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ULTraSim, a Traffic Simulator Incorporating Submicroscopic BEV, HEV, ICEV Models

Michael Richter, Daniel Thierauf, Herbert Kabza
University Ulm, Ulm, Albert-Einstein-Allee 47, Germany, michael.richter@uni-ulm.de

Abstract

For future traffic management systems an important question is what effect different vehicle topologies (BEV, ICEV, EREV, HEV, FCEV)will have on traffic flow, energy consumption as well as route choice. In this paper we present a quasi-continuous traffic simulator with submicroscopic vehicle models. Beside V2I and V2V communication as well as intelligent traffic light control it is possible to integrate very detailed submicroscopic vehicle models of BEV, EREV, ICEV, HEV with different level of motorization. This allows to simulate future vehicle populations and to analyse the behaviour with respect to energy consumption and particularly state of charge (SOC).

Keywords: BEV, PHEV, electric drive, city traffic, navigation

1 Introduction

The majority of forecasts tells that in the future the traffic volume will increase more and more. In addition these will be an increasing varioty of drive types such like HEV and BEV in all their different architectures like as EREV, FCEV or PHEV. Now the question arises as to how it will be possible to optimize traffic volume, travel time and energy consumption of all road users. To develop new operation strategies and more efficient routing strategies detailed knowledge of many different vehicle parameters of every single route user is necessary. The best known representatives of microscopic and submicroscopic traffic simulators are PELOPS [1], VISSIM, PARAMICS or [2], [3],[4]. By mean of our own development of ULTraSim we have the possibility to access the whole source code of the simulator and to implement any necessary changes quickly.

2 Simulation grid, network

GPS as well as SRTM3 data serve as base for the simulator. With the help of these data a three- dimensional road grid was generated (fig. 1). Due to exact height and slope information a very exact calculation of the regenerated energy of BEV, HEV is possible. In addition the road bends were recorded for the simulation of a very realistic velocity course of the vehicles.
Altogether the simulator considers 39 controlled traffic lights, 126 intersections, 694 tracks as well as 385 kilometres segmented into one meter steps. For the exact analysis of the data every route has three sensors to record the vehicle density, the average velocity as well as many other parameters. With the grid generation tool it is possible to build a detailed road network of a real city. The data set comprises information on the altitude, bend profile of the roads as well as the road signs of the street. Based on the curve radius and a driver-specific maximum transversal acceleration it is possible to calculate a maximum curve velocity as well as a desired velocity.

2.1 Traffic light control

ULTraSim makes a distinction between four different junction types. Besides a simple intersection with right-of-way from the right (as is typical in Germany), there are intersections with a contact loop and fixed dynamically controlled traffic lights. Contact loop-controlled intersections switch the light of the branch road with the smaller traffic flow green only if there is an actual vehicle request. The most significant type of traffic lights for big intersections is dynamically controlled and fixed-time controlled traffic lights.

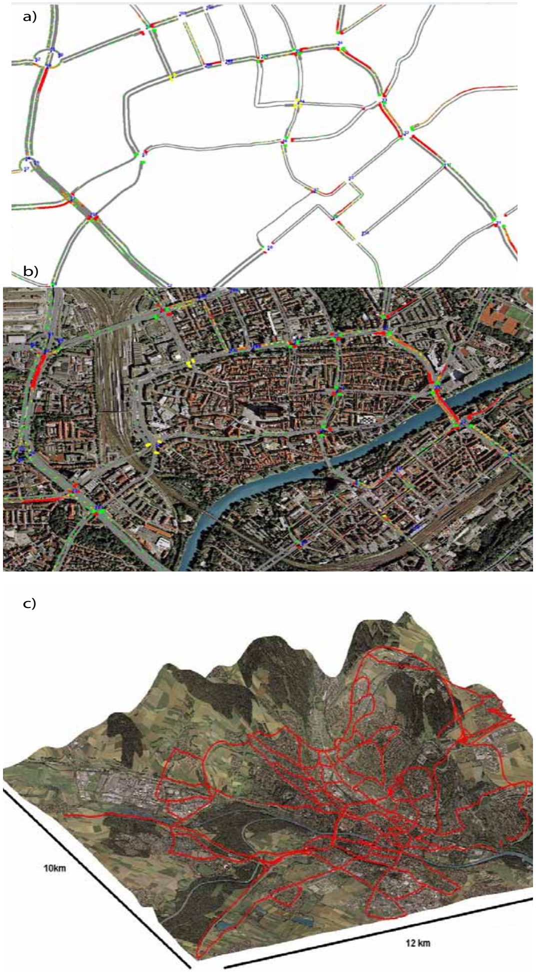

Figure 1: a) Part of street grid with the vehicles, b) satellite image with the street grid c) Topography of the simulation grid with a simulation area of around 120 km^2

