Optimisation of Gearbox Control Units by Driver Assistance Systems

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When testing the software of an electronic control unit, the number of states to be considered amounts to approximately ten raised to the power of 1000. The ITI GmbH meets this challenge with the implementation of a distributed simulation by means of the co-simulation approach.

GROWTH IN COMPLEXITY

In the development of modern automotive gearboxes – as in the case of all technical systems – there is a growth in complexity due to ever more extensive functions to be observed. In order to be able to reliably test and approve interlinked functions, their integration into a virtual prototype is indispensable and has by now become a commonly used approach. Particularly in the case of advanced driver assistance systems that acquire the vehicle environment through a wide range of sensors and interpret the environmental information via an environment model the simulative representation of such systems poses a growing challenge.

The increasingly diverse interactions between the individual sub-systems of different physical domains such as mechanical, electrical/electronic, hydraulic and control technology can most efficiently be represented by means of object-oriented modelling that takes dynamic effects into account. Such multi-physical models are used in various scenarios such as hybridisation, cylinder deactivation or advanced driver assistance connection for the design and analysis of new gearboxes. In this context available potential can be optimally tapped only by combining powertrain tuning and operating strategy optimisation.

Consequently, there is a growing trend in the further development of advanced driver assistance systems that no longer exclusively focuses on aspects of traffic safety but increasingly includes the assumption of driver tasks for fuel-efficient, predictive driving. A large number of functions and applications have already gone into production or are currently in development. Tools that can carry out the work of engineers in the fields of software development, application and testing in the virtual world are becoming increasingly indispensable.

A wide range of modelling types and approaches are available to represent technical systems. As experience has shown that the limits of signal flow oriented models can easily be overcome by non-causal modelling, non-causal object-oriented modelling with Modelica in SimulationX is the tool of choice for modelling a gearbox process unit. In contrast, the signal flow oriented Matlab/Simulink tool is used for creating the gearbox software.

VIRTUAL DEVELOPMENT AND TESTING ENVIRONMENT FOR SHIFTING STRATEGIES

In addition to weight, assembly space and shifting comfort, a current automatic gearbox has to satisfy further requirements such as improving the car's fuel economy. The shifting strategy plays a major part in this. As mentioned earlier, important information from the environment can be acquired, interpreted and forwarded to systems and components as process information via assistance functions, **FIGURE 1**. The example of the ZF 8HP, an eight-speed automatic gearbox by ZF Friedrichshafen AG consisting of four planetary gear-sets and five shifting elements (three multi-plate clutches and two brakes) shows how these aspects are taken into account in early development stages.

The gears are selected by opening and closing the shifting elements. The shifting elements are either open or closed, depending on the engaged gear, so that the flux of force is changed via the planetary gears, thereby setting a specific gear ratio. This is performed by a transmission control unit (TCU), that was implemented in the Matlab/Simulink modelling environment. Using elements of the 1-D Rotational Mechanics Library and signal elements, the 8HP gearbox including the actuator technology was represented in SimulationX, **FIGURE 2**. The model was extended by an interface that has the same inputs and outputs as the Carmaker open integration and test platform to ensure smooth integration. The desired gear, or gear sequence in the case of a dynamic gear change, can be allocated to the gearshift logic mechatronic module, **FIGURE 2** (left), in which the control unit for the brakes (A, B) and clutches (C, D, E) of the 8HP gearbox has been implemented. Clutches and brakes were modelled by means of elastic friction points equipped with signals for (de-) activating the torque flow between powertrain components by the control unit. Due to the good interoperability of the SimulationX and Carmaker tools a dual approach that combines the advantages of both tools was selected. A simulation concept like this is achieved by means of FMI for co-simulation, which supports the linking of several simulation tools in a co-simulation network.

VALIDATION AND OPTIMISATION OF SHIFTING STRATEGIES IN VIRTUAL TEST DRIVING

Initially, the Gearshift_Logic mechatronic module is complemented by other software modules to show how these functions can be validated and optimised in virtual test driving. For this purpose, the gearbox model is integrated as a Functional Mock-Up Unit (FMU) from SimulationX and the control logic for the gearbox as an FMU from Simulink into Carmaker. During exporting the model behaviour is extracted as C Code including the solver. The FMU that has been exported this way for co-simulation runs as a slave in the extraneous simulation environment and exchanges the calculated results pertaining to discrete communication points with the Carmaker master environment. In the meantime the sub-systems are calculated by their individual solvers independently of each other. The software for the shifting strategy is provided with additional environmental information, **FIGURE 3**.

