Design of look-ahead control for road vehicles using traffic information

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Abstract— **The paper proposes a look-ahead control method in which traffic information is considered. Information about the local traffic is an important factor considering the wider transportation system. The purpose of the method is to reduce control energy and fuel consumption, keep speed limits and travelling time while preceding and following vehicles are taken into consideration. Consequently, the energy-efficient cruise control strategy is able to adapt to the motion of the surrounding vehicles. Moreover, vehicle dynamics, road data and traffic flow in the surroundings are incorporated. The method leads to a multi-objective optimization problem. The design method is illustrated through a complex simulation example based on the CarSim software.**

I. INTRODUCTION AND MOTIVATION

In the paper a look-ahead control method is applied. The purpose of the method is to reduce control energy and fuel consumption, keep speed limits and travelling time while preceding and following vehicles are taken into consideration. Thus, the method leads to a multi-objective optimization problem. The speed design based on look-ahead control can be applied to an autonomous vehicle directly. The method can also be applied as a driver assistance system. The driver of the look-ahead vehicle is able to create a balance between energy/fuel saving and journey time according to his own priorities. However, other drivers on the road without the look-ahead control method have different priorities, which may lead to conflict with other vehicles.

Several papers have been published in the field of look-ahead control. The optimization problem was handled by using a receding horizon control approach in [1] and [2]. The predicted control approach was also evaluated in real experiments, based on the combination of GPS signals and information about the road geometry, see [3]. The design of speed for road vehicles based on road inclinations, speed limits and traveling time was proposed by [4]. An ECO-cruise control strategy, in which the multi-criteria optimization between journey time and fuel consumption was converted into a constrained fuel optimization task, was proposed by [5]. Several scenarios for the relationship between travel time, energy and the emission of the vehicle were presented by [6]. A predictive cruise control, which was able to consider upcoming traffic signal information to improve fuel economy and reduce traveling time, was proposed by [7].

In the papers the effects of the traffic are hardly analyzed, i.e., the motion of the other vehicles on the road is not taken into consideration. However, since the vehicle is in the traffic, the motions of the preceding and follower vehicles must also be taken into consideration. The goal of the research is to design an optimal look-ahead control strategy which is able to consider traffic information. Consequently, the energy-efficient cruise control strategy is able to adapt to the motion of the surrounding vehicles. Moreover, vehicle dynamics, road data and traffic flow in the surroundings are incorporated.

The paper is organized as follows. Section II presents the principles of the look-ahead concept and the multi-objective optimization using a weighting strategy. Section III analyzes the interaction with the follower and preceding vehicles and calculates a safety distance. Section IV illustrates the operation of the look-ahead method through simulation examples. Finally, Section V gives some concluding remarks.

II. DESIGN OF LOOK-AHEAD CONTROL BASED ON A MULTI-OBJECTIVE OPTIMIZATION

A. Principles of look-ahead control

The road ahead of the vehicle is divided unevenly, which is consistent with the topography of the road. In the method the vehicle is assumed to be traveling in a segment from the initial point to the first division point. The speed at the initial point is predefined. The aim is to calculate the speed at which the reference speed of the first point can be reached. This thought can be extended to the next segments and division points. In the case of n number of segments and $n+1$ number of points as Figure 1 shows, n equations are formulated between the first and the end points. Although the acceleration of the vehicle may change in the different intervals, it is assumed that acceleration is constant within an interval.

The speed of the vehicle at point $i \in \{1, 2, ..., n\}$ is expressed by using the initial speed, the longitudinal force and the disturbances as follows: $\dot{\xi}_i^2 = \dot{\xi}_0^2 + \frac{2}{m} \sum_{j=1}^{i} s_j \left(F_{lj} - F_{dj}\right)$, where $\dot{\xi}_0$ is the speed of the vehicle at the initial point, $\dot{\xi}_i$ is the speed of vehicle at the interval i, s_j is the length of the interval, F_{lj} is the longitudinal control force and F_{dj} is the disturbance. The disturbances considered in vehicle dynamics are divided in two groups. The first group is force resistance from the road slope $F_{dj,r}$, which is considered as a known signal $F_{dj,r} = mg \sin \alpha_j$,

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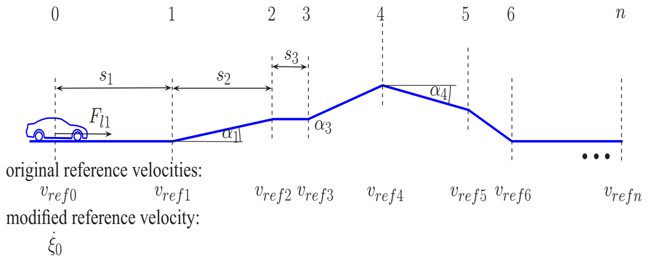


Fig. 1. Division of road

depends on the mass of the vehicle and the angle of the slope α_j. The second group $F_{dj,o}$ contains all of the other unknown resistances, such as rolling resistance and aerodynamic forces.

In the calculation of the control force at point i, only F_{l1} is used, while the additional forces $F_{li}, i \in [2, n]$ are not considered. Thus, the actual F_{l1} control force is applied as momentary intervention. Thus, the predicted speed at the i^{th} section point is as follows: $\dot{\xi}_i^2 = \dot{\xi}_0^2 + \frac{2}{m}(s_1 F_{l1} - \sum_{j=1}^{i} s_j F_{dj})$. The aim is that at every section point the vehicle speed $\dot{\xi}_i$ must reach the predefined reference speed $v_{ref,i}$: $\dot{\xi}_i^2 \rightarrow v_{ref,i}^2$. Consequently, the equations of the vehicle speeds at the section points are calculated in the following way:

$$\dot{\xi}_0^2 + \frac{2}{m} s_1 F_{l1} - \frac{2}{m} s_1 F_{d1,o} \rightarrow v_{ref,i}^2 + \frac{2}{m} \sum_{j=1}^{i} s_j F_{dj,r}. \quad (1)$$

In the following, prediction weights are introduced in the speed design method. Prediction weight Q determines the tracking requirement of the current reference speed $v_{ref,0}$, while the prediction weights $\gamma_1, \gamma_2, ..., \gamma_n$ apply to road slopes. By increasing Q the momentary speed becomes more important while road slopes become less important. The sum of the prediction weights is: $Q + \gamma_1 + \gamma_2 + ... + \gamma_n = 1$. By making an appropriate selection of the prediction weights the importance of the road condition is taken into consideration.

Taking the prediction weights into consideration the following formula is yielded:

$$\dot{\xi}_0^2 + \frac{2}{m} s_1 (1-Q) F_{l1} - \frac{2}{m} s_1 (1-Q) F_{d1,o} = \vartheta \quad (2)$$

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

$$\vartheta = Q v_{ref,0}^2 + \sum_{i=1}^{n} \gamma_i v_{ref,i}^2 + \frac{2}{m} \sum_{i=1}^{n} s_i F_{di,r} \sum_{j=i}^{n} \gamma_j. \quad (3)$$

In order to take the road conditions into consideration in the control design (2) is applied as a performance of the controlled system.

Finally, a speed tracking problem is deduced, whose reference signal contains the predicted road information. The momentary acceleration of the vehicle is expressed in the following way: $\ddot{\xi}_0 = (F_l - F_{d,o} - F_{d1,r})/m$ where $F_{d1,r} = mg \sin\alpha$. From (2) the estimated speed is:

$$\dot{\xi}_0 \rightarrow \lambda, \quad (4)$$

where parameter λ is calculated in the following way based on the designed ϑ:

$$\lambda = \sqrt{\vartheta - 2 s_1 (1-Q)(\ddot{\xi}_0 + g sin\alpha)} \quad (5)$$

A detailed description of the method is found in [4].

B. Optimization of the vehicle speed based on weighting factors

Equation (2) shows that the designed speed $\dot{\xi}_0$ depends on the prediction weights. By choosing these values the effects of road conditions can be tuned. The design of the vehicle speed profile poses two optimization problems, which are written in the following forms:

1./ The longitudinal control force must be minimized, i.e.,

$$F_{l1}^2 \rightarrow \min. \quad (6)$$

In this criterion the road inclinations and speed limits are taken into consideration by using appropriately chosen prediction weights $\bar{Q}, \bar{\gamma}_i$. This requirement leads to a quadratic optimization problem.

2./ The momentary speed must approach the reference speed, i.e.,

$$|v_{ref,0} - \dot{\xi}_0| \rightarrow \min. \quad (7)$$

The optimal solution is achieved by selecting the prediction weights in the following way: $\check{Q} = 1$ and $\check{\gamma}_i = 0, i \in [1, n]$.

In the paper two performance weights are introduced in order to create a balance between the two optimization results. Performance weight R_1 $(0 \leq R_1 \leq 1)$ is related to the importance of the minimization of the longitudinal control force F_{l1}, while performance weight R_2 $(0 \leq R_2 \leq 1)$ is related to the minimization of the difference between the momentary speed and the reference speed $|v_{ref,0} - \dot{\xi}_0|$. There is a constraint according to the performance weights $R_1 + R_2 = 1$. Thus the performance weights, which guarantee a balance between optimizations tasks, are calculated in the following expressions:

$$Q = R_1 \bar{Q} + R_2 \check{Q} = 1 - R_1(1 - \bar{Q}) \quad (8a)$$

$$\gamma_i = R_1 \bar{\gamma}_i + R_2 \check{\gamma}_i = R_1 \bar{\gamma}_i, \quad i \in \{1, .., n\} \quad (8b)$$

The equations show that prediction weights depend on R_1 linearly. Based on the calculated performance weights the modified speed can be calculated by using (5).

III. CONSIDERATION OF THE MOTION OF THE PRECEDING AND FOLLOWER VEHICLES

A. Handling the preceding vehicle in the speed design

Since the vehicle travels in traffic and it may catch up with a preceding vehicle, due to the risk of collision it is necessary to consider the speed of the preceding vehicle v_{lead}: $\dot{\xi}_0^2 \rightarrow v_{lead}^2$. Prediction weight $\mathcal{W}$ is applied to the distance from the preceding vehicle in order to track its speed v_{lead}.

Value ϑ on the right-hand-side of (2) must be modified by adding a term with the prediction weight $\mathcal{W}$:

$$\vartheta_m = \vartheta + \mathcal{W} v_{lead}^2. \tag{9}$$

The role of prediction weight $\mathcal{W}$ is important since the control must focus on the velocity instead of energy saving, in order to avoid a collision. The safe stopping distance between the vehicles is calculated according to the 91/422/EEC, 71/320/EEC UN and EU directives: $d_{st} = 0.1\dot{\xi}_0 + \dot{\xi}_0^2/150$. Consequently, the consideration of the preceding vehicle is determined by $\mathcal{W}$, which is set based on d_{st}.

$$\mathcal{W} = \begin{cases} 1 & \text{if} \quad d < d_{st} \\ 1 - 2 \cdot (d - d_{st}) & \text{if} \quad d_{st} \leqq d \leqq 1.5 \cdot d_{st} \\ 0 & \text{if} \quad d > 1.5 \cdot d_{st} \end{cases} \tag{10}$$

B. Predicting the speed of the vehicle using look-ahead control

Normally the driver sets performance weight R_1 based on his goals and requirements, thus he creates a balance between energy saving and travelling time. However, a vehicle preferring energy saving may be in conflict with other vehicles preferring cruising at the speed limit. Thus, an energy-efficient vehicle may decelerate the other vehicles on the road. Preferring performance weight R_1 leads to a non-optimal motion for traffic globally. In the next section a weight calculation method which guarantees a balance between the energy-efficient speed profile and the flow of the local traffic is proposed for R_1.

The motion of the vehicle using the look-ahead control and the motion of the follower vehicle are analyzed in order to formulate the safety distance between them. This is the basis of the re-design of performance weight R_1.

Besides the reduction of control energy the aim of speed prediction is to follow the specified reference speed. When $R_1 = 0$ the predicted speed at point n must be $v_{ref,n}$, i.e., $\dot{\xi}_n \to v_{ref,n}$. The speed prediction of the vehicle using look-ahead control is based on (1). Based on (3) the expression of ϑ can be rewritten as:

$$\begin{aligned} \vartheta =& v_{ref,0}^2 - R_1(1-\bar{Q})v_{ref,0}^2 + \\ &+ R_1 \sum_{i=1}^{n} \bar{\gamma}_i v_{ref,i}^2 + R_1 \left(\frac{2}{m} \sum_{i=1}^{n} s_i F_{di,r} \sum_{j=i}^{n} \bar{\gamma}_j \right) = \\ =& v_{ref,0}^2 \left(1 - R_1\right) + R_1 \bar{\vartheta} \end{aligned} \tag{11}$$

where $\bar{\vartheta}$ contains the value of ϑ calculated with energy-efficient prediction weights $\bar{Q}, \bar{\gamma}_i$.

From (4) the reference speed λ is calculated based on the predicted road information. It shows that through Q and ϑ performance weight R_1 plays an important role in the calculation of the reference speed. Moreover, the predicted values of the prediction weights γ_i also depend on R_1, see (8). The square of the reference speed is calculated in the following form:

$$\begin{aligned} \lambda^2 =& v_{ref,0}^2 \left(1 - R_1\right) + R_1 \bar{\vartheta} - 2 s_1 R_1 (1-\bar{Q})(\ddot{\xi}_0 + g \sin\alpha) \\ =& v_{ref,0}^2 \left(1 - R_1\right) + R_1 \bar{\lambda}^2 \end{aligned} \tag{12}$$

where $\bar{\lambda}$ contains the value of λ calculated with energy-efficient prediction weights $\bar{Q}, \bar{\gamma}_i$.

From (1) and (12) the predicted estimated speed of the vehicle at section point n is

$$\begin{aligned} \dot{\xi}_n^2 =& v_{ref,0}^2 (1 - R_1) + R_1 \bar{\lambda}^2 \\ &+ \frac{2}{m} s_1 F_{l1} - \frac{2}{m} s_1 F_{d1,o} - \frac{2}{m} \sum_{i=1}^{n} s_i F_{di,r} = \\ =& R_1 \mathcal{N}_1 + \mathcal{N}_2 \end{aligned} \tag{13}$$

According to (13) the predicted speed $\dot{\xi}_n$ at point n is independent of $v_{ref,n}$. However, when $R_1 = 0$ the predicted speed at point n must be $v_{ref,n}$. In order to meet this requirement, the predicted speed must be modified using the reference speed and the weighting factor in the following way:

$$\dot{\xi}_n^2 = (R_1 \mathcal{N}_1 + \mathcal{N}_2) R_1 + (1 - R_1) v_{ref,n}^2 \tag{14}$$

The advantage of this equation is that the reference speed is built into the predicted speed, thus the numerical procedure is more reliable.

C. Predicting the motion of the follower vehicle

Now it is necessary to determine the criterion of the safety distance between the vehicle using the look-ahead control and the follower vehicle. It requires the prediction of the motion of the follower vehicle. The controlled vehicle moves from point ξ_0 to ξ_1, whose distance is s_1 while the traveling time is Δt_1. Meanwhile the follower vehicle moves from point η_0 to η_1.

In the estimation of the follower vehicle several assumptions are considered. First, the controlled vehicle has information about the speed and acceleration of the follower vehicle ($\dot{\eta}_0$, $\ddot{\eta}_0$) and the momentary distance between the vehicles e_0. Second, the follower vehicle accelerates evenly until it reaches the speed limit, i.e., $i < j$. When the follower vehicle reaches the speed limit $v_{ref,j}$ it does not accelerate further, thus in the oncoming sections the predicted speeds of the vehicle are $v_{ref,j}, \ldots, v_{ref,n}$, i.e., $i \geqq j$.

The calculation is performed in the following two steps. Based on the information ($\dot{\eta}_0$, $\ddot{\eta}_0$, e_0) the motion of the vehicle must be calculated in every section in which the traveling time is Δt_i, $i = \{1 \ldots n\}$. Until the follower vehicle reaches the speed limit, i.e., $k < j$, the distance of the vehicle is the following:

$$\eta_1 = \frac{\ddot{\eta}_0}{2} \Delta t_1^2 + \dot{\eta}_0 \Delta t_1 \tag{15a}$$

$$\begin{aligned} \eta_2 &= \frac{\ddot{\eta}_0}{2} \Delta t_2^2 + \dot{\eta}_0 \Delta t_2 + \eta_1 = \\ &= \frac{\ddot{\eta}_0}{2} (\Delta t_1^2 + \Delta t_2^2) + \dot{\eta}_0 (\Delta t_1 + \Delta t_2) \end{aligned} \tag{15b}$$

$$\vdots$$

$$\eta_{j-1} = \frac{\ddot{\eta}_0}{2} \left(\sum_{i=1}^{j-1} \Delta t_i \right)^2 + \dot{\eta}_0 \sum_{i=1}^{j-1} (\Delta t_i) \tag{15c}$$

When the follower vehicle reaches the speed limit at section j the equation is the following:

$$\eta_j = \eta_{j-1} + v_{ref,j}\Delta t_j \tag{16a}$$

$$\vdots$$

$$\eta_n = \eta_{j-1} + \sum_{i=j}^{n}(v_{ref,i}\Delta t_i) \tag{16b}$$

After this section the speed of the follower vehicle is considered $v_{ref,l}$.

D. Safety distance criterion

Now the safety distance between the vehicle using the look-ahead control and the follower vehicle must be guaranteed. The safety distance s_{safe} is assumed to be predefined.

The controlled vehicle intends to use the energy-efficient predicted cruise control, while the follower vehicle aims to keep the speed limit. Thus, the look-ahead control strategy is modified in such a way that the motion of the follower vehicle is taken into consideration. A possible method is to modify performance weight R_1 during the journey and create a balance between the designed speed and the required speed of the follower vehicle. The aim of this section is to develop a method for the re-design of weight R_1.

The criterion of the safety distance is based on the motion of the vehicles. During the journey in every section the distance between the two vehicles must be guaranteed by the following inequalities:

$$\xi_i + e_0 - \eta_i \geq s_{safe}, \quad i \in \{1, 2, .., n\} \tag{17}$$

where ξ_i is the predicted displacement of the controlled vehicle, e_0 is the momentary distance between the vehicles ($t = 0$) and η_i is the predicted displacement of the follower vehicle. It is necessary to find the maximum of performance weight R_1, which satisfies the inequality constraints (17). Note that an increase in R_1 induces longer journey time. Therefore R_1 can be limited by the driver using a predefined bound $R_{1,max}$.

The optimization criterion for safe cruising is formulated as follows:

$$\max_{[0;R_{1,max}]} R_1 \tag{18}$$

such that the following conditions are satisfied:

$$\sum_{i=1}^{j} s_i + e_0 - \eta_j - s_{safe} \geq 0, \quad j \in \{1, ..., n\} \tag{19}$$

The result of the optimization $R_{1,opt}$ is used in the calculation of the prediction weights Q and γ_i. Based on the prediction weights and equation (5) the reference speed of the controlled vehicle λ is computed. The optimization procedure (18) is performed in each step, thus performance weight R_1 is rewritten continuously according to the current local traffic information.

E. The design method in practice

In practice the solution of the optimization processes may require a great deal of computation effort. However, the constrained quadratic optimization problem is reformulated to a linear programming task. The solution of the previous computation step $R_{1,old}$ is applied as initial value. The new solution $R_{1,new}$ is searched for in the interval $[\max(R_{1,old} - \alpha, 0), \min(R_{1,old} + \alpha, R_{1,max})]$ with $n = 10$ points and $\alpha = 0.1$. Note that $R_{1,max}$ is set by the driver. Its default value is $R_{1,max} = 1$. Both optimizations are solved with a predefined sample time. The purpose of this procedure is to guarantee that the complexity of the optimization method is reduced and, thus, the method can be applied in practice.

A survey of the future communication possibilities in automotive and traffic control was provided by [8]. A computer vision-based approach to tracking surrounding vehicles and estimating their trajectories in order to detect potentially hazardous situations was proposed by [9]. The integration of radar-based and virtual perception measurement technologies for vehicle detection was developed in [10]. An extension of adaptive cruise control with traffic information considering vehicle-to-roadside and vehicle-to-vehicle communication was proposed in [11]. Vehicle-to-vehicle communication and vehicle-to-infrastructure sensor communication to prevent accidents and assist investigations were proposed by [12].

IV. SIMULATION RESULTS

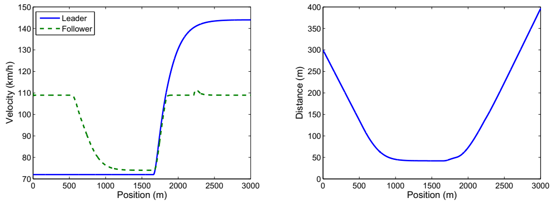
A. Handling the preceding vehicle in the speed design

The following example analyses the incidence when another vehicle overtakes the controlled vehicle or the vehicle catches up with a preceding vehicle.

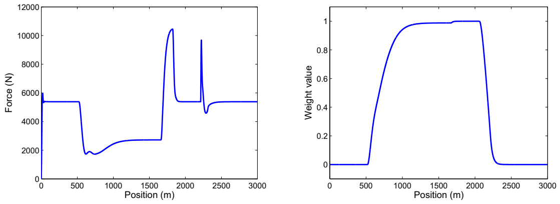
In the first part of the simulation example, the preceding vehicle is slower, however, in the second part its velocity is higher than that of the follower vehicle. Furthermore, in the example the preceding vehicle also exceeds the official speed limit ($110km/h$). Figure 2(a) and 2(b) show that in the first part of the simulation the follower vehicle approaches the preceding vehicle taking the braking distance into consideration, while in the second part the follower vehicle avoids exceeding the speed limit and falls behind. This speed control is achieved by using the value of $\mathcal{W}$ as it is shown in Figure 2(d). In the first part of the simulation the weight is increased to reduce the risk of incidents while in the second part it is reduced by the increasing distance. This simulation example shows that the designed control system is able adapt to external circumstances.

B. Handling the follower vehicle in the speed design

In the scenario, a maneuver is considered, in which a controlled vehicle with the presented method overtakes slower preceding vehicles on the highway (controlled). The overtaking maneuver is carried out by using an energy-efficient method. At the same time another vehicle drives onto the highway and accelerates to reach the speed limit and also begins an overtaking maneuver (follower). Thus, there is a conflict between the vehicles caused by the reduced



(a) Velocities of vehicles (b) Distance between vehicles



(c) Actuated longitudinal force (d) Value of $\mathcal{W}$

Fig. 2. Adaptive control systems with a preceding vehicle

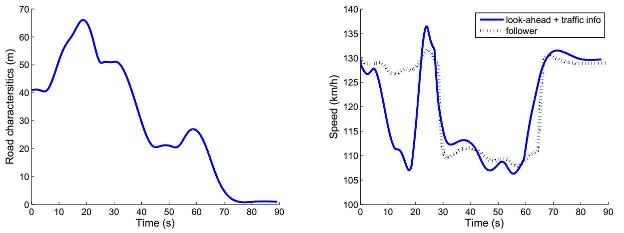
distance between the two vehicles during their maneuvers. The controlled vehicle adapts to the motion of the follower one, thus the traffic is not congested.

In the second scenario the controlled vehicle uses only the look-ahead information and does not take into consideration the information on the follower vehicle. Therefore, the traffic is congested and the follower vehicle must decrease its speed with abrupt braking to avoid the dangerous conflict. In the next section the efficiency of conflict handling based on the proposed control strategy is presented.

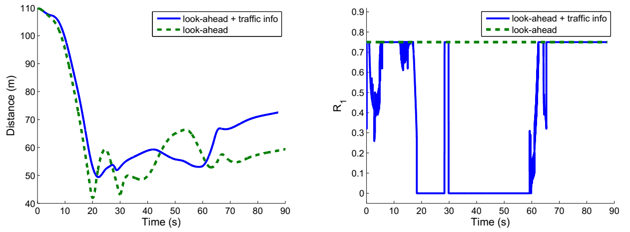
The terrain characteristics of the road are illustrated in Figure 3(a). This road contains downhill sections, whose inclinations are different. The energy-efficient cruising of the vehicle requires the reduction of vehicle speed before the downhill sections. The speed limit on the highway is $130km/h$, which is reduced to $110km/h$ before the second inclination. The speed profiles of the controlled vehicle with a control strategy and the follower vehicle are shown in Figure 3(b).

In the first part of the simulation (0-18s) the controlled vehicle reduces its speed. The reduction is caused by the speed limit and the downhill section ahead, which information is incorporated in the look-ahead strategy. Therefore the follower vehicle reaches the safety distance, see Figure 3(c). The reduced distance induces the sharp decreasing of R_1, see Figure 3(d). Thus, the speed of the controlled vehicle is increased, which results in larger distance between the vehicles.

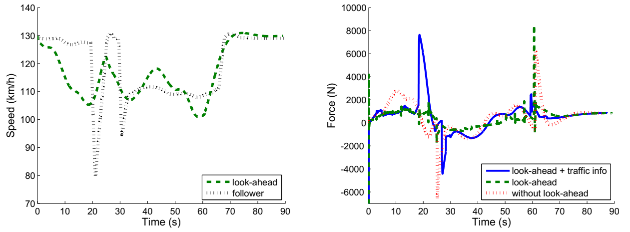
In the second scenario the controlled vehicle uses only the look-ahead information, and the performance weight $R_1 = R_{1,max} = 0.75$ through out the simulation, see Figure 3(d). The speed profiles of the vehicles are shown in Figure 3(e). The controlled vehicle adapts to the terrain characteristics and speed regulations to minimize control force F_{l1} and save the energy. However, the follower vehicle has higher speed, which must be reduced to avoid the further decrease of distance, see Figure 3(c) and the speed reduction is significant.



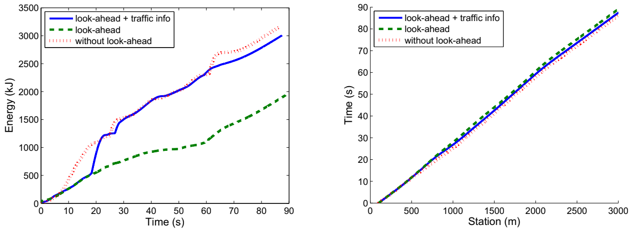
(a) Terrain characteristics (b) Speed profile - with traffic information



(c) Interdistance of vehicles (d) Performance weight R_1



(e) Speed profile - without traffic information (f) Control force F_{l1}



(g) Control energy consumption (h) Traveling time

Fig. 3. Simulation results of the overtaking maneuver

The control forces F_{l1} in the different scenarios are depicted in Figure 3(f). A further scenario, which does not consider look-ahead strategy ($R_1 = 0$) is also illustrated. In the first scenario F_{l1} is close to the force requirement of the second scenario until 18 s. After that R_1 is reduced to zero, thus the force characteristics are closer to those of the vehicle without look-ahead information. This shows the flexible adaptivity of the method, i.e., the proposed algorithm is able to create a balance between energy saving and traffic-efficient cruising.

