of the vehicle. The information may be used to improve control functions that have already been automated, such as cruise controls and automated gear shifting, but the information may also be used to optimise other functions, e.g., control of auxiliary systems, which are lower level systems that the driver normally does not control.

Cruise Control and Downhill Cruise Control (to keep a set speed downhill by using the auxiliary brakes) are widely used functions in heavy trucks today. Moreover, Adaptive Cruise Control (to keep a set distance to the vehicle ahead) is currently entering the market. Information about the road ahead may both extend and improve these applications.

The traditional Cruise Control is designed to keep a set reference speed. It is possible to cruise in a more cost efficient way if the system has information about the topography ahead and if the speed is allowed to vary within a certain tolerance around the reference speed.

The functionality of the Downhill Cruise Control can be improved by lowering the speed before a downhill section. The blending of different brake systems when driving downhill may be optimised using information about the hillside (slope and length), the capacity of the foundation brakes (to avoid overheating), limitations of the auxiliary systems (e.g., cooling system capacity) and the vehicle weight.

In a similar manner speed, gear and brakes could be appropriately chosen when driving uphill, when the road bends or when the speed limit changes.

The basic idea is to provide the control system with the essential information that the driver normally uses when driving manually. Driving in an optimal manner requires consideration of several inputs. This is a complex and exhausting task, even for the best drivers, and thus supporting control functionality is of interest. Moreover, it should be noted that sometimes it could be valuable to get information even beyond the horizon of sight of the driver.

In addition, the effects of auxiliaries, driveline and brakes are not independent. For example, the cooling system cools both the engine and the auxiliary break, the retarder, although they normally need cooling at different occasions. Further on, the auxiliaries (e.g., cooling system, air compressor, alternator) provide a small brake effort on the vehicle, which preferably should be applied when braking will be unavoidable, which need to be considered together with the dedicated brake systems. Thus, all the sub-systems need to be considered together for optimality.

In the next section the research project "Vehicle control by using preview information" is presented. Section three contains a survey of other efforts in the area, and the fourth section briefly describes results from the first stages of the project. Finally the paper is concluded in section five.

2. PROJECT DESCRIPTION

A project funded by IVSS[1] and Scania CV AB called "Vehicle control by using preview information - 'Look Ahead'" has been initiated. The project started 2005 and involves two full time PhD students, Per Sahlholm (KTH) and Maria Ivarsson (LiU).

The research problem considered in the project is how to meet higher safety and comfort demands and obtain reduced fuel consumption by the use of real-time road information (navigation systems and on- or off board databases) for vehicle control. This project aims to develop a control system architecture for such functions, together with the required parameter estimations and control algorithms. The overall project is visualized in figure 2. The vehicle control systems need to access map and position data through some interface. The data can be used to improve the operation of several subsystems in the vehicle, controlling a multitude of actuators.

[1] Intelligent Vehicle Safety Systems is a program run by the Swedish road administration and the Swedish vehicle manufacturers

Fig. 1. When driving over a hill a preview information enabled cruise control could automatically lower the speed before the peak. Due to the many sharp bends in the road, braking will probably be inevitable at some point, and the auxiliary systems can be controlled to engage only when there is an energy surplus.

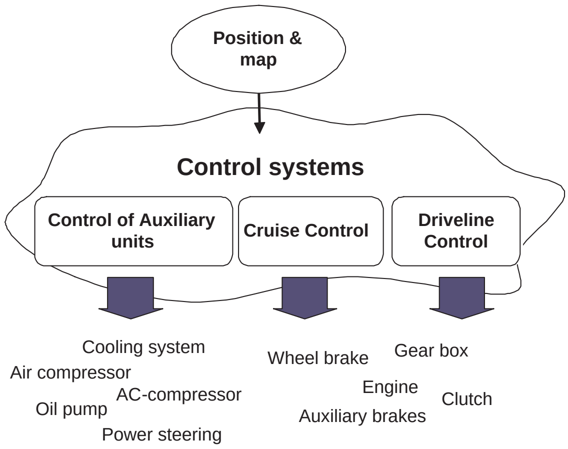

Fig. 2. Overview of the project "Vechicle control using preview information". Various aspects of utilizing position and map data to improve vehicle control algorithms are investigated.

A number of theoretical and practical questions will be researched. Properties of the preview information affect the feasible control actions and associated performance. Control algorithms to utilize the information will be deduced and evaluated through analytical and numerical sudies. Figure 3 illustrates a number of important fields of study.

