Multicriteria Cruise Control Design Considering Geographic and Traffic Conditions

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Abstract: The paper presents the design of cruise control systems considering road and traffic information during the design of speed trajectories. Several factors are considered such as road inclinations, traffic lights, preceding vehicles, speed limits, engine emissions and travel times. The purpose of speed design is to reduce longitudinal energy, fuel consumption and engine emissions without a significant increase in travel time. The signals obtained from the road and traffic are handled jointly with the dynamic equations of the vehicle and built into the control design of reference speed. A robust H_∞ control is designed to achieve the speed of the cruise control, guaranteeing the robustness of the system against disturbances and uncertainties.

Keywords: look-ahead control; multicriteria optimization; robust H_∞ control

1 Introduction and Motivation

The driveline system plays an important role in energy consumption and the emission of vehicles, therefore the development of longitudinal control systems is in the focus of research and the industry. Adaptive Cruise Control (ACC) systems guarantee the adaptation of the vehicle to the environment, such as instantaneous road disturbances, road slopes, rolling resistances, and the speed of preceding vehicles. However, these systems are not able to take into consideration the road and traffic information expected from the subsequent road sections, such as speed limits and road inclinations.

In this paper a longitudinal control system is proposed which is able to consider predicted road and traffic information in the design of the longitudinal control force. Using the signals of road inclinations and speed limits, fuel consumption, the energy required by the actuators, and engine emissions can be reduced. Moreover, the unnecessary activation of the brakes is also avoided, which is desirable for reducing the wear of the brake pads/discs and the loss of kinetic energy. The control of longitudinal dynamics requires the integration of these control components, see [6].

Several methods have already been published on the topic of look-ahead control; see [5, 10]. The robust H_∞ control design method was proposed by [9] for the design of vehicle speed based on road inclinations. In [8] the emission of the vehicle was also taken into consideration. The optimization problem was handled in the same manner, using the receding horizon concept on spatial increments in [3, 11]. The terrain and traffic flow were modeled stochastically using a Markov chain model in [7]. [4] evaluated the approach in real experiments.

This paper focuses on the design of vehicle speed based on signals obtained from the road and traffic. Several aspects are considered, such as road inclinations, traffic lights, preceding vehicles, speed limits, travel times and the effect of engine emissions. Since the designs for different aspects result in different solutions, a balance needs to be achieved between them by using multi-objective optimization. The novelty of the paper is that it considers the signals of traffic lights during the design of speed trajectories. In this way it is possible to reduce the number of unnecessary brakings, accelerations and stop-and-starts, which may considerably increase the required energy, fuel consumption and engine emissions. Since the proposed method also handles speed limits and preceding vehicles, it can be applied on motorways and in urban traffic networks as well.

The paper is organized as follows: Section 2 presents the aspects of the speed design, such as road inclinations, emissions and oncoming road intersections. The design of the control strategy for oncoming traffic lights is detailed in Section 3. Section 4 presents the multi-criteria optimization of vehicle cruise control by the appropriate choice of prediction weights. Section 5 shows the operation of the control system on a transportational route. Finally, Section 6 summarizes the conclusion remarks.

2 Geographic and Traffic Criteria of Speed Design

2.1 Speed Design for Road Inclinations

The design of the speed trajectory is based on road inclinations and speed limits. Since the design of optimal speed has already been proposed in an earlier paper, only a brief summary is given, for details see [9].

Road inclinations are considered in the design of the longitudinal control force. On a downhill slope the speed of an undriven vehicle increases by itself, thus the control force of the vehicle before the slope may decrease. Consequently, the brake system can be activated later, or it is not necessary to be activated at all.

Before the section where a speed limit is imposed, the speed can be reduced, therefore less braking energy is necessary for the vehicle. By choosing the appropriate speed profile according to the road and traffic information, the number of unnecessary longitudinal interventions and their durations can be significantly reduced.

For the consideration of predicted information, the route of the vehicle is divided into *n* sections using *n+1* number of points. The division of the route is of arbitrary lengths. The rates of the inclinations of the road and the locations of the speed limits are assumed to be known at the endpoints of each section. In each section point of the road, reference speeds are defined, which depend on the speed limits. The speed at section point *j* should reach the predefined reference speed $v_{ref,j}^2 \quad j \in [1,n]$. The control task is then to track the momentary value of the speed, which is formulated in the following form: $\dot{\xi}_0^2 \rightarrow v_{ref,0}^2$.