The energy consumption of the controlled vehicle using the presented strategy is shown in Figure 3(g). It is compared with a vehicle without traffic information and another vehicle without look-ahead strategy. As long as $R_1 = 0.75$, the energy consumption of the vehicle with traffic information

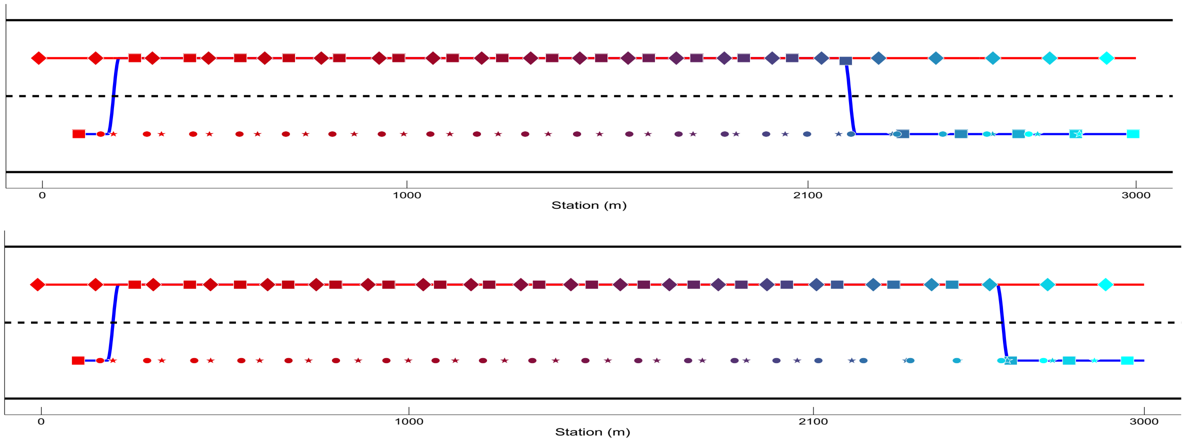


Fig. 4. Path of controlled vehicle (red line with squares) and follower vehicle (blue line with diagonals) (a) in the scenario the look-ahead control with the traffic information is used (b) only the look-ahead control is used

and the vehicle without it is the same, see Figure 3(g). When R_1 is reduced control energy consumption increases significantly because terrain characteristics are considered to a lesser extent. Thus, the tendency of energy consumption is close to that of the vehicle without look-ahead strategy. The saved energy compared to that of the vehicle which ignores the look-ahead information is 6%. The traveling times of the controlled vehicle during the different scenarios are shown in Figure 3(h). Although the energy saving of the look-ahead strategy is considerable, the traveling time of the vehicle increases. The time increase of the proposed strategy is 1%. The results show that energy saving is significantly lower than the time lost. It means that the energy consumption derives mainly not from the speed reduction, but from the optimal consideration of terrain characteristics and speed limit changes.

The traffic scenarios with the two cases are illustrated in Figure 4. The red line with squares illustrates the motion of the controlled vehicle, while the blue line with diagonals belongs to the follower vehicle. There are four vehicles in a line formation in the next lane, which are overtaken by both the controlled and follower vehicles. In the figure the changes in the shape and colors represent the actual position of the vehicles in time.

V. CONCLUSIONS

The paper has proposed a look-ahead control in which several factors such as energy reduction, road slopes, traveling time, speed limits are taken into consideration. Since the vehicle is part of the transportation system, this energy-efficient cruise control strategy is coordinated with the motion of the surrounding vehicles, i.e., both the preceding and the follower vehicles. The method leads to a multi-objective optimization procedure, which uses several weighting factors such as performance weights and prediction weights. In the design method the safety distance between vehicles are considered. The simulation example has shown that by considering the predicted speed of the other vehicles conflict events can be reduced significantly.

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