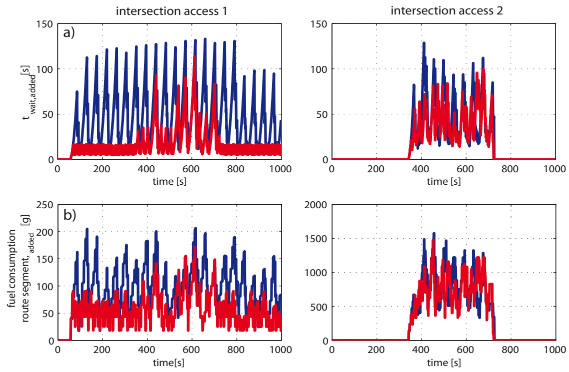

Figure 2: Comparison of the accumulated waiting times (a) and fuel consumptions of the route segment(b) of a dynamically controlled traffic light (red) and an optimally controlled fixed-time traffic light (blue) for two accesses to an intersection

Fixed-time controlled traffic lights are very difficult to adjust to variations in traffic flow, so that the influence of the traffic is as small as possible for they have a fixed time of circulation and the optimal circulation time is a function of the current traffic flow. Because ULTraSim was developed for the investigation of new routing algorithms and to keep the influence of badly adjusted traffic lights as low as possible a large part of the traffic light controlled crossings was equipped with dynamically controlled traffic lights. The literature reports different algorithms for the control of traffic lights [5]. In ULTraSim an algorithm was choosen which adds up the waiting time of all vehicles in the intersection accesses. The switching sequence with the minimum waiting time of all vehicles involved is choosen according to the minimization criterion.

Fig. 2 shows the accumulated waiting times and the fuel consumption on the route segment of all vehicles at an intersection with two accesses. The first access of the intersection has a constant traffic flow of 500 vehicles/h and at the second access after 300 seconds a constant flow of 100 vehicles arrives. An optimally adjusted traffic light with a constant switching sequence (blue) is compared to the dynamically controlled traffic light (red) which is recalculating the optimal switching sequence and the green light phase duration every 30 seconds. So this traffic light can react dynamically on varying traffic flows. As can be seen the waiting time and the fuel consumption of the vehicles in the intersection area can be clearly reduced with the dynamic traffic controller.

2.2 Driver model

For the realisation of realistic vehicle movement different driver models were implemented. Besides the analytical IDM (Intelligent driver model) [6], [7] the psycho-physical driver model of Wiedemann was implemented [8]. With the help of an individual parameter pool it is possible to simulate a stochastic vehicle population. This results in an individual behavior of every vehicle. Because the IDM was developed primarily for car following models the driver model was adjusted by means of a two step algorithm. This algorithm calculates a desired velocity for the car with taking into account a comfortable cross acceleration and curvature of the bend. Moreover, the curvature is sampled along the course of bend starting from the current position, and the maximum curvature is determined. Then the average is formed within this interval. In fig. 3 (a) the desired velocity for two different curve drives with different preview times is shown. Without preview (blue) the maximum cross acceleration of the vehicle is exceeded. An optimal curve velocity with a moderate cross acceleration is given with a preview of 5-10 seconds. With the consideration of the future road information the IDM reacts with more foresight and unnecessary acceleration processes between two bends are prevented (blue, red 1040 sec), leading to fuel savings of 6 % in this case.