The road sections to be taken into consideration are qualified by different weights. A weight Q is applied to the initial speed and weights $\gamma_i, i \in [1,n]$ are applied to the further reference speeds. A weight W represents the tracking of the speed of the preceding vehicle v_{lead} in order to avoid a collision, see [9]. The safety distance between the vehicles is determined according to directives: $d_{st} = 0.1\dot{\xi}_0 + \dot{\xi}_0^2/150$. The prediction weights should sum up to one, i.e., $W + Q + \sum_{i=1}^{n} \gamma_i = 1$. The interpretation of the importance of W, Q, γ_i prediction weights is the following. If Q weight is set to 1 and the other weights are 0, the simple cruise control is achieved. If equal weights for Q and γ are set and W is 0 in the cruise control, the predicted road sections have the same importance. When *W=1* and $Q = \gamma_i = 0, i \in [1,n]$, only the tracking of the leader vehicle is realized. The optimal determination of weights is a key issue, i.e., to achieve a balance among speed limits, effect of road slopes and traffic situations.

During the design of the vehicle speed the prediction weights are taken into consideration. The momentary vehicle speed $\dot{\xi}_0$ must be modified in the following way:

$$\lambda = \sqrt{\vartheta - 2s_1(1 - Q - W)(\ddot{\xi}_0 + g sin\alpha)} \qquad (1)$$

where the value ϑ depends on the predicted road slopes, the reference speeds and the prediction weights:

$$\vartheta = W v_{lead}^2 + Q v_{ref,0}^2 + \sum_{i=1}^{n} \gamma_i v_{ref,i}^2 + \frac{2}{m}(1 - Q - W) \sum_{i=1}^{n} (s_i F_{di,r} \sum_{j=i}^{n} \gamma_j) \qquad (2)$$

where v_{ref} and v_{lead} denote the reference speed and the velocity of the leading vehicle respectively, s_i denotes the length of segment *i* and $F_{di,r}$ denotes the unmeasured longitudinal disturbances.

The calculation of λ requires the measurement of the longitudinal acceleration $\ddot{\xi}_0$. Consequently, the aim of the control design is to track the calculated speed trajectory: $\dot{\xi}_0 \rightarrow \lambda$.

2.2 Speed Design for Emissions

The pollution emerging from road traffic has become a serious environmental issue over the past decades. Modeling the amount and composition of exhaust gases is essential for an effective control aimed at minimizing emissions and fuel consumption. When individual vehicles are analyzed, emission models can be classified into two categories based on the number of input variables: traffic situation models and average speed models. Input variables of the former models include information of the current traffic situation or more specifically, instantaneous acceleration in addition to the speed variable. Average speed models are used if no information is available on the current driving pattern apart from average speed, and thus the output of the model is the emission assigned to validated measurement cycles of the average speed value.

Emission can be described by its temporal rate (emission rate function) or – throughout a journey – by its spatial rate (emission factor function). Emission factors from road vehicles can be derived via different approaches. The functions of single vehicles can be measured by dynamometer tests, by transient chassis dynamometers or by engine emission measurements [14]. The most common approach to obtain emission factors of great resolution with regard to vehicle technology is to sample a range of cars of a given category and emission control technology (e.g. gasoline passenger car 1.4-2.0l, Euro 4), drive them according to pre-defined driving patterns (driving cycles) on a chassis dynamometer, and then record their emissions over such conditions. The total produced emissions divided by the total distance driven results in a mean emission factor which is considered representative of the particular vehicle technology (provided that the vehicle sample is sufficient large) when driven under similar driving conditions as those covered by the driving cycle. Model functions are then fitted to these data sets. A standard method is that emission factors of the pollutants are modeled by convex rational functions of average vehicle speed, see e.g. the model COPERT [13]. For the use of model COPERT in a macroscopic traffic emission framework, see [15]. The emission factor functions are specific for different vehicle classes, fuel types, Euro norms and engine capacities. For vehicle type *c* and pollutant *p*:

$$ef^{\,p,c} = \Big(\sum_{i=0}^{m} \beta_i^{p,c} \dot{\xi}(t)\Big) / \Big(\sum_{i=0}^{n} \delta_i^{p,c} \dot{\xi}(t)\Big) \qquad (3)$$

where $\dot{\xi}$ (t) denotes the instantaneous longitudinal vehicle speed, and $\beta_i^{p,c}$, $\delta_i^{p,c}$ are constant model parameters, depending on pollutant *p* and vehicle class *c*.

The following pollutants were modeled in the control design: CO, CO_2, NO_x and hydrocarbons (HC). These are considered the most significant exhaust gases that cause both global (greenhouse effect) and local harms (health problems, acid rain). Elaborating the reaction stochiometrics of internal combustion engines, a linear connection between the fuel consumption and the CO_2 emission of a vehicle can be stated [12]: $ef^{CO_2,c} = K \cdot f^c$, where f^c is the fuel consumption of a type *c* vehicle and *K* depends on the fuel type, e.g. in Diesel fuel *K=26.29*. Unfortunately, further analytic relationships cannot be drawn among emission functions of the pollutants as secondary reactions of internal combustion engines depend on several factors (i.e. engine and fuel type, engine load, technology of engine etc).

During the performance analysis, the normed sum of emissions is examined:

$$ef_{total}(t) = \sum_{c=1}^{N_c} \frac{ef^{CO_2}(t)}{ef_{nom}^{CO_2}} + \sum_{c=1}^{N_c} \frac{ef^{CO}(t)}{ef_{nom}^{CO}} + \sum_{c=1}^{N_c} \frac{ef^{HC}(t)}{ef_{nom}^{HC}} + \sum_{c=1}^{N_c} \frac{ef^{NO_X}(t)}{ef_{nom}^{NO_X}} \quad (4)$$

where $ef_{nom}^{p} = max_{v\in[60,90]} ef^{p}(v)$ denotes the nominal emission for pollutant *p*.

2.3 Speed Design for Oncoming Intersections

In the proposed control, the third criterion is the consideration of oncoming intersections. The proposed system uses traffic signal scheduling information for the design of the reference speed of the controlled vehicles. This proposition involves the matching of traffic and vehicle control for which certain hardware equipment is required. The technology is similar to that used in transit priority detection with the difference that the control intervention is executed in the vehicle only. In order to establish an effective cooperation, both the infrastructure and the vehicle are equipped with communication devices.

Different communication systems using this layout are known: e.g. the detection method using roadside beacons, the GPS-based detection method and the infrared detection method, see [1]. The former two methods rely more on the devices applied to the infrastructure (e.g. roadside beacons). In the infrared detection method, which is widespread in the United States, the vehicle is detected by a standard traffic inductive loop detector (ILD) embedded in the pavement which alerts the signal controller of the approaching HDV. After receiving the entrance request, the traffic signal controller (TSC) sends the timing data of the traffic signal via an infrared emitter (most commonly located on the signal mast arm or span wire). The scheduling information is then received by the IR (Infrared) detector of the vehicle and further used for the control design. The system layout is illustrated in Figure 1.

The main advantage of loop detection systems is that the system is compatible with commonly used loop detectors. It also does not require line-of-sight or visibility, and IR transponders may be set on already installed traffic controllers. The effective range of the system highly depends on the geographical layout of the intersection and may range up to 500m.

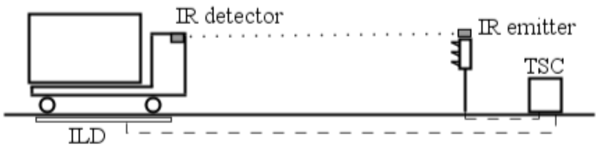


Figure 1
Communication architecture of the transit vehicle system

3 Control Strategy at Traffic Lights

Reference speed (1) is designed by taking road inclinations, preceding vehicles and speed limits into consideration. In the following a traffic signal of the intersection as a further criterion is used in the speed design. It is assumed that the traffic signaling data are available during the design process. For the strategy, necessary traffic information involves the distance between the vehicle and the traffic light s_{int}, the signal of the traffic light and the expiry time of the current signal. According to this information, the control strategy of speed calculation is chosen by making a decision logic, which is illustrated in Figure 2.

When the vehicle receives an information package from a traffic light, it makes a decision based on its current speed, etc. The following scenarios are analyzed in three cases: there is a green signal along the route, and in two additional cases there are red (or amber) signals.

Case 1: In the first case, the vehicle reaches the intersection during the green signal without increasing its speed, i.e., $s_{int}/\dot{\xi}_0 \le T_{gr}$. However, the speed of the vehicle may be reduced if it turns at the intersection. In this case the speed at the intersection must be modified to a safe cornering speed, thus $\dot{\xi}_0 = v_{int}$. It is achieved by setting the weight $Q = 1$ and $v_{ref,0} = v_{int}$. The condition for this case is:

$$\frac{2s_{int}}{\dot{\xi}_0 + v_{int}} \le T_{gr} \qquad (5)$$

where T_{gr} is the unexpired green time. Here the linear relationship between the initial speed $\dot{\xi}_0$ and the final speed v_{int} is exploited. Note that in straight motion, the speed and the weights are not modified, thus $v_{int} = \dot{\xi}_0$.

