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ADVANTAGES OF DEVELOPING AN ELECTRIC VEHICLE FOR ADVANCED REAL LIFE VEHICLE SIMULATIONS

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ABSTRACT: The traditional design process of any vehicle (small class, compact class, van, SUV or maybe hybrid, electric or yet undefined) is very long, rigid and not cost effective. At the end of this process the vehicle manufacturer doesn't end up with too many prototypes for testing, and not many things can be changed on those prototypes. During the design process, the simulations are mainly focused on the dynamic and the energetic performances, the passive and the active safety features and on complying with the environmental standards. The simulations are done "offline" without feedback from the real system or "online" (real-time) with a degree of feedback from components of the real system (HiL) and limited feedback of human operator (H^2iL). Whatever the case, the simulations cannot ensure the human feedback on the vehicle comfort or driving pleasure. This project proposes a new approach: developing an electric test platform (simulator) with fully customizable parameters, on which any type of vehicle characteristics can be loaded. This will allow testing/simulating the vehicle in real life traffic conditions while being driven by a regular driver. During the tests, the platform will allow the study of dynamic and energetic performances and the study of comfort while driving in real life traffic conditions (launch, braking, accelerating, gear change etc.).
KEYWORDS: simulator, real life, comfort, electric vehicle, H^2iL

INTRODUCTION

Vehicle simulation is a huge domain. Although there are many simulation software available, all of them being very flexible and allowing accurate modeling, they cannot offer real feedback on the vehicle comfort and driving pleasure when used in "offline" simulation. The now becoming classical HiL (hardware-in-the-loop) simulations offer a degree of feedback from individual components of the real system [11] and the modern H^2iL (human-and-hardware-in-the-loop) systems give back a limited feedback of the human operator [8], [10]. Despite becoming more precise and more complex, the H^2iL systems offer data on simulated vehicle comfort and performances under simulated driving conditions.

Current H^2iL systems can be used on studying a large variety of parameters: the dynamic and the energetic performances, the passive and the active safety features, the in-car entertainment systems etc.

This project proposes the development of a powertrain H^2iL simulator that can be used for the study of comfort for different maneuvers (launch, gearshift, tip-in). In order to choose the solution, an analysis of some of the simulators and methods used for vehicle dynamics is done.

The "inDrive Simulator" project from Ingenieurgesellschaft Auto und Verkehr (IAV) was developed as a testing platform for future cars and can be used before the first prototype is even built, [5]. This is a simulator capable of being drive in real-life road traffic which can be used by virtually any individual after appropriate training. Using the accelerator pedal, the brake pedal and the gear selector lever, the driver of the simulated vehicle will not be controlling the actual drive of the base vehicle, but a virtual drive in a virtual vehicle. These virtual components are simulated as mathematical models on the computer and calculated in real time on the basis of the virtual vehicle's operating state and driver instructions. The results will then provide the input values for controlling the vehicle's longitudinal dynamics and for computing further target variables. The main advantage of this project is that it closes the gap between the early design and prototype testing because there is no need to finalize the target hardware at this stage. All that is required are mathematical models and a base vehicle, not necessarily the target vehicle, but as similar as possible.

The UNIKAT vehicle from Automotive Testing Papenburg (ATP) is a universal chassis with adjustable kinematics and adjustable masses. It was developed by ATP for the investigation of the effects of kinematics, mass distribution, tires and brakes on vehicle dynamics and comfort. The chassis is also the core of a dedicated training program for testing engineers, chassis designer engineers and people involved in vehicle dynamics simulations, [6]. The maximum variability regarding the attributes relevant to vehicle dynamics and vehicle comfort is ensured by allowing the *following adjustments: track from 1400mm to 1600mm, kingpin inclination from 6° to 13°, castor angle from 4° to 9°, steering offset -10mm to +30mm, camber from 0° to -5°, antidive from 0 to 40%, roll center from 0mm to 60mm. Spring rates, antiroll bar and dampers are adjustable too [12].*

The problem of using scale models in the vehicle dynamics research has also been explored. In the study of the Pennsylvania State University, a model is used to determine the fidelity of using scaled vehicles for vehicle chassis dynamics and control studies. In the PURRS (Pennsylvania State University Rolling Roadway Simulator) project, a scale-sized vehicle is driven freely on a moving roadway surface. The purpose of the study was to match the planar dynamic performance of a scale vehicle to a specific full-size vehicle and to directly compare the behaviors of two parametrically equivalent vehicles, [7].