During this process Carmaker receives the road curvature and gradient data from the navigation system via the standardised Adasis protocol. The distance from the preceding vehicle is acquired via a radar or camera model. All sensor-acquired data is forwarded to the gearbox software and can now be

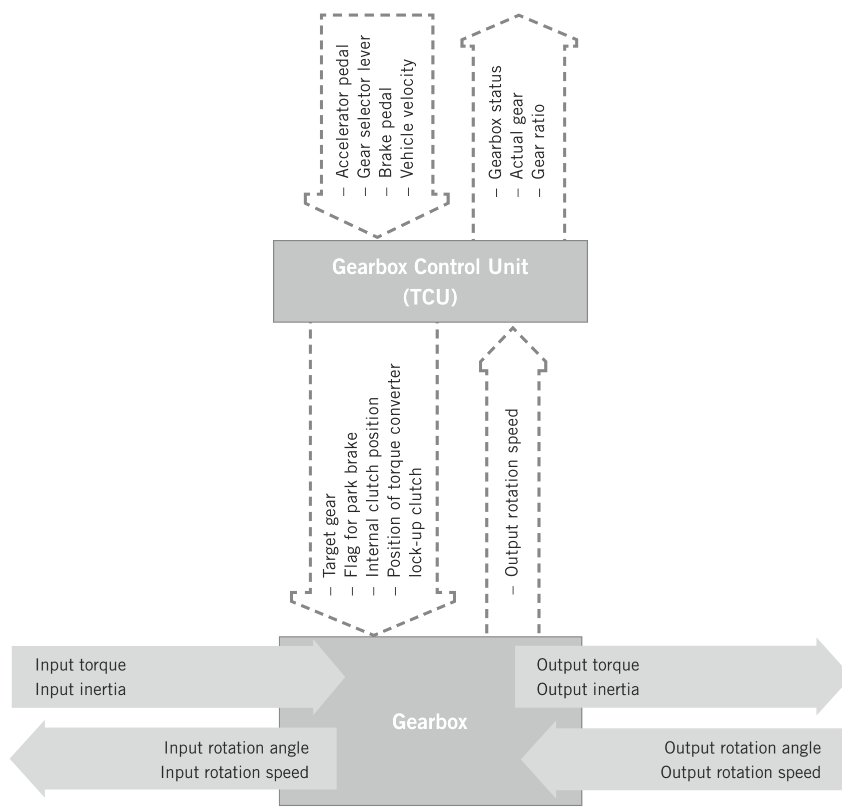

FIGURE 1 Realistic interfaces with gearbox components are necessary for an easy and continuous integration; additional inputs and outputs can be included (© IPG)

used for the development of the following functions in order to:
- avoid shifting events while cornering or to finish the shifting event before cornering
- switching to neutral for a downhill stretch in order to make use of coasting stages
- using the recuperation in coasting events or in downhill driving in order to maintain the distance from the preceding vehicle or to charge the battery.

The two latter requirements complement each other. Through variant simulation various strategies and distances from the preceding vehicle can be generated and the optimal strategy for gear engagement and disengagement developed.

The controlled gearbox process and the gearbox software are integrated in MiL, SiL, HiL and on the test bench in the following combinations:
- In MiL the gearbox model and the software are integrated as FMUs in CarMaker.
- In SiL the gearbox control software is replaced by production code and may be integrated into Carmaker as C Code or also as Autosar-FMU.
- In a subsequent step, in the HiL test, the gearbox software is replaced by a real-world component, the electronic control unit.
- In the final step, on the gearbox test bench, the gearbox FMU is replaced by a real-world gearbox as well.

In this process Carmaker is retained as the integration tool in all development stages. The test cases generated in the MiL stage, as well as the vehicle model and the parameterisation, can be consistently used in all the stages shown. The generated data reflects very high reproducibility and can be superbly used for both the test and the further development of the gearbox software. By means of the gearbox test bench physical effects, which contribute to a higher level of maturity in the development of the gearbox software, can now also be systematically transferred to the gearbox model. For further investigations the driver can be involved as well. The driver, for example, can either use the manual shift gate for overtaking events or switch to comfort or economy mode. These options, as well, may be combined in a wide range of route variants and distances from the preceding vehicle. For performance reasons such a large number of tests can only be carried out in a meaningful manner in MiL or SiL. On the HiL or gearbox test bench only load cases concerning current/pressure and torque as well as certain boundary cases of the defined spaces are run in order to minimise the number of test cases. In all stages a physical engine model including engine control unit software may be integrated in order to optimise the shifting characteristics and torque reduction during gear changes.

Finally, the driver actions, as well as the vehicle and gearbox parameters, can be recorded in a real-world road test. The driver inputs and the speed are used again as input signals for the simulation in all stages in order to be able to compare the various simulation calculations with the real-world road test. Only a meaningful model comparison provides the basis that makes it possible to carry out the variant calculations with a high level of realism.

