Look-ahead Cruise Control Considering Traffic Information Based on Floating Car Data

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Abstract: The paper focuses on the design of an adaptive cruise control system which optimizes the longitudinal energy and fuel consumption of the vehicle. In the velocity design process a look-ahead method is used considering road information of road sections ahead of the vehicle. By using road information about the characteristics of the oncoming road sections, e.g. oncoming speed limits or road slopes, it is possible to modify the speed during the journey in advance. The main novelty of the paper is the adaptation of forward traffic mean speed in the look-ahead control algorithm. It is demonstrated in real data simulation that with the proposed method significant amount of fuel can be saved compared to a conventional cruise control or a human driver.

Keywords: floating car data, look-ahead control, energy optimization, cruise control

1. Introduction

Vehicles equipped with conventional cruise control systems are able to maintain steady speed set by driver. In general this is the maximum prescribed velocity on the given road section, i.e the speed limit. Adaptive cruise control systems are becoming widespread in vehicles of today. This device augments the functionality of the standard cruise control by following the preceding vehicles automatically at a predefined safe distance. However, these cruise control systems do not have information about farther road sections (speed limits and terrain characteristics), thus the selected speed is not optimal in terms of economy and emission.

Several methods in which road inclinations are taken into consideration have already been proposed, see [13, 3]. In [12] the approach was evaluated in real experiments where the road slope was estimated. Thus a look-ahead system with road information consideration can select speed in coherence with the oncoming road, for example reduce the speed in advance of slopes or speed limits. A look-ahead control method for the design of the vehicle's speed has been proposed by [10, 9], where it has been shown that by considering oncoming road sections significant amount of energy can be saved.

However, as adaptive cruise control systems mentioned above consider the instantaneous traffic information by following the preceding vehicle velocity profile if necessary, the look-ahead systems proposed by the authors do not consider traffic information about the oncoming road sections.

The aim of this paper is to incorporate traffic information gained by floating car data (FCD) systems in the velocity planning process of the look-ahead cruise control system. By this means, the energy optimal velocity profile of the vehicle can be in coherence with the oncoming traffic augmenting the functionality of the look-ahead method.

This paper is organized as follows. In Section 2 the technical issues and future trends in the field of FCD systems are detailed. In Section 3 the proposed look-ahead control method augmented with the consideration of FCD data is discussed. In Section 4 the operation of the look-ahead controller is presented in a real data simulation example. Finally, Section 5 contains some concluding remarks.

2. Floating Car Data

As on-board electronic devices such as GPS systems are becoming increasingly popular in today's vehicles, the possibility of gaining useful information about vehicles on the road network to improve short and long term predictions of traffic data is getting increasingly desirable. The main idea of FCD systems is to collect data available by already existing on-board devices. The basic FCD collection system records time and vehicle location provided by a GPS receiver or cellular data of mobile phones, and uses a GSM/GPRS transmitter to send the information package to the central system for post-procession. If a sufficient number of vehicles (often referred to as probe vehicles) are involved in the data collecting process this can be used to detect congestion on given road sections and estimate the traffic flow speed.

In contrast with traditional and widespread fixed-point traffic data collection technologies (video cameras, inductive loops, radar sensors, etc) floating cars act as moving sensors traveling with the traffic stream. One of the biggest advantage of the FCD system is that it does not require any additional instrument to be set up and maintained on the road network, thus the cost of gathering real-time traffic information makes it valuable to realize. If additional information is gained from the vehicle electronic control unit (gear status, brake usage, revolutions per minute, windshield wipers application, temperature, traction control, etc.) weather conditions can be estimated and accident hazards can be detected as well. These data are referred to as Extended Floating Car Data (xFCD). Several FCD research projects have already been proposed by authors. The main contributions in the field of FCD and xFCD data systems have been summarized by [2].

A method based on GPS floating-car data (FCD) to acquire traffic congestion information is studied by [5]. Here data is generated by 500 taxis and after preprocessing, map matching, travel speed estimation, and several other key steps, a map which exhibits the traffic congestion distribution of the city is produced. A traffic estimation method based on a large scale real-time FCD system was developed and operated along the Italian motorway network with a penetration level of about 1.7 percent, as depicted by [8]. A historical floating car data based travel time estimation for the traffic network links was presented by [7]. An extension of the FCD principle was introduced by [11] with a novel approach based on a method of indirect detection of traffic objects (cars, cyclists, pedestrians) using radio-based Bluetooth/Wi-Fi technologies. The spatial structure and the interpolation of floating car speeds were analyzed by exact floating car speed data of the study area in Beijing, see [16]. The results showed that geostatistics as a new spatial analysis method can solve the spatial variability problems which traditional statistics methods cannot.