Case 2: In the second case, the vehicle reaches the intersection during the green signal if the speed is increased to the maximum allowed speed. In this case, the speed at the intersection must be modified to the original reference speed, thus $\dot{\xi}_0 = v_{ref,0}$. It is achieved by setting the weight Q=1. The condition for this case is:

$$\frac{s_{int}}{v_{ref,0}} \le T_{gr} \tag{6}$$

In this scenario, the intersection overwrites the modified reference speed and high acceleration and deceleration are applied.

Case 3: If the vehicle does not reach the intersection during the green signal, the deceleration of the vehicle and a safe stop condition are required. They are achieved by setting the speed $v_{lead} = 0$ and modifying the weight W in the following way:

$$W = 1 - \frac{s_{int}^2}{s_{int,max}^2}, \tag{7}$$

where $s_{int,max}$ is the distance between the vehicle and the traffic light when the signal arrives. Thus, in the calculation of speed, the predicted road information becomes less important when the vehicle is approaching the traffic light, and the stopping manoeuver has priority, i.e., $\dot{\xi}_0 \to 0$.

The further scenarios involve situations when the signal is red (or amber).

Case 4: If the signal is red, the time requirement for reaching the intersection at the vehicle's current speed is calculated. If during this time the red signal turns to green in straight motion, the speed and the weights are not modified, thus $v_{int} = \dot{\xi}_0$. However, the speed of vehicle may be reduced if the vehicle turns at the intersection. In this case, the speed at the intersection must be modified to a safe cornering speed, thus $\dot{\xi}_0 = v_{int}$. It is achieved by setting the weight $Q=1$ and $v_{ref,0} = v_{int}$. The condition for this scenario is:

$$\frac{2s_{int}}{\dot{\xi}_0 + v_{int}} \ge T_{red} \tag{8}$$

where T_{red} is unexpired red time. Note that at straight motion the speed and the weights are not modified, thus $v_{int} = \dot{\xi}_0$.

Case 5: If the signal is red and the unexpired red time is too long, it is necessary to stop the vehicle. In this scenario *W* is influenced according to (7).

Also note that in the previously formulated decision logic, the other preceding vehicles are ignored. In the case of a preceding vehicle *W* is modified according to [9].

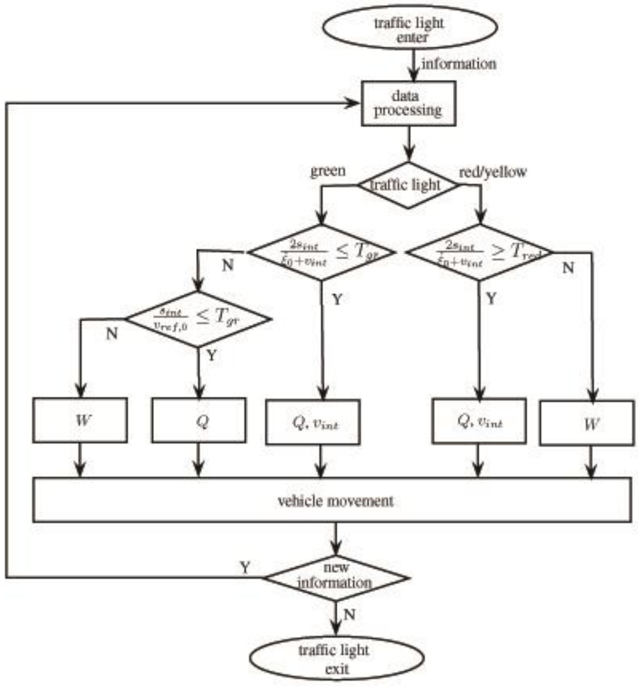


Figure 2
Flowchart of the traffic signal strategy

4 Formulation of Performance Criteria

4.1 Multicriteria Optimization

The aim of this section is to find an optimal speed $\dot{\xi}_0$, which guarantees the joint minimization of the control force, travel times and emission. The fulfilment of these performances individually results in different W, Q, γ_i weights according to equation (1).

In the minimization tasks, W is handled as an exogenous signal, which is set according to different special scenarios, i.e., preceding vehicles or traffic lights, see Section 3. Thus, in the optimization task, the weight W=0 is set in the standard case. During travelling Q and γ_i are calculated and applied. However, in case of preceding vehicles or oncoming intersections they are completed by weight W in such a way that $W+Q+\sum_{i=1}^{n}\gamma_i=1$ is guaranteed.