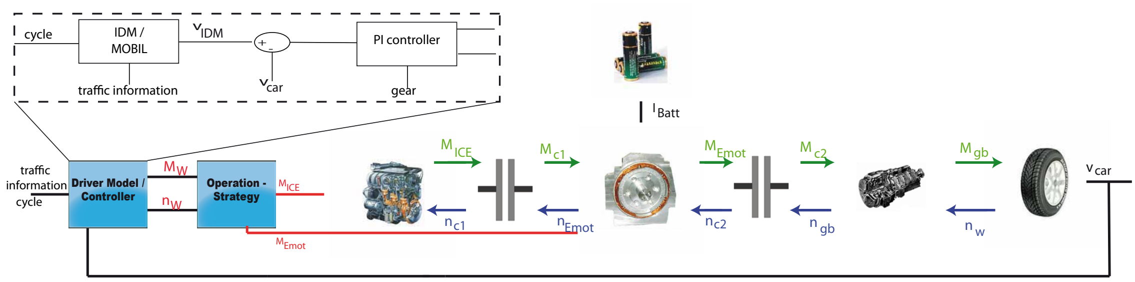

Figure 4: Dynamic vehicle model, parallel hybrid

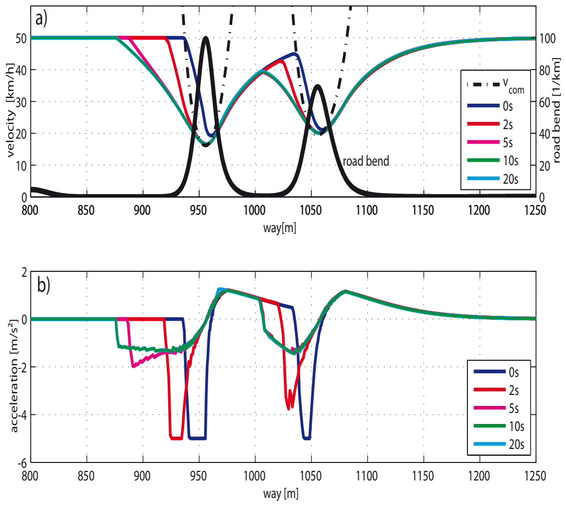

Figure 3: Velocity (a), acceleration (b) during curve passage of the driver model with different prediction times

3 Submicroscopic vehicle models

One big advantage of a submicroscopic traffic simulator is that access to all vehicle parameters like torque, motor speed, SOC, energy-, fuel consumption, gear, etc is possible. Thus very detailed and exact calculations of the energy consumption are possible and there is no necessity for estimations. In addition the total dynamic traffic model is simulated with the complete electric respectively hybrid drive train including all controllers like velocity and braking controllers. So the vehicles interact very realistically with the driver model. The advantage of this is that very exact analyses of operation strategies for BEV or HEV in vehicle fleets in big traffic volumes are possible [9], [10], [11]. With the help of a TCP/IP communication it is also possible to integrate a Matlab/Simulink model in the traffic simulator.

3.1 Dynamic vehicle model

For the longitudinal dynamics modelling of the vehicle a model of the drive train was built. A detailed model of every component of the drive train like ICE, generator, gear box, clutch, wheels etc. was built and verified with real data. The input parameter of the models is the desired acceleration of the vehicle which is generated by the driver model. In the dynamic model the component models form a chain whose input parameters contribute to the solution of the complete differential equation in the last part. Fig. 4 shows the model of a parallel hybrid in the motor mode (driving power flowing to the wheels). For the speed control a PI controller was implemented which compensates the non-linearites of the longitudinal models. Further more a brake regulator which adapts the actual velocity to the desirable velocity during deceleration phases is needed.

3.1.1 Operation strategy

The aim of ULTraSim is the integration of different operation strategies and to investigate the mutual interaction of the different strategies. Therefore every vehicle is equipped with an individual operation strategy. For the parallel hybrid electric vehicle a cost function based operation strategy was implemented [11]. It distributes the requested power between the ICE and electric motor according to the SOC of the battery and a cost function. For the ICEV a gear selection algorithm was implemented which is choosing the gear with the maximum efficiency of the ICE. Also a suppression of gearhunting was realised to avoid too frequent changes of gears on account of just slightly better operation points. Table 1 shows all different vehicle tyes with their levels of motorization. The table also shows how a bus model is implemented. This bus model can be routed on different bus routes with individual stop times at the stops. Thereby an individual dynamic mass variation (varying no. of passengers) and stopping time of the bus is possible.