2.1. Communication and data acquisition

Communication is an essential element of the FCD systems. The communication is two ways: reporting data from the probe vehicles to the traffic information center and transmitting processed data back to the drivers of the vehicles (see Figure 1).

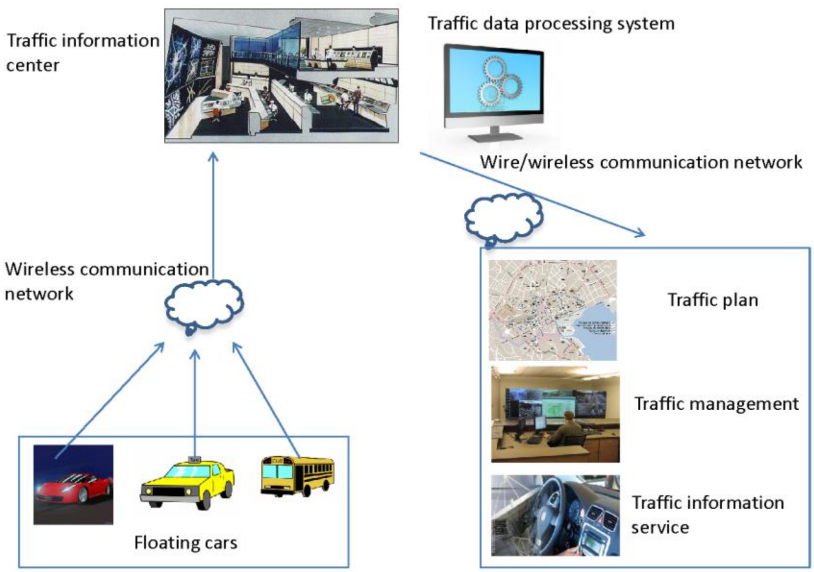

Figure 1. Composition of the floating-car system (based on [17])

During the data reporting of the FCD system time-relevant short messages are sent containing traffic relevant information such as location, speed and direction data. In the case of xFCD system other safety-related information collected by the vehicle sensors and ECU can also be sent for post procession. However, these data are outside the scope of this paper. Transmission delays of several minutes are acceptable in the case of standard FCD messages. The frequency of the messages are much more important. Implicitly, shorter sampling period results in higher data precision. [17] presented a theoretical method for floating-car sampling period optimization: considering velocity as a stochastic signal its frequency spectrum is analyzed using Fourier transformation and the optimal sampling frequency is decided by the Shannon sampling theory. The result shows that the optimal sampling frequency can achieve high data precision, which is suitable for practical applications.

The traffic stream must contain a certain number of probe vehicles as well in order to obtain reliable information for traffic analysis. The so called penetration level refers to the proportion of probe vehicles in traffic. Depending on the type and quality of the data required, this proportion can vary from 1 to 5 percent [4]. Speed is one of the most important floating car data used in this paper to develop a new look-ahead cruise control method. Accurate and reliable speed information is possible when the proportion of floating cars is over 3 percent in the traffic [6].

Data reporting can be accomplished with different types of communication channels, including cellular data, GPRS, DSRC, or wireless hotspot technology [2]:

- DSRC beacons are operated by the governments of Japan and Europe for their ITS information systems. This two-way short- to medium-range wireless communication channel is specifically designed for automotive use and its main function is electronic toll collection.
- Wireless hotspots are beginning to proliferate along the road network to serve professional truck drivers. The nature of the messages is not radically different from that used for electronic payment.
- Cellular network-based data is provided by the switched on mobile phones of the drivers and passengers of the probe vehicles. Triangulation and hand-over data stored by the network operator are used for localization, which is less accurate than GPS based systems. Thus, for reporting high data quality, several devices need to be tracked and more complex algorithms must be used. However, in metropolitan areas, where congestions are frequent and the distance between antennas is smaller, high data accuracy can be achieved. One of the main advantages of this data reporting is that no extra hardware is needed aboard in the probe vehicles.
- GPS-based FCD systems are the most common today. The GPS device receives the satellite signals to determine the location and speed of the probe vehicle.