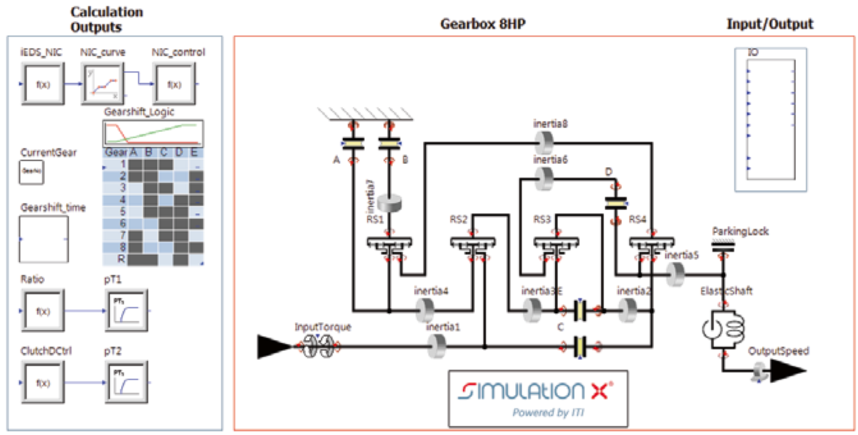

FIGURE 2 Screenshot of a SimulationX model of the automatic gearbox 8HP by ZF (© ITI)

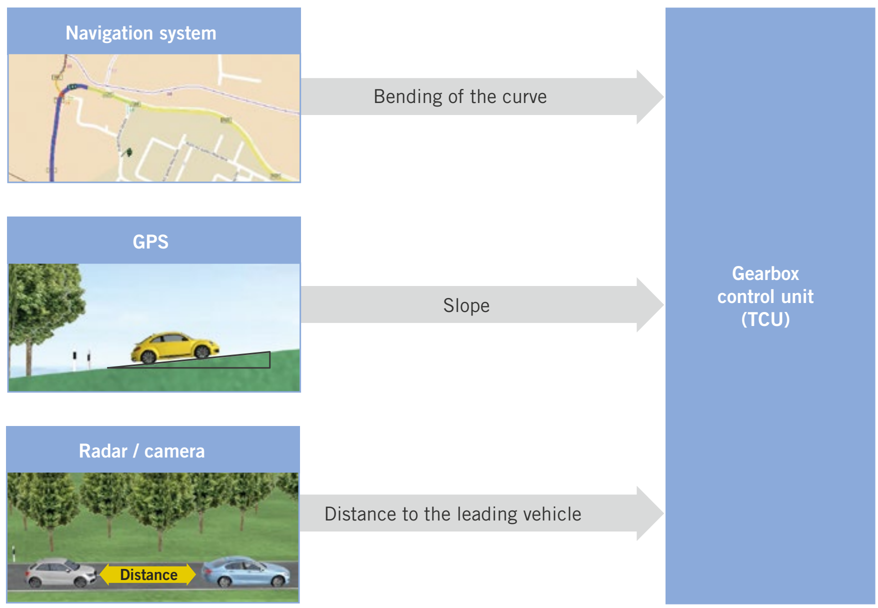

FIGURE 3 Information which is acquired by sensors and forwarded to the gearbox (transmission) software (© IPG)

SUMMARY AND OUTLOOK

Due to the benefits of the object-oriented, non-causal modelling approach increasingly heterogeneous domains are combined with each other and simulated in a single model. In the case of heterogeneous models the simulation performance reaches its technical limits. The implementation of a distributed simulation by means of the co-simulation approach described above provides a good possibility to successfully meet this challenge.

The separate integration of the gearbox and software offers various advantages – including, among others, the reduction of the number of variants to be made available, as well as the fast, virtual testing of new concepts.

The comparison of the real-world and simulated vehicle handling characteristics creates a valid basis for the establishment of virtual test driving. As a result, not only safety-critical functions but also those which are relevant to economy and comfort can be tested and optimised early and efficiently within a seamless tool chain. Examples include the development and testing of fuel economy instruments for manually shifted vehicles that instruct the driver to "lift" or to "switch to neutral". Other energy-saving functions based on advanced driver assistance sensors such as road sign or traffic light detection as the basis for an increased use of coasting or recuperation stages could be achieved this way as well. In addition, other focal topics of virtual testing and optimisation of operating strategies for hybrid and non-hybrid vehicles – e.g. Car-to-X or Car-to-Car – are relevant. Last but not least, test drives which are hard or even impossible to reproduce in reality are an important field for virtual validation.