In the first optimization criterion, the longitudinal force F_{l1} must be minimized, i.e., $|F_{l1}|\to Min$. The force can be expressed as the linear function of prediction weights by using equation (1):

$$F_{l1}(Q,\gamma)=\beta_0(Q)+\beta_1(Q)\gamma_1+\beta_2(Q)\gamma_2+\ldots+\beta_n(Q)\gamma_n \tag{9}$$

where β_i are the coefficients of Q and γ_i. In practice, however, the following optimization form is used because of the simpler numerical computation:

$$F_{l1}^2\to Min \tag{10}$$

The optimal solution leads to $\overline{Q}$ and $\overline{\gamma}_i$, satisfying the constraints $0\le\overline{Q},\overline{\gamma}_i\le 1$ and $\overline{Q}+\sum\overline{\gamma}_i=1$. The solution of the optimization problem is found in [2].

The second optimization criterion is the minimization of traveling time. In this case the vehicle has to travel at the predefined reference speed. Therefore, the difference between momentary speed and reference speed needs to be minimized, i.e.,

$$|v_{ref,0}-\dot{\xi}_0|\to Min \tag{11}$$

This means that this optimization criterion is fulfilled if the road inclinations are ignored. The optimal solution of the performance (1) is: $\breve{Q}=1$ and $\breve{\gamma}_i=0, i\in[1,n]$.

The emission model of the vehicle is approximated by using a second order polynomial function according to equation (3): $ef_{total}(t)=\alpha_0+\alpha_1\dot{\xi}_0+\alpha_2\dot{\xi}_0^2$, where $\alpha_0,\alpha_1,\alpha_2$ are constant parameters. There is a formal analogy between $ef_{total}(t)$ and the unmeasured longitudinal disturbances $F_{d1,o}$, see [8]. In the third optimization criterion, the total emission $ef_{total}(t)$ is minimized: $|ef_{total}(t)|\to Min$. In practice, the following optimization form is used:

$$\left(ef_{total}(t)\right)^2\to Min \tag{12}$$

This minimization leads to a quadratic optimization problem, similarly to the first performance. The solutions of the optimization are denoted by $\hat{Q},\hat{\gamma}_i$ weights.

It is important to emphasize that the three performances (minimization of longitudinal force, traveling time or emission) result in different prediction weights. Thus, it is necessary to guarantee a tradeoff between them. In the multi-criteria optimization, three further performance weights are introduced. The roles of these factors are different. Performance weight R_1 is related to the importance of the minimization of the longitudinal control force, performance weight R_2 is related to the minimization of traveling time, while performance weight R_3 is related to the importance of emission. Since there is a constraint on the performance weights, $R_1 + R_2 + R_3 = 1$, a balance between the optimizations tasks can be achieved. The form of the final weights are the following:

$$Q = R_1\overline{Q} + R_2\breve{Q} + R_3\hat{Q} = R_1\overline{Q} + R_2 + \hat{Q}R_3 \tag{13}$$

$$\gamma_i = R_1\bar{\gamma}_i + R_2\breve{\gamma}_i + R_3\hat{\gamma}_i = R_1\bar{\gamma}_i + R_3\hat{\gamma}_i \tag{14}$$

with $i \in [1, n]$. The calculated multi-criteria optimal Q, γ_i prediction weights with the exogenous W are used for the calculation of the modified reference speed λ, see (1), and they are used during the travelling.

4.2 H$_\infty$-based Robust Control Design

During traveling, different disturbances which are not considered in the speed design may influence the vehicle dynamics. Thus it is necessary to find a robust speed controller *K*, which is able to track the calculated speed value. The controller can guarantee robustness against external disturbances, such as sensor noises and road disturbances, and also handle unmodeled disturbances.

The purpose of tracking is to ensure that the system output follows a reference value with an acceptably small error, which is the performance of the system. The control problem is as follows:

$$|\lambda - \dot{\xi}_0| \rightarrow Min! \tag{15}$$

where parameter λ is the reference value according to (1). Thus, the performance signal is $z = \dot{\xi}_0 - \lambda$.

The standard form of the closed-loop interconnection structure, which includes the feedback structure of the model *P* and controller *K*, is shown in Figure 3.

The control design is based on a weighting strategy. The purpose of weighting function W_p is to define the performance specifications of the control system. In the selection of W_p an accurate matching is required at low frequencies and a less accurate matching is acceptable at higher frequencies. The function W_p is selected as $W_p = \alpha/(Ts+1)$, where α and T are constants. Here, it is required that the steady state value of the tracking error is below $1/\alpha$ in steady-state.