2.2. FCD acquisition of mean speed for road sections

The principle of FCD data acquisition is shown in Figure 2. The speed data are recorded with a certain frequency using a GPS receiver or a cellular network database and sent to the traffic information center where these data are analyzed and statistically condensed with different algorithms. Every FCD message transmitted contains the probe vehicles' last-known positions for the evaluation of the map matching process. The mean journey speed and the variation on the predefined road sections can be calculated, which provides the basic information to augment the look-ahead cruise control system described later.

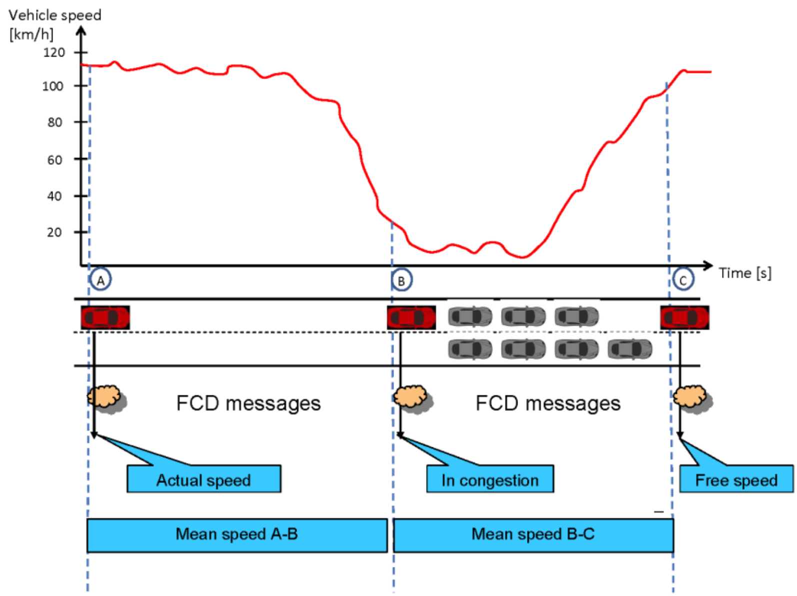

Figure 2. FCD vehicle speed acquisition (based on [4])

The FCD algorithm can be divided in three steps [8]:

- Map matching for each position using reported data. The most commonly used map-matching algorithms are the algorithm of point-to-curve and the algorithm of curve-to-curve [1]
- Routing (between subsequent positions) to determine the average speed along the tracks.
- The link travel speed is estimated based on the GPS position speed and the track average speed weighted exponentially with the GPS time distance for all cars passing the links.

3. Look-ahead control considering traffic information based on the FCD system

Given the real time mean velocities of the road network sections by the FCD system, there is an possibility to consider the oncoming traffic in the individual vehicle velocity design. If the forward traffic mean speed is considered, the look-ahead cruise control operation can be more effective and comfortable for the driver. For example, a cruise control system without the knowledge of oncoming traffic conditions must be deactivated and braking must be applied before a congested road section, which results in discomfort for the driver and an increase of the fuel consumption and emission. A look-ahead cruise control considering traffic information gained by the FCD system can adopt the real time (or even historical) data in the velocity design of the vehicle, thus the speed can be decreased in advance of a congestion (or slower traffic flow) on the road.

3.1. Energy efficient look-ahead control

The relationship between the energy optimal speed profile and the road inclinations was introduced in [10]. Thus, in this paper the detailed calculation of the optimal velocity is omitted, only the main results are summarized. The assumption is, that the path of the vehicle can be divided into *n* number of sections using *n*+1 number of points, see Figure 3.

