Implