# Road Grade Estimation for Advanced Driver Assistance Systems

Modern vehicles are equipped with many assistance control systems that aid the driver in operating the vehicle safely and economically. Several of these systems can be programmed to use stored information from a map, enabling actions to be taken before the driver can even see the road in question. Knowledge of the current and future road grade can be used in engine and gearbox control systems to help meet instantaneous power demand while keeping fuel consumption and environmental impact as low as possible. Heavy-duty vehicles are especially affected by the road grade, and by using information about the future gradient, the energy efficiency of the cruise controller can be greatly increased. On downhill road segments, the vehicle's brakes often need to be used to maintain a safe speed. By automatically coasting over the top of the hill, braking can be minimized and fuel conserved. When going uphill, the number of gear shifts required can often be reduced if the vehicle speeds up before the hill and the gearbox has information about the coming road grade. A map with road grade information can thus reduce the fuel consumption and environmental impact of heavy-duty vehicles. These ideas have been implemented in production systems for Scania trucks and are deployed all over Europe.
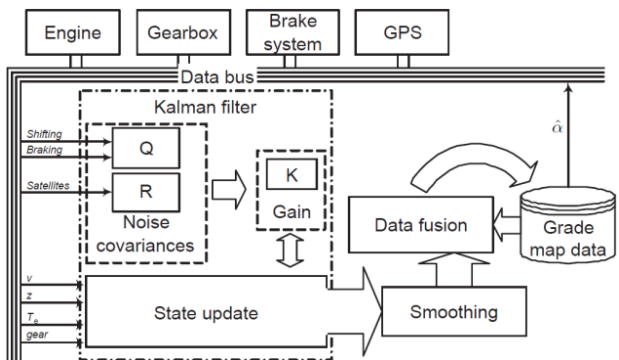

Vehicle Fleets as Sensor Networks

As long-distance trucks go about their daily business of delivering cargo, onboard algorithms can develop estimates of the road grades they encounter on their routes. This is much more efficient than the conventional approach of creating digital road maps with specialized probe vehicles that drive around specifically for the purpose of collecting data. In this new approach, only sensors already available in current heavy-duty vehicles are used to estimate road grade information. This effectively turns every truck on the road into a mobile sensor node, and the entire fleet of vehicles forms a constantly moving sensor network. The road grade information is stored in a map and updated each time a vehicle passes over a road segment. The estimation is performed using a Kalman filter that combines information from onboard vehicle sensors and the current driving situation (see figure on the next page). An estimate of the road grade accuracy is also stored in the map. When a vehicle returns to an already mapped road segment, the accuracy is used to determine how much the new data should be trusted relative to the data already stored in the map. If each vehicle is equipped with a communication device, the information gathered can be shared with other vehicles through a server. This way a vehicle gains access to data about roads it has not yet driven. With more measurements of the same road segment, the statistical uncertainty decreases, giving better road grade information and higher performance in the control systems using the estimate.
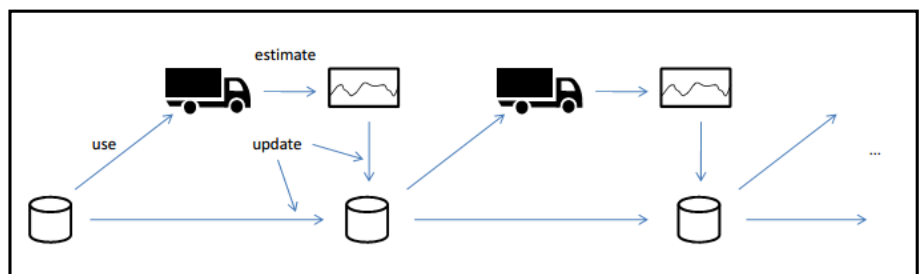
Each vehicle uses the current map, creates a new estimate, and updates the stored map (either on board or on a remote server).

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A Kalman filter is used to estimate the road grade based on vehicle sensors and the current driving situation. The estimates are combined with previous estimates stored in a grade map database.
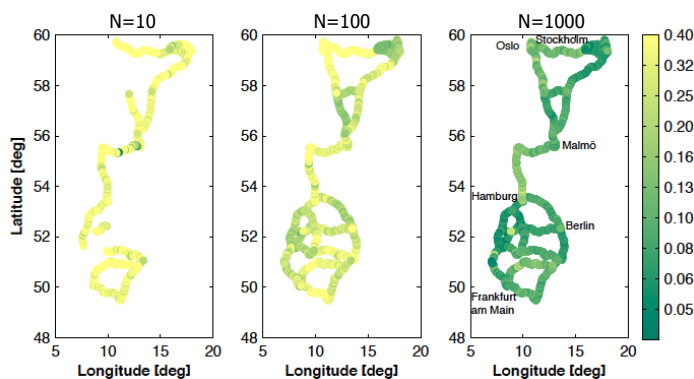
Estimated road network and estimation error (in percent road grade) after N = 10, 100, and 1000 vehicle trips in a region

Vehicle Sensor Network Implementation

Advanced driver assistance systems using mapped road data are already in production and being used by customers on highways. Examples include the Scania Active Prediction and Eco-roll systems. Using road grade information collected by a network of vehicles in daily operation instead of the current manually collected information for these applications would ensure that all relevant roads are covered and that changes in the road network are quickly incorporated into the map. Data collected with traditional probe vehicle methods soon become outdated, and coverage is lacking in many countries.

Scania Active Prediction in use. The cruise controller adjusts the vehicle speed within a range around the desired average speed in order to traverse hills more efficiently.

Future Applications

Many systems yet to be developed may benefit from road grade estimates. Examples include heavy-duty vehicle navigation systems that choose the most energy-efficient route with respect to topography; vehicle platooning systems that automate driving, maintaining short distances between vehicles in hilly terrain; and emergency braking systems that take the road grade into account when calculating the stopping distance. The described approach may be expanded into additional types of data. Examples include road curvature, road friction, and vehicle speed at various times of the day. All these variables are useful in developing the next generation of advanced driver assistance systems for heavy-duty vehicles, and they may all be gathered using a mobile sensor network made up of trucks moving about our highways every day.

For more information: P. Sahlholm, Distributed Road Grade Estimation for Heavy Duty Vehicles, doctoral dissertation, KTH Royal Institute of Technology, Stockholm, 2011; P. Sahlholm and K.H. Johansson, Road grade estimation for look-ahead vehicle control using multiple measurement runs, Control Engineering Practice, vol. 18, no. 11, pp. 1328-1341, 2010.