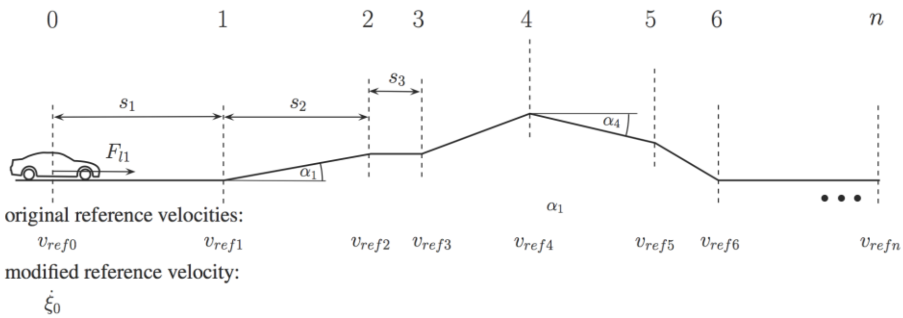

Figure 3. Division of predicted road

The rates of the inclinations of the road and those of the speed limits are assumed to be known at the endpoints of each section. The speed at section point *j* should reach a predefined reference speed $v_{ref,j}$, *j in [1,n]* which is the speed limit on the section, while the momentary value of the speed limit must also be taken into consideration in the following form: $\xi^2 \rightarrow v^2_{ref,0}$. The speed of the n^{th} section point is the following:

$$\dot{\xi}_n^2 = \dot{\xi}_0^2 + \frac{2}{m} s_1 F_{l1} - \frac{2}{m} \sum_{i=1}^{n} s_i F_{di} \qquad (1)$$

where F_{di} is the disturbance force originating from the road slopes ($F_{di,r}$) and other disturbances such as rolling resistance, aerodynamic forces ($F_{di,o}$).

After adding weight *Q* to the momentary speed and weights $\gamma_1, \gamma_2, \ldots, \gamma_n$ to the reference speeds of the road sections in advance ($\gamma_1 + \gamma_2 + \ldots + \gamma_n + Q = 1$) following formula is yielded for the optimal vehicle velocity:

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

where

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

Equation (2) shows that the modified reference speed depends on weights *Q* and γ_i .Weights have an important role in control design. By making an appropriate selection of the weights the importance of the road condition is considered. The aim of the control design is to find an adequate balance between longitudinal force required by the travel (energy efficiency) and the tracking of the momentary value of the reference speed. This requirement can be fulfilled with the use of quadratic optimization procedure detailed in [10].

3.2. Energy efficient look-ahead control integrating traffic information in the design

The look-ahead control method discussed in Section 3.1 has defined the path ahead of the vehicle and divided it into *n* number of sections. It is assumed that the road inclination rates and the speed limits are known for all of these sections by using on-board devices such as GPS. Assuming that the vehicle can receive traffic information from the FCD system discussed in Section 2, there is a possibility to consider the mean speed of the traffic stream along the designed path of the vehicle. Denoting the mean traffic velocities at each section point ahead with $v_{traffic,j}$, *j in [1,n]* , it is possible to modify the look-ahead control algorithm as follows.

If the speed limit $v_{ref,j}$ at section point *j* exceeds the traffic stream velocity $v_{traffic,j}$, i.e $v_{ref,j} > v_{traffic,j}$, then the speed limit $v_{ref,j}$ is substituted for the mean traffic velocity $v_{traffic,j}$. Thus in the calculation of the optimal velocity λ in equation (2) theta is modified as follows:

$$\vartheta_{\mathrm{mod}} = \vartheta - \sum_{i=1}^{n} \gamma_i v_{ref,i}^2 + \sum_{i=1}^{n} \gamma_i \min(v_{ref,i}; v_{traffic,i})^2 \tag{4}$$

After adding design weights for the road sections as detailed in Section 3.1, the energy optimal momentary velocity can be calculated using equation (2) substituting with the modified theta.

3.3. Realization of the method

The proposed look-ahead cruise control system can be realized in three steps. Based on optimization tasks the weighting factors are calculated along with the reference speed is, see equation (2). In the second step the longitudinal control force of the vehicle (F_{l1}) is calculated. F_{l1} can be positive or negative forces as well, therefore the driving and braking systems are actuated. In the third step the real physical inputs of the system, such as the throttle, the gear position and the brake pressure are generated by the low-level controller. Figure 4 shows the architecture of the low-level controller.

In the proposed method the steps are separated from each other. Thus the reference signal unit can be designed and produced independently of automobile suppliers and only a few vehicle data are needed. The independent implementation possibility is an important advantage in practice.