The solution chosen for the developed simulator is an electric vehicle implemented on a universal chassis with adjustable parameters. The electric motor is piloted by an acceleration control to follow an acceleration profile. This profile can be obtained by "offline" simulation or from a powertrain model that runs in real time on the simulator control unit. Currently it is possible to simulate in real time with a high degree of accuracy a great variety of powertrains [1], [2]. A small electrical motor is chosen to cover especially the low velocities maneuvers for passenger cars in the lower segments. For the higher segments the scaling method will be evaluated.

POWERTRAIN INFLUENCE ON LONGITUDINAL DYNAMICS

In order to determine if a certain vehicle's dynamic behavior can be uploaded and simulated onto the electric test platform, a study has been conducted for a number of representative vehicles. They were chosen from the A (economy), B (city), C (compact) and D (medium) classes, [13]. The analysis of the power/weight ratio for every vehicle (figure 1) is used to choose a number of vehicles for the detailed study.

Six representative vehicles have been chosen from B, C and D segments for a compared analysis. The purpose is to identify which acceleration range is needed to be covered by the simulator. The vehicles considered are amongst the most common on the European market. The important parameters needed for the acceleration computation are presented in table 1.

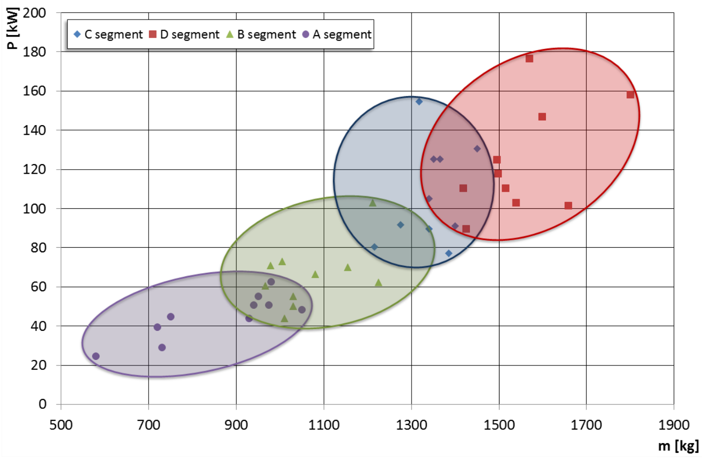


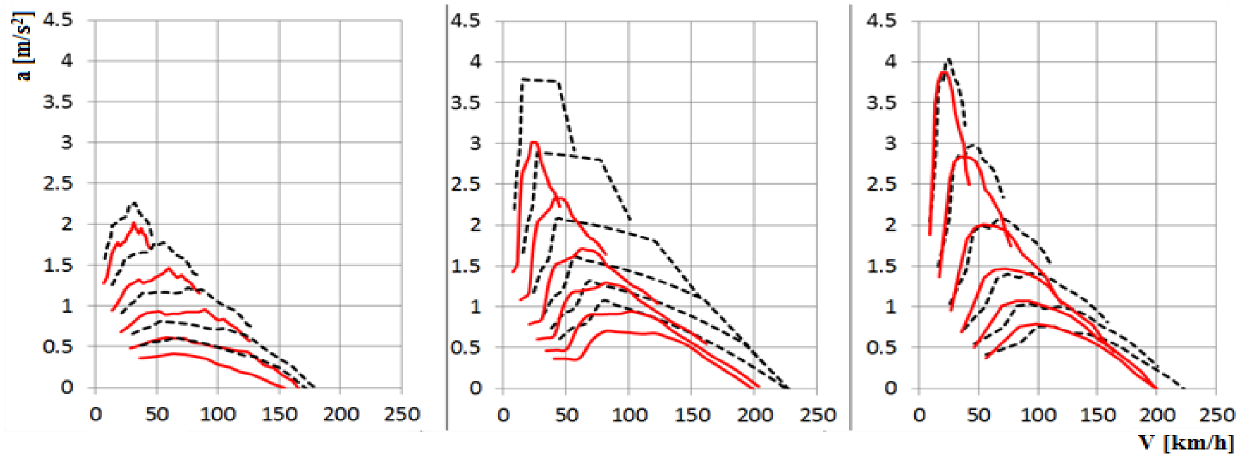
Figure 1. Vehicle distribution in function of mass and power

Table 1. Parameters of the representative vehicles

Vehicle	Class	Power/Weight [kW/kg]	Power [kW]	Overall Gear ratio	Weight [kg]	Rolling radius [m]	Drag coefficient [-]	Frontal area [m^2]
Opel Corsa 1.2i	B	0.055	54	15.59...3.18	975	0.307	0.32	2.01
Fiat Grande Punto 1.3 M-Jet	B	0.064	67	16.03...3.43	1040	0.34	0.3	2.15
Volkswagen Scirocco 2.0 TSi	C	0.103	145	13.78...2.67	1400	0.317	0.34	2.14
Ford Focus 1.0 EcoBoost	C	0.068	92	15.17...2.81	1350	0.3	0.295	1.95
BMW 320d	D	0.079	120	13.16...2.12	1515	0.32	0.26	2.17
Volkswagen Passat 2.0 TDi	D	0.07	105	13.19...2.18	1500	0.327	0.29	2.29

In order to verify the acceleration range coverage, the acceleration profile for each vehicle had to be determined. The premise of the calculation is that the vehicle is accelerating on a straight road, without incline and with no wind speed. The process started with gathering power and torque values for each vehicle. The next step was the determination of a vehicle's speed in each gear and the acceleration, [4]. The results are presented in figure 2.

Because of the dynamic limitation on the engine torque (for example smoke limit on Diesel engine), in reality, it is expected a lower level of acceleration. In order to cover at least the A and B segments a minimum acceleration of around 2 m/s^{2}at low speeds is needed.



a) b) c)

Figure 2. a) - B segment acceleration range; b) - C segment acceleration range; c) - D segment acceleration range

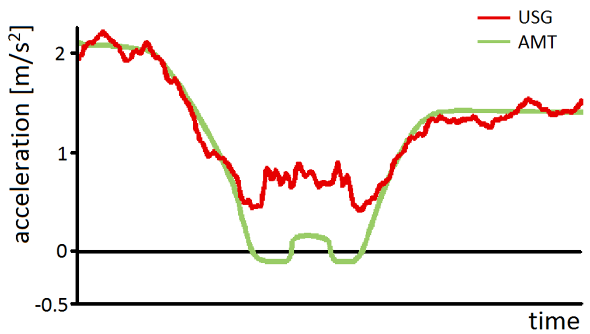


Figure 3. Acceleration profiles at gearshift (1^{st} to 2^{nd}, WOT) for different transmissions

Another important factor that must be covered by the simulator is the capacity to reproduce the acceleration profiles for different types of transmissions (MT, AMT, AT, DCT, CVT) and maneuvers (launch, gearshift, tip-in, tip-out).

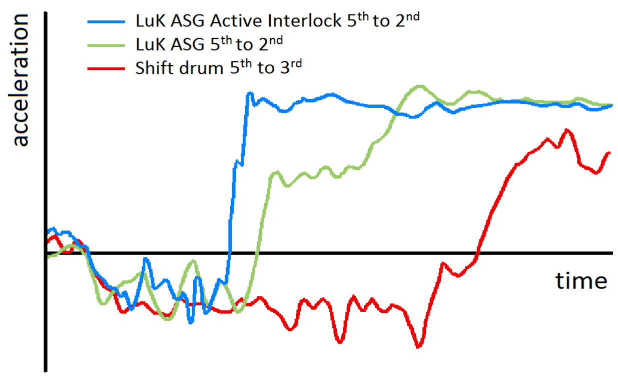


Figure 4. Acceleration profiles at gearshifts for different actuators

The gearshift is one of the most critical in terms of comfort and is very dependent on the transmission type. The gearshift comfort of new types of transmission can be evaluated before the prototype realization.

In figure 3 the acceleration profiles for 1^{st} to 2^{nd} gearshift at WOT (Wide Open Throttle) is compared for AMT and USG (Uninterrupted Shift Gearbox) a new type of transmission [3].

Another application of the simulator is the study of the actuators influence on gearshifts for AMT. In figure 4 one can easy see the high influence of the actuators on the acceleration profiles [9]

VALIDATION OF THE SIMULATOR TESTING RANGE

The actual simulator will be similar to a C segment vehicle powered using an AZURE Dynamics conversion kit. The body of the electrical test platform can be supplied by a donor Dacia Logan 1.6 MPi. A weight reduction process will be conducted on the vehicle by removing the unnecessary internal combustion engine related items. Considerable weight will be lost by removing the K4M engine and JR5 gearbox, together weighing 191kg. The reservoir, exhaust system, cooling system, rear seats, spare tire and others reductions will lead to another 125kg won. The final weight of the vehicle can be decreased from 980kg to 660kg. The electric drive system is composed of the AC24LS electric motor and the DMOC445 Controller, both supplied by AZURE Dynamics. The electric drive system is coupled with the AT1200 gearbox with an internal differential. After mounting the electric drive system, the final weight of the vehicle can reach the minimum value of 733kg.

The modularity for the longitudinal dynamics is ensured by two possible gear ratios for the gearbox and different rolling radius. The parameters of the original vehicle and the simulator are presented in table 2.

Table 2. Parameters of the representative vehicles

Vehicle	Max. power [kW]	Mass [kg]	Power/weight [kW/kg]	Rolling radius [m]	Gear ratio
Dacia Logan 1.6 MPi	66	980	0.067	0.31	13.52...0.8
Dacia Logan AC24LS	47	733+	0.064	0.285...0.324	10 / 12

For the electric test platform in its standard configuration (with a weight of 800kg and a rolling radius of 0.31m) a maximum acceleration value of 2.09 m/s^2 with a top speed of 122 km/h has been obtained, figure 5.

This basic test platform can offer a narrow range of adjustments which can be made in order to increase or decrease the acceleration values, depending on the vehicle which is needed to be simulated (table 3). After varying these parameters within the simulation, the acceleration range obtained varies from 1.84 m/s^2 to 2.28 m/s^2 with a respective maximum speed variation from 148 km/h to 110km/h, figure 6.

Table 3. Qualitative influence of the simulator adjustable parameters

Parameter	Evolution	Applicability	Impact	
Vehicle mass	Increase	Easy	Max. acceleration ↘	Max. velocity ↘
	Decrease	Difficult	Max. acceleration ↗	Max. velocity ↗
Rolling Radius	Increase	Easy	Max. acceleration ↘	Max. velocity ↗
	Decrease	Easy	Max. acceleration ↗	Max. velocity ↘
Drive ratio	10	Difficult	Max. acceleration ↘	Max. velocity ↗
	12		Max. acceleration ↗	Max. velocity ↘

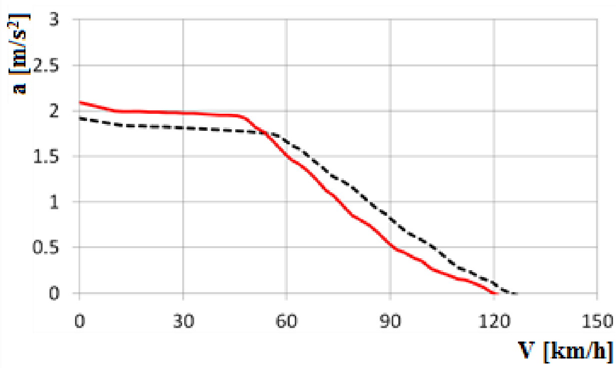


Figure 5. Acceleration profile with standard configuration

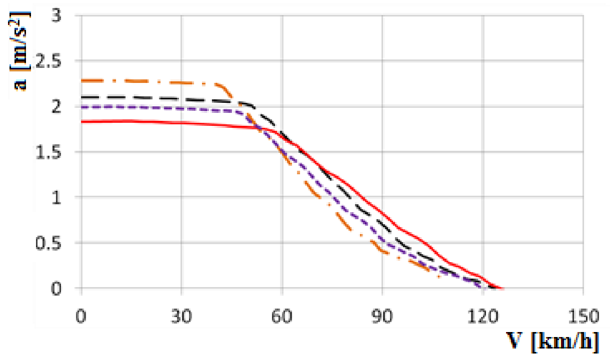


Figure 6. Acceleration profile with parameter adjustment

A model of the electric vehicle is developed in LMS Imagine.Lab AMESim in order to verify the capacity to follow an imposed acceleration profile, figure 7.