The project aims to find out how the interface between vehicle control systems and the information supplier (e.g., navigation system) should be designed. This means that an important part of the research problem is on information retrieval and processing. Traffic and location data could be available to the vehicle control unit in a variety of formats, resolutions and temporal accuracies. How such data should be transformed and pre-

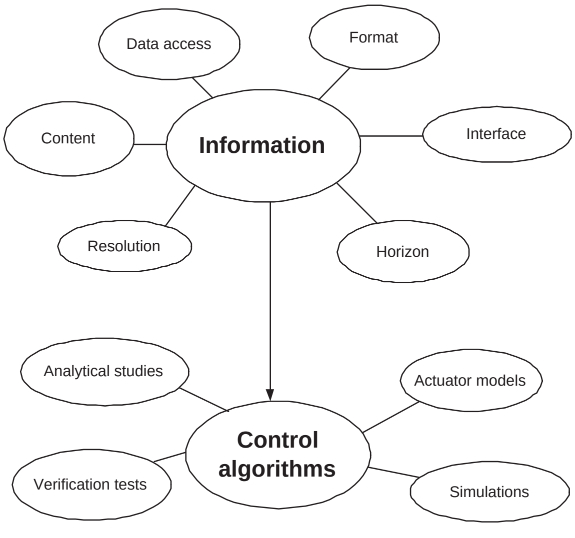

Fig. 3. Main fields of study within the project.

processed is another main part of the project. The road information is also likely to be fused with sensory data.

General principles for vehicle control using road information will be developed within the project. It is however likely that details in the approaches will differ from application to application. This will be simulated and verified by the use of both models and real test trucks.

The project is also associated to another IVSS-project with partners such as Scania, Volvo AB, Vägverket and NavTeq. The associated project focuses on the collection of commercial map data, especially truck attributes and ADAS-attributes, and definition of map interfaces. These two projects will most likely influence each over the coming years.

3. RELATED RESEARCH

Both numerical and analytical research aimed at using preview information for heavy vechicle control has been performed previously. This section outlines some important contributions in the area.

By using dynamic programming, DP, as the optimisation algorithm for a Model Predictive Control, MPC, (Hellström, 2005; Hellström *et al.*, 2006), it has been shown that 2.5% reduction of fuel consumption can be achieved by controlling the speed of a heavy truck. The control signals in this study were accelerator level, break level and gear. These control signals are chosen by using a dedicated cost function. To ensure this result in all driving situations, the cost function must be general and case insensitive.

The cost function must include all factors that influence the desired performance of the control system. It is important to penalize the source problem and not its side effects. If the objective is to minimize costs for the truck owner; time and energy consumption are the main issues. These two should therefore be the two only terms that add up in the cost function. How to tune the control algorithm, i.e. how to set the coefficients of the two terms, has to depend on the market of the truck business.

Further on, the numerical affects must be secured to be as little as possible. Simulations have showed that different resolutions of the discrete velocity grid give different optimal solutions. Since the amount of computations grows exponentially with the state space, a high resolution will lead to calculation times that are not acceptable in real time systems. However, a low resolution can give non-acceptable solutions. Moreover, the fault that appears when using numerical calculations can also influence the choice of optimal control signals. It is important to know the magnitude of the potential fault of the numerical solver, to implement the algorithm in the best way.

Analytical studies have resulted in optimal control strategies to minimize fuel consumption for heavy truck applications (Fröberg *et al.*, 2006). In this study the truck has been modelled with an engine torque that has a linear dependency to fuel mass and engine speed. The influence on the optimal control of this approximation has not been evaluated. To get closer to the optimal control strategy for a heavy truck it is necessary to consider the non-linearity of the torque of the truck engine.

Another approach to reducing fuel consumption by controlling the speed of the truck is described in method 3 in (Wingren, 2005). This method, which has been designed and simulated at Scania, results in an economical cruise control that imitates a skilled driver. The simulations showed a reduction of the fuel consumption in the range $1.5\% - 3.4\%$. The control uses a dedicated logic in a finite number of driving situations, given that the topography of the road is a known input to the system. The economical cruise control can be extended to include even more strategies that have been found optimal in analytical studies.

Two variants of a predictive powertrain control for heavy duty trucks has been described by representatives of DaimlerChrysler research. A 3D digital road map is used in order to let the cruise control imitate a skilled driver. A lowered fuel consumption of $4.1\% - 5.2\%$ with an increase in travel time of $.3\% - 1.4\%$ is reported in the second reference (Lattemann *et al.*, 2004; Terwen *et al.*, 2004).

An adaptive cruise control uses data from a distance sensor to adjust the driving speed in order to follow a vehicle ahead when the set cruising speed cannot be kept. BMW has described such a system for passenger vehicles with an added feature to adapt the dynamics of the speed control depending on various road features. The system uses a standard interface developed in the European project MAPS&ADAS to obtain the map data from the on-board data provider (Loewenau *et al.*, 2005).

The energy consumption, and possibilities for improved control, of auxiliary systems has been analysed in (Pettersson and Johansson, 2004) and (Pettersson and Johansson, 2006). The combined energy consumption of all auxiliary systems is estimated to account for 4.7% to 7.3% of the total fuel used. It is predicted that this can be significantly reduced by replacing current auxiliary systems with versions that can be freely controlled using appropriate algorithms. Look ahead is used to obtain the optimal control of the cooling system in a heavy truck. The cooling system is a dynamic system where energy can be stored in terms of temperature, this turns out to be beneficial in a look ahead control system.

4. PROJECT RESULTS

In the initial phases of the project the main focus has been areas related to optimal speed control. The problem of finding and supplying a sufficiently accurate vector of look-ahead slope profile data has been studied. A summary of results on estimation of the driven road slope profile are presented in this section.