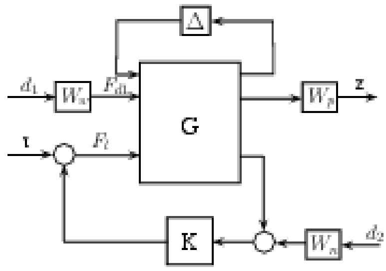


Figure 3
Closed-loop interconnection structure

Three additional weights are also applied. W_n reflects to the speed sensor noise, while W_w represents the effect of longitudinal disturbances. In the modeling, an unstructured uncertainty is modeled by connecting an unknown but bounded perturbation block (Δ) to the plant. The magnitude of multiplicative uncertainty is handled by a weighting function W_u. The weighting functions W_u, W_w and W_n are selected in linear and proportional forms.

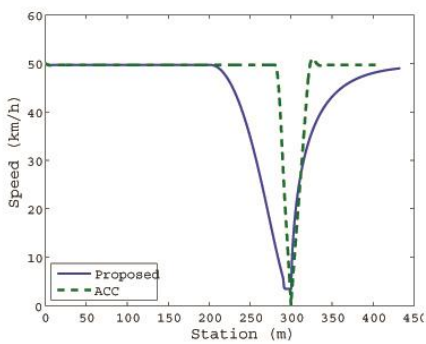
5 Simulation Results

In this section the operation of the vehicle system is analyzed in case studies. Both road and traffic information are taken into consideration. Note that in the simulation example only the longitudinal force will be in the focus. The balance between the three performances are analyzed in another paper, see [8].

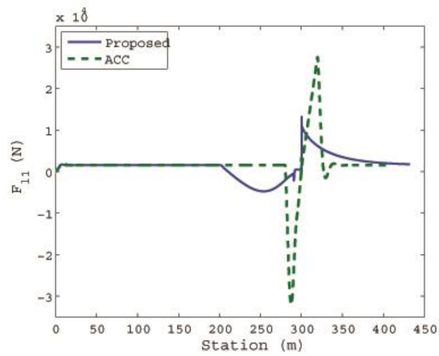
In the simulation examples two cruise control systems are compared. The first system uses a conventional adaptive cruise control (ACC) ignoring the predicted weights. This system always tracks predefined $v_{ref,i}$ reference speeds. The system using a cruise control (Proposed) considers the road and traffic conditions through predicted weights. Consequently, this system is able to modify the reference speed during traveling. In the figures the proposed control is denoted by solid line, while the conventional control is denoted by dashed line. Figures show the time responses of the simulation, i.e., the speed, the longitudinal force, the unexpired time and the weight W.

In the first simulation example the vehicle arrives within the range of the traffic light, which is red. Moreover, the expiry time of the red signal is long, thus it is necessary to stop the vehicle (see Case 5 in Section 3). The simulation starts when the distance between the vehicle and the traffic light is 300 m, but the range of the traffic light is 100 m. The proposed control receives the information package of the traffic light at 200 m, therefore vehicle speed is reduced up to this point. The unexpired red time decreases as Figure 4(c) shows. To guarantee the stopping of the vehicle, it is necessary to increase *W* weight, which is shown in Figure 4(d).

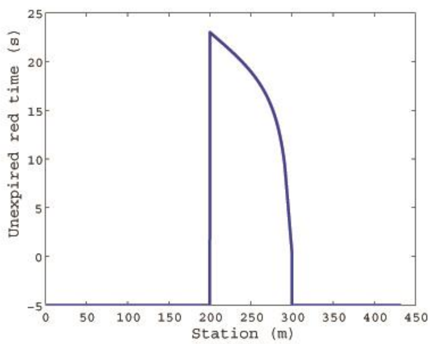
The conventional control reduces the speed abruptly, when the vehicle is close enough to the traffic light, see Figure 4(a). Thus, both the duration and the magnitude of the longitudinal force are higher in the ACC case, see Figure 4(b). Less longitudinal force and energy are required during the journey in the proposed control method. The saved longitudinal force is about 16% compared to the conventional cruise control system. Consequently, using the proposed control strategy smaller energy consumption can be achieved.