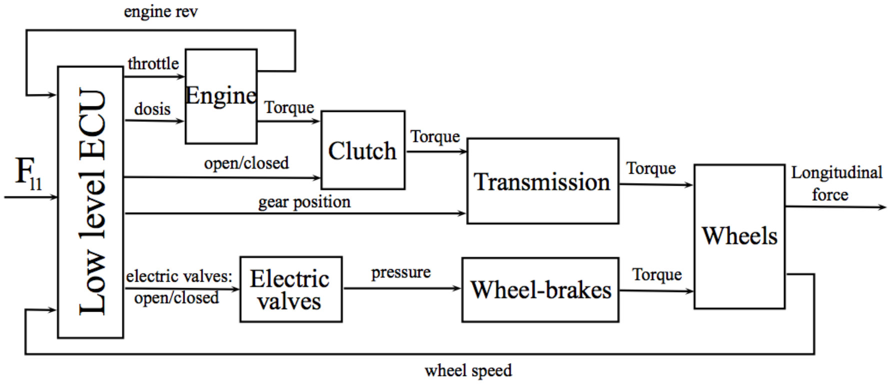

Figure 4. Architecture of the low-level controller

4. Simulation results

In this section the proposed look-ahead method considering road and traffic information is tested and compared in a real data simulation using Carsim simulation environment. The proposed look-ahead control method considering FCD for the velocity design is implemented in Matlab/Simulink. The road characteristics are those of the access road between M7 Hungarian motorway and the city of Gyor in a 5.3 km long section, as it is shown in Figure 5 denoted by the black line.

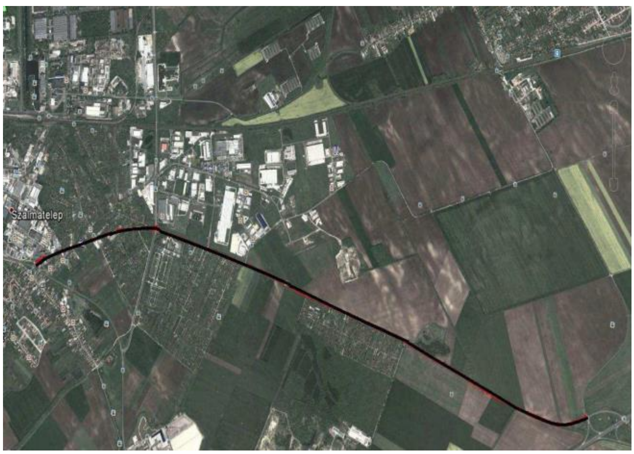

Figure 5. Selected road for simulation

The selected road section has a maximum slope angle of 5 percent. The terrain characteristics are shown in Figure 6. The vehicle used for the simulation is an F-Class sedan with a 300 kW engine, meeting the EURO 4 emission standards. The speed limit on the road is 90 *km*/*h* before it reaches the urban area, where it is decreased to 60 *km*/*h* and 50 *km*/*h*, as it is shown in Figure 7 denoted by the red line. It is assumed that before the first roundabout between 3.5 *km* and 4.5 *km* the velocity of the traffic stream decreases to 25 *km*/*h*.

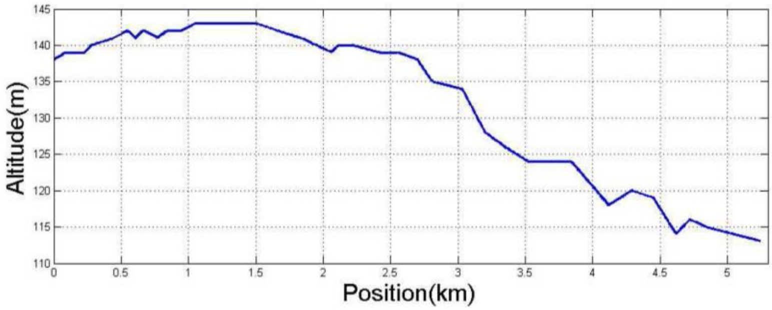

Figure 6. Terrain characteristics of the road

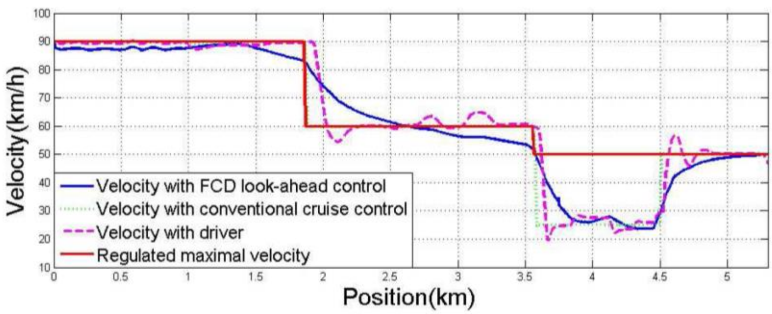

Figure 7: Velocity profile of the different methods

For the validation of the optimization method listed in Section 3 three different simulations were carried out and compared. In the first simulation the behavior of the driver is demonstrated using a longitudinal linear driver model described in [2]. In the second simulation the operation of a conventional cruise control is realized. The look-ahead control considering FCD system traffic information detailed in Section 3.2 is implemented in order to minimize the actuated energy of the vehicle, thus minimizing the fuel consumption of the vehicle.