4.1 Road slope estimation

Two studies of road slope estimation using current truck sensors have been performed, resulting in MSc. theses. In the first study the truck's own sensors were used one by one to estimate the slope profile of the driven road. Three different methods were studied; GPS, driveline information and barometric pressure. Each of the methods showed specific strengths and weaknesses, which prompted a second project aimed at integration of several data sources (Johansson, 2005).

Using the three data sources together it was possible to obtain a much more robust estimate of the slope. The redundancy that follows from the use of several sensors allows the estimator to work reasonably well during most driving conditions. However, further testing on well-known reference roads is needed to get a good quantitative measure of the estimation performance. Except for the thesis (Kozica, 2005) the results are presented in (Jansson *et al.*, 2006). Estimation results with loss of input data are illustrated in figure 4.

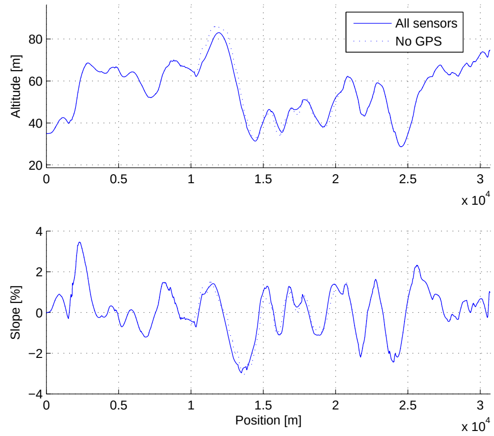

Fig. 4. Slope and altitude estimate of road E20, Strängnäs - Kjula. The plot shows estimates with full sensor fusion, and the result obtained during GPS data loss between positions $1e4$m and $2e4$m.

4.2 Sensitivity of optimal cruise control

Preliminary attempts at assessing the sensitivity of velocity optimisation to errors in road profile data have been made. This problem is of particular interest since it provides information of what quality of slope data has to be provided in order to realize the theoretically predicted fuel savings. The data can thus be valuable in deciding on data collection and storage methods. In the near future there are plans to extend this work.

5. CONCLUSION

During the work so far it has been noted that high quality preview information is crucial to realizing the potential of look-ahead applications. It is necessary to consider not only the potential gains of the preview information, but also the associated cost of supplying information of a given quality.

The air system is similar to the cooling system, in terms of potential of energy storage. The objective of the air system is to give high pressurized air for the brake system of heavy vehicles. The pressure in the air system is a dynamic state and the consumption of air is dependent of the driving situation. If the road ahead of the vehicle is known experiences from the treatment of the cooling system suggests that the control systems could benefit from that.

There are many possibilities to explore in the area of using preview information for vehicle control.

REFERENCES

Fröberg, Anders, Erik Hellström and Lars Nielsen (2006). Explicit fuel optimal speed profiles for heavy trucks on a set of topographic road profiles. In: *SAE Technical Paper 2006-01-1071*. SAE.

Hellström, Erik (2005). Explicit use of road topography for model predecitive cruise control in heavy trucks. Master's thesis. Linköping University. Sweden. LiTH-ISY-EX-05/3660-SE.

Hellström, Erik, Anders Fröberg and Lars Nielsen (2006). A real time fuel-optimal cruise controller for heavy trucks using road topography information. In: *SAE Technical Paper 2006-01-0008*. SAE.

Jansson, Henrik, Ermin Kozica, Per Sahlholm and Johansson Karl Henrik (2006). Improved road grade estimation using sensor fusion. In: *Proceedings of the 12th Reglermöte in Stockholm, Sweden*.

Johansson, Ken (2005). Road slope estimation with standard truck sensors. Master's thesis. Royal Institute of Technology. IR-RT-EX-0510.

Kozica, Ermin (2005). Look ahead cruise control: Road slope estimation and control sensitivity. Master's thesis. Royal Institute of Technology. IR-RT-EX-0524.

Lattemann, Frank, Konstantin Neiss, Stephan Terwen and Thomas Connolly (2004). The predictive cruise control - a system to reduce fuel consumption of heavy duty trucks. In: *SAE Technical paper 2004-01-2616*. SAE.

Loewenau, J.P., W. Richter, C. Urbanczik, L. Beuk, T. Hendriks, R. Pichler and K. Artmann (2005). Real time optimization of active cruise control with map data using standardized interface. In: *Proceedings of the 12th World congress on ITS*. San Francisco, CA, USA. paper 2015.

Pettersson, Niklas and K H. Johansson (2004). Optimal control of the cooling system in heavy vehicles. In: *Proceedings of the 1st IFAC Symposium on Advances in Automotive Control*.

Pettersson, Niklas and K H. Johansson (2006). Modelling and control of auxiliary loads in heavy vehicles. *International Journal of Control* **79**(5), 479–495.

Terwen, Stephan, Michael Back and Volker Krebs (2004). Predictive powertrain control for heavy duty trucks. In: *Proceedings of the 1st IFAC Symposium on Advances in Automotive Control*.

Wingren, Anna (2005). Fordonsreglering med framförhållning. Master's thesis. Linköping University. Sweden. LiTH-ISY-EX-05/3644-SE.