3.2 Traffic analysis

For the analysis of the traffic flow every road was splitted into three equally long segments and equipped with sensors. The sensors are to detect the velocities and the no. of vehicles. Fig. 5 (a) shows the velocity of the vehicles vs the traffic density. The two distributions are due to two differing speed limitations on the three segments.

drivetrain / typ	power[kW]	max. torque[Nm]	mass[t]	length[m]
BEV	37	207	1,2	4
BEV	50	270	1,3	4
BEV	80	451	1,6	5
EVB	100	570	1,6	5
ICE	60	128	1,2	4
ICE	98	210	1,7	5
ICE	250	535	2,2	5
ICE	220	1250	20	9
ICE (bus)	220	1250	16-26	18
HEV	98 + 30	210 + 140	1,3	5
HEV	98 + 6	210 + 199	1,3	5

Table 1: Vehicle configurations

Therefore each sensor delivers a different maximum velocity vs the traffic density for every road segment. The diagram in fig. 5 (b) shows the traffic flow vs the road traffic density.

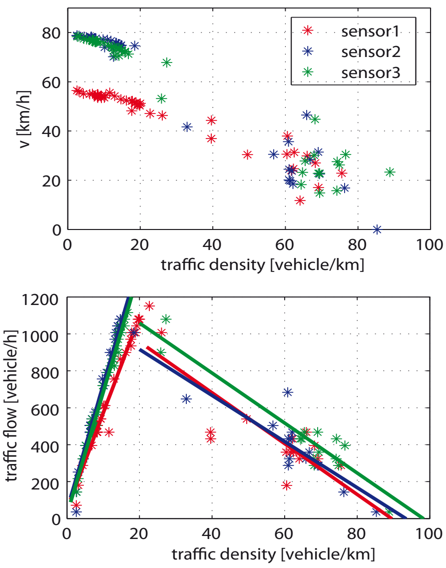

Figure 5: Fundamental diagram of a single lane road

Up to a traffic density of 22 vehciles/km the traffic flow increases up to a maximum of 1150 vehicles/h again for higher densities the flow then decreases. This indicates a traffic jam. The sensors allow a detailed analysis of the different road segments and their congestion.

4 Possible simulation scenarios

For example a scenario is chosen where a constant vehicle flow of 800 vehicles/h (altogether 430 vehicles) approach a traffic light signalized intersection. The green phase of the traffic light control is 26 seconds with a circulation time of 45 seconds.
The analysis in fig. 6 shows the velocity profile of all 430 vehicles over the route distance. Each vertical course in fig. 6 corresponds to a speed course of one vehicle. As can be seen from the figure vehicle no. 1 can pass the crossing straight through. However, vehicle 400 has to wait several traffic light phases, as can be seen on the blue areas with very low velocity. In addition you can see in fig. 6 that a jam has been developing of a maximum length of 800 meters.

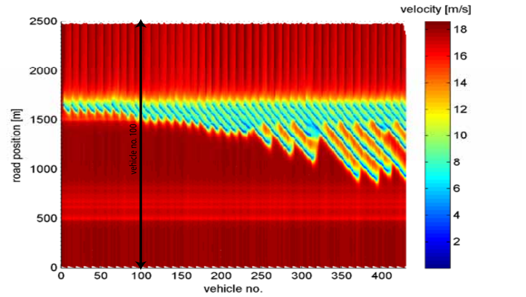

Figure 6: Velocity of vehicle in fleet of 430 vehicles approaching a traffic light, shown is the velociy profile of every vehicle over the route distance

Because all vehicles are simulated submicroscopically it is possible to compare each value of the drive train of any vehicle in fleets. As example fig. 7 shows the energy consumption in kWh of all vehicles over the distance.
In figure fig. 7 b) the energy consumption of an ICEV vehicle fleet is shown. For this the fuel consumption was calculated in kWh with the energy content of diesel fuel. As can be seen the fuel consumption of the vehicles no. 110-430 increased considerably. In comparison to fig. 7 a) with a BEV it can be seen that through the regeneration term (compare green circle fig. 7 a)) the increase of the energy consumption is lower.
Moreover, the consumption of the ICE of a PEV is shown in fig. 7 c) and the energy exchange of the battery in fig. 7 d). In the HEV vehicles no. 1-200 the ICE is supported very much by the electric motor of the HEV on the distance 1000-1500 meters. The more the traffic jam builds up the more the electric support decreases.

4.1 Analysis of fleet energy consumption

In figure fig. 8 the whole energy consumption of all vehicles of the fleet with reference to the first vehicle is shown. As can be seen the energy consumption of the ICEV has been increasing by 70 %; HEV and BEV have a much lower increase (15-20 %).

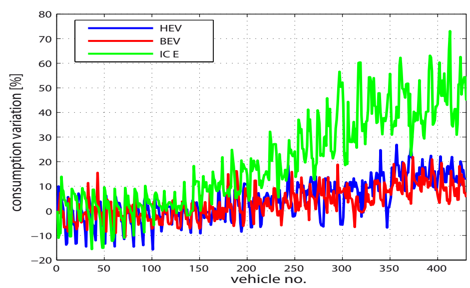

Figure 8: Energy consumption in fleet traffic of ICEV, HEV, BEV normalized to vehicle no. 1

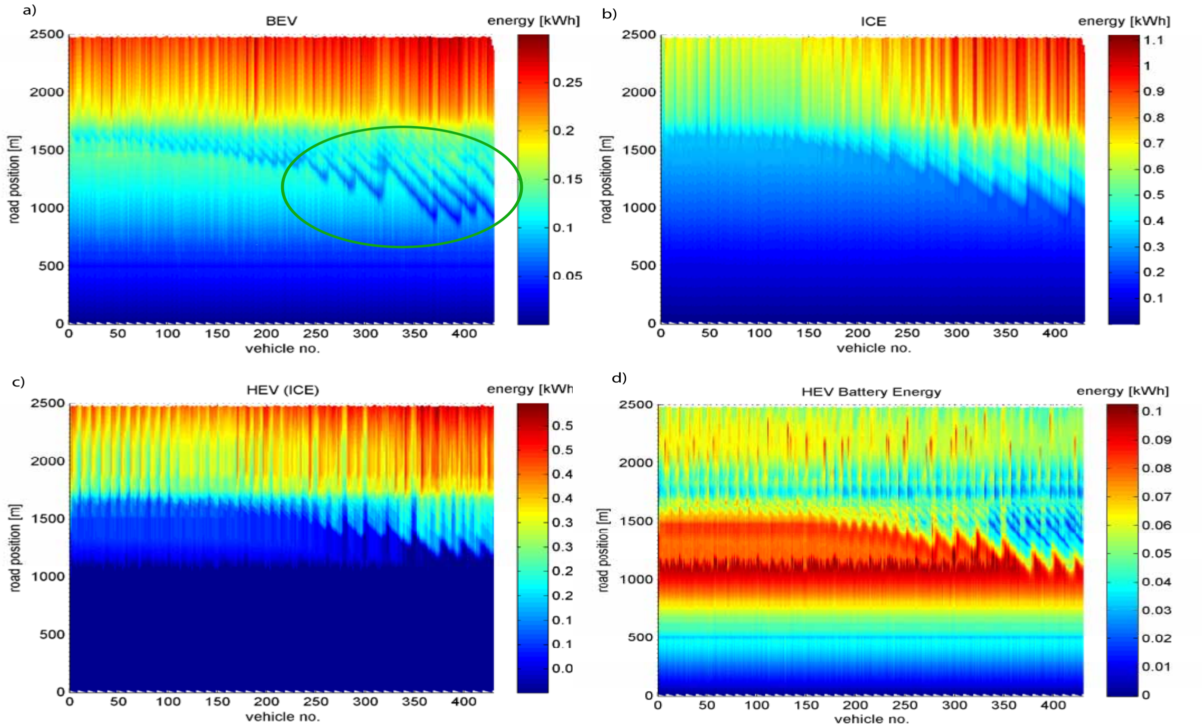

Figure 7: Energy consumption [kWh] of a fleet approaching a traffic light. Shown is the energy consumption of all 430 vehicles of the fleet over the route position a) BEV b) ICEV c) the ICE of HEV d) Battery energy of HEV

5 Thread management

One advantage of the simulator is that with the help of an intelligent thread management very low simulation times are possible at high vehicle density, because the submicroscopic vehicles and the traffic simulator are running on different threads. Fig. 9 shows the simulation time over the number of submicroscopic vehicles for one simulation of one hour. Up to a number of 5000 vehicles simulation times take less than 2.25 times the real time. The simulation time is independent of the size of the grid and depends only on the number of the vehicles.