In Figure 7 the velocity profile resulting from different control methods is shown, including the case where the speed is regulated by the driver. It is well demonstrated that the different methods result in very different velocity trajectories. The conventional cruise control follows the velocity set by the driver accurately, and does not consider the forward speed limits, terrain characteristics or traffic conditions in the velocity control. The velocity profile of the driver is more uneven and the vehicle velocity exceeds the speed limit when traveling on a steep slope, while the velocity of the vehicle falls back on uphill sections. This is due to the fact that the driver does not have information about the oncoming road disturbances or traffic, and responds with a time delay to changes in road conditions. The velocity profile resulting from the proposed look-ahead method is basically different because of the consideration of forward road and traffic information. It is well demonstrated that the controller calculating with FCD information begins to decrease the vehicle velocity in advance of the road section where the heavy traffic induces lower travel speed than that given by the speed limit.

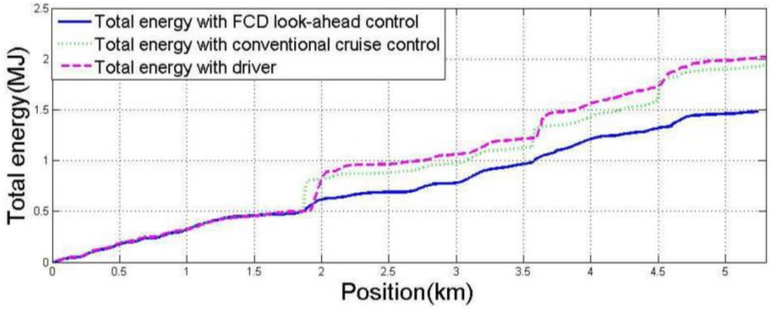

Figure 8: Total energy consumption of the different methods

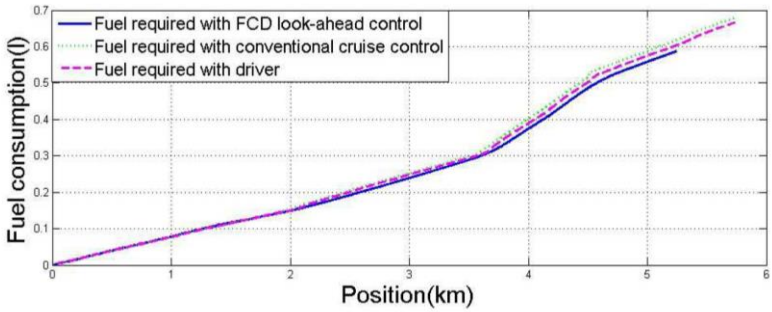

Figure 9: Fuel consumption of the different methods

In Figure 8 the total actuated energy of the different methods are compared. The lack of forward road information consideration resulting in abrupt speed changes by the driver and the conventional cruise control induce harder and more frequent use of the brake and acceleration compared to the proposed method. Thus, the total energy consumption (including the energy of the braking process) can be decreased by almost 25 % with the proposed method. The same conclusion can be drawn for the fuel consumption of the vehicle, which correlates with the total energy consumption. The difference in fuel consumption between the three methods is smaller because it does not reflect the energy loss of the braking process, see Figure 9. However, it is worth mentioning the reduced usage of the brake system implies longer lifetime for the brake pads and discs, thus the cost of vehicle maintenance can be decreased as well.

5. Conclusion

The paper has presented a design for vehicle speed control considering forward road information such as speed limits, terrain characteristics and traffic stream velocity gained with the use of a floating car data system. It has been demonstrated by simulation that the proposed method has great traffic benefits in terms of actuated energy and fuel consumption. The main novelty of the paper is the incorporation of the forward traffic mean speed information gained by the FCD system in the automatic look-ahead cruise control velocity design process.

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