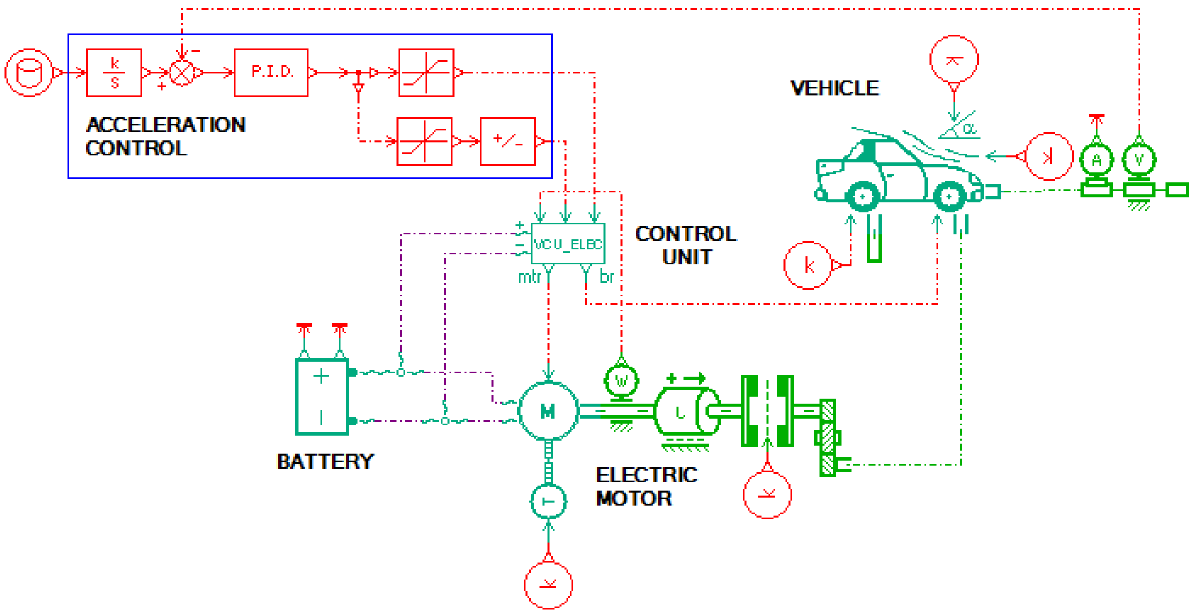


Figure 7. Electric vehicle model

The very simple acceleration control is based on a PID controller (proportional-integral-derivative controller) that attempts to minimize the velocity error. The outputs are the acceleration and brake command.

The case considered is a gearshift from 1st to 2nd at full load for a B segment car. There are values of the tuning parameters that ensure a good correlation between the imposed vehicle acceleration and the vehicle acceleration (simulated). The vehicle's acceleration profile is retarded with 0.13 s (figure 8), but it is following the imposed acceleration very closely (figure 9).