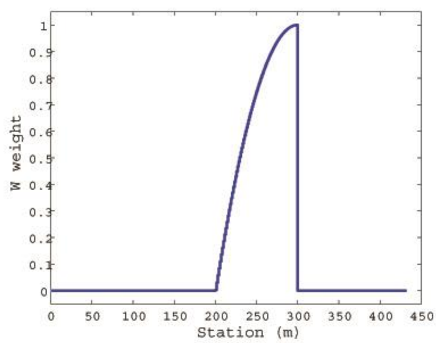
(a) Speed



(b) Actuated force



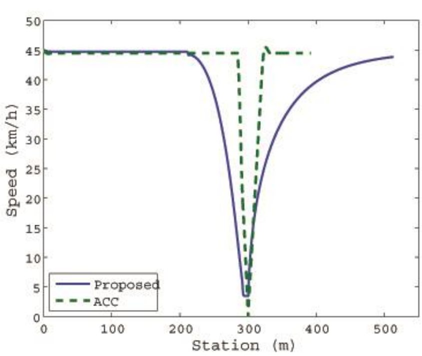
(c) Unexpired red time



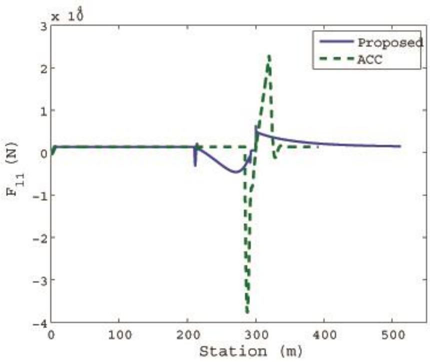
(d) *W* weight

Figure 4
Traffic light with long unexpired redtime

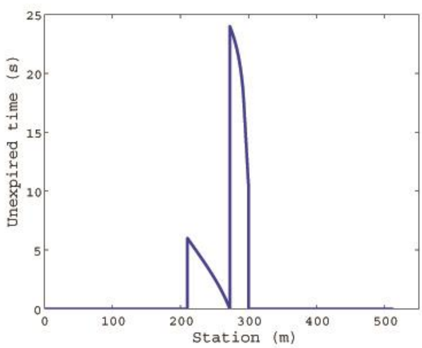
In the second simulation example, the vehicle receives the green signal in the range of the traffic light. It shows that during the green signal the vehicle does not reach the intersection; see Case 3 in Section 3. Figure 5(c) shows the unexpired green time and then the red time. Thus, the speed must be reduced. The requirement of the deceleration and the safe stopping at the traffic light is defined by the modification of weight *W*, which is illustrated in Figure 5(d). The speed and the necessary longitudinal force are shown in Figures 5(a) and 5(b), respectively. Less longitudinal force and energy are required during the journey in the proposed control method. The saved longitudinal energy is about 11% compared to the conventional cruise control system.