The linear dependence due to the fact that with rising vehicle density the finding of the next vehicle ahead in achieved in shorter time.

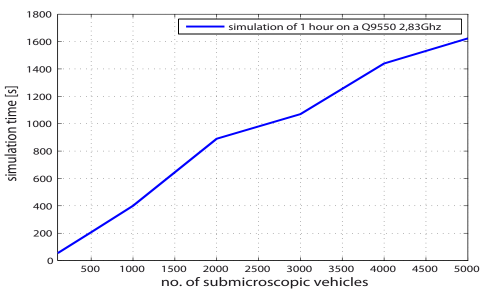

Figure 9: Simulation time vs. the vehicle number

6 Vehicle Interface

For a graphical description the simulator uses several different GUIs. On the one hand it is possible to visualize the whole simulation two-dimensionally. On the other hand the simulator employs a three-dimensional visualisation which is implemented in Java3D. Full submicroscopic vehicle data are described in vehicle-GUIs which can be individually selected for each vehicle (fig. 10). Therefore it is possible anytime to display and analyse the detailed data of the respective drive train. By the detailed representation of the operation points of the various routes in the efficiency maps of the ICE, motor or generator an exact analysis of the operation strategies is possible.

7 Conclusion

ULTraSim gives the possibility to analyse future traffic volumes realistically and in detail. Besides that it can integrate different vehicle topologies that will be found in the near future on our roads. Due to the modular programming the simulator is flexible and easy to expand. ULTraSim may also be connected with energy grid simulators in the future. The example scenario have demonstrates a small part of analyses possible with ULTraSim. Due to the very detailed and different vehicle models ULTraSim is an optimal simulation platform to develop operation and routing strate-

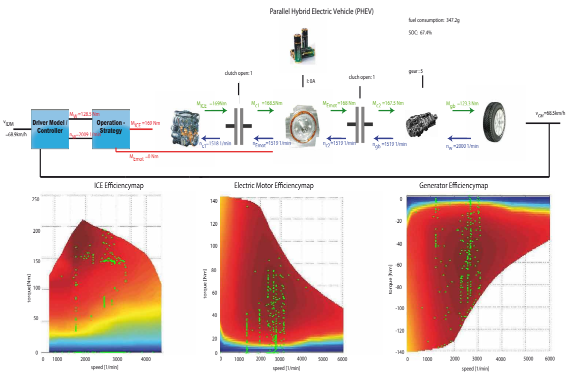

Figure 10: Submicroscopic UserInterface for a PEV with the motor / generator efficiency maps, operation points (green) and all values of the drive train

gies which can optimize the energy consumption and the travel time of many route users.

8 Explanation of symbols

ULTraSim	Ulm Traffic Simulator
ICEV	Internal Combustion Engine Vehcile
HEV	Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
PHEV	Plug-In-Hybrid Electric Vehicle
EREV	Extended-Range Electric Vehicle
FCEV	Fuel Cell Vehicle
V2I	Vehicle to Infrastructure Communication
V2V	Vehicle to Vehicle Communication

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Authors

Dipl.-Ing. Michael Richter received his diploma with distinction in Electrical Engineering with focus on ”Automation and Energy Engineering” in July 2010. Since then he has been working as research assistant in the Institute of Energy Conversion and Storage at the University of Ulm, Germany. His main research in pursuing a PhD degree in engineering science focusses on the investigation of operation strategies of hybrid electric vehicles as well as on optimisation of traffic flows.

Prof. Dr. Herbert Kabza graduated from the Ludwig-Maximilians-University, Munich, Germany with a diploma in physics. After finishing his PhD thesis there in 1979 he joined Siemens where he was engaged in microelectronics and power semiconductor development. In 1996 he started up the Institute of Energy Conversion and Storage at the University of Ulm, Germany where he is engaged in research on management in isolated, stand-alone energy systems and hybrid drive configurations.