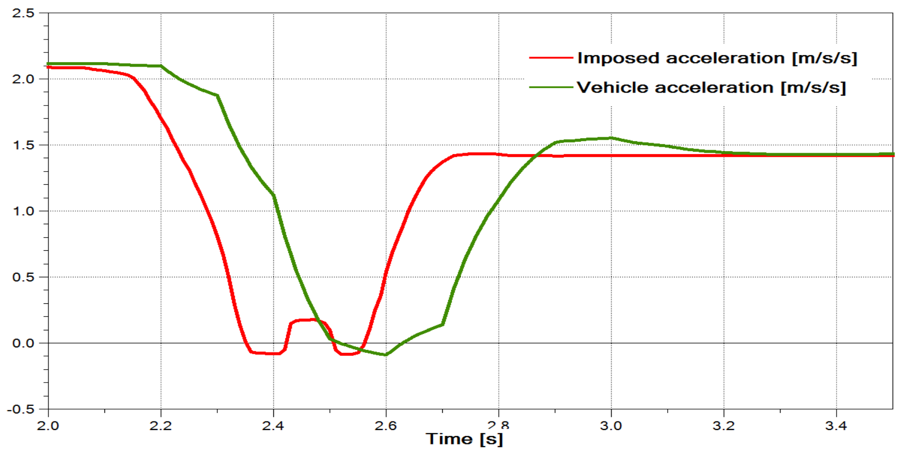


Figure 8. Imposed and simulated vehicle acceleration

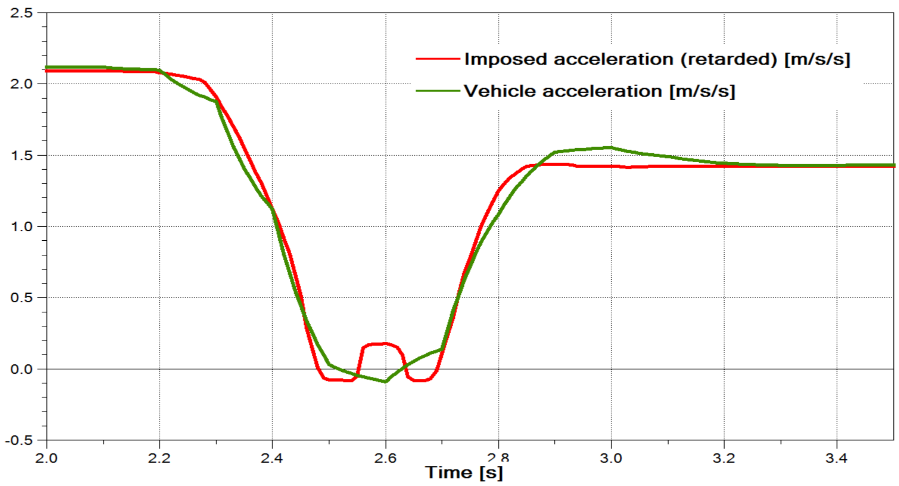


Figure 9. Imposed acceleration (retarded with 0.13 s) and simulated vehicle acceleration

CONCLUSIONS

It was shown that a powertrain H^2iL simulator that can be used for the study of comfort during different maneuvers (launch, gearshift, tip-in) can be made based on an electric vehicle. Furthermore, it was shown that the low velocities maneuvers for passenger cars in the lower segments can be covered using a small electric motor. Even with reduced power, the high torque and the light chassis ensure high acceleration levels. The computation done using the theoretical test platform with the AC24LS electric motor from AZURE Dynamics mounted on a Dacia Logan body, has shown that the acceleration values obtained can be used to cover the simulation of at least two or three gear changes for A, B and lower power to weight ratio C segments.

The article describes the existence a control solution that allows the following of an imposed acceleration profile. Additional validations are needed to check the stability of the control for different maneuvers. A more elaborate vehicle model (2D with vertical and longitudinal suspensions) and powertrain model (with elastic shafts) must be employed to fully validate the control.

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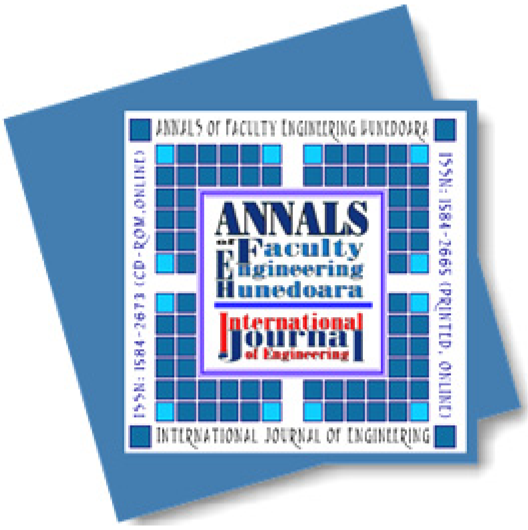

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