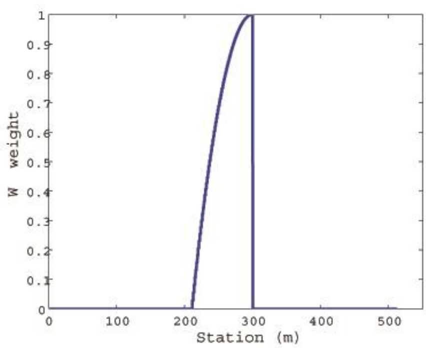
(a)Speed



(b) Actuated force



(c)Unexpired red time

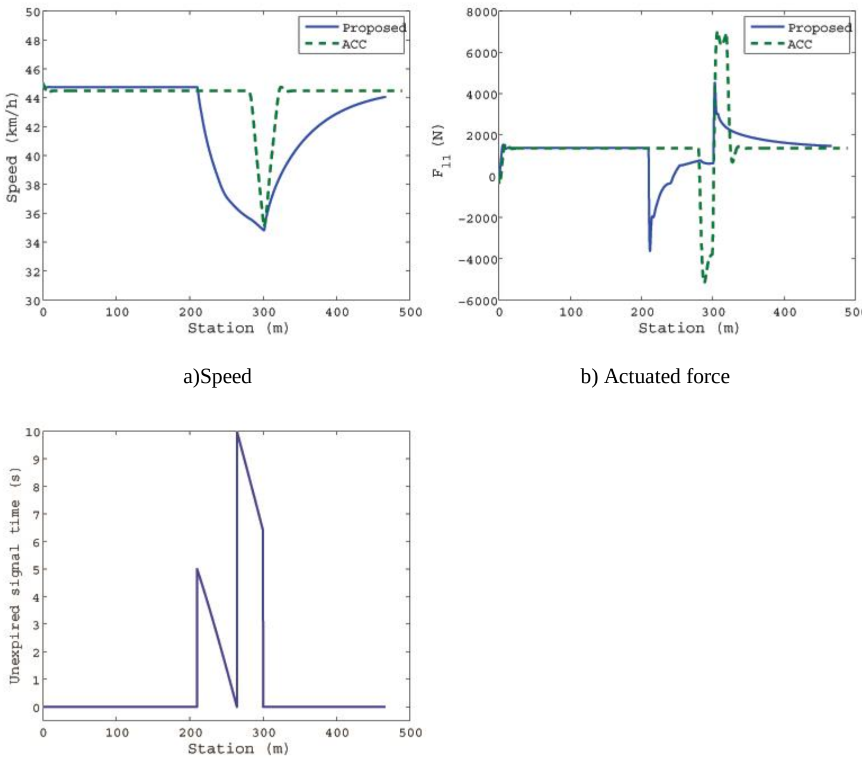


(d) *W* weight

Figure 5

Traffic light with green and red signals

In the third example the vehicle receives traffic information about the red signal, which turns to green. Figure 6(c) shows the short unexpired red time, which is followed by the green time. Thus, the speed must be reduced to the safe cornering speed v_{int}, see Figure 6(a). In this scenario v_{int} can be achieved within relatively long time with reduced longitudinal force by exploiting the adhesion coefficient of the road, see Figure 6(b). Less longitudinal force and energy are required during the journey in the proposed control method. The saved longitudinal force is 19% compared to the conventional cruise control system.



a)Speed

b) Actuated force

c) Unexpired red time

Figure 6
ACC systems with a compulsory speed limit

Conclusions

The paper has proposed the design of a cruise control system which is able to exploit information received from both geographic features and traffic. The main result of the research is that an intersection with a traffic light is included in the speed design. An optimal speed trajectory is computed according to the balance between the three factors, i.e., the longitudinal force, traveling time and emission. The control design is based on the robust H_∞ method, in which performance specifications, disturbances and uncertainties are considered. The simulation results show that the designed control reduces the energy required by the actuators.

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References

[1] K. Gardner, C.D. Souza, Nick Hounsell, Birendra Shrestha, and David Bretherton. Review of Bus Priority at Traffic Signals around the World. *UITP Working Group Technical Report*, 2009

[2] P. E. Gill, W. Murray, and M. H. Wright. *Practical Optimization*. Academic Press, London UK, 1981

[3] Erik Hellström, Jan Åslund, and Lars Nielsen. Horizon Length and Fuel Equivalents for Fuel-Optimal Look-Ahead Control. Munich, 2010

[4] E. Hellström, M. Ivarsson, J. Åslund, and L. Nielsen. Look-Ahead Control for Heavy Trucks to Minimize Trip Time and Fuel Consumption. *Control Engineering Practice*, 17(2):245-254, 2009

[5] M. Ivarsson, J. Åslund, and L. Nielsen. Look Ahead Control - Consequences of a Non-Linear Fuel Map on Truck Fuel Consumption. *Proc. Institution of Mechanical Engineers, Journal of Automobile Engineering*, 223:1223-1238, 2009

[6] U. Kiencke and L. Nielsen. *Automotive Control Systems for Engine, Driveline and Vehicle*. Springer, 2000

[7] I. V. Kolmanovsky and D. P. Filev. Stochastic Optimal Control of Systems with Soft Constraints and Opportunities for Automotive Applications. *IEEE Conference on Control Applications, St. Petersburg*, 2009

[8] B. Németh, A. Csikós, I. Varga, and P. Gáspár. Design of Platoon Velocity-based on Multi-Criteria Optimization. *7th IFAC Symposium on Robust Control Design (ROCOND)*, 2012

[9] B. Németh and P. Gáspár. Road Inclinations in the Design of LPV-based Adaptive Cruise Control. *18th IFAC World Congress*, 2011

[10] L. Nouveliere, M. Braci, L. Menhour, and H. T. Luu. Fuel Consumption Optimization for a City Bus. *UKACC Control Conference*, 2008

[11] B. Passenberg, P. Kock, and O. Stursberg. Combined Time and Fuel Optimal Driving of Trucks Based on a Hybrid Model. *European Control Conference, Budapest*, 2009

[12] Abhishek Tiwary and Jeremy Colls. *Air Pollution. Measurement, Modelling and Mitigation. Third edition*. Taylor and Francis Group, Routledge, 2010

[13] M. Ekström, Å. Sjödin, K. Andreasson: Evaluation of the Copert III Emission Model with On-Road Optical Remote Sensing Measurements. Atmospheric Environment, Vol. 38, Issue 38, December 2004, pp. 6631-6641

[14] Thomas D Durbin, Ryan D Wilson, Joseph M Norbeck, J. Wayne Miller, Tao Huai, Sam H Rhee: Estimates of the Emission Rates of Ammonia from Light-Duty Vehicles Using Standard Chassis Dynamometer Test Cycles. Atmospheric Environment Vol. 36, Issue 9, March 2002, pp. 1475-1482

[15] Alfréd Csikós, István Varga: Real-Time Estimation of Emissions Emerging from Motorways Based on Macroscopic Traffic Data. Acta Polytechnica Hungarica 8:(6) pp. 95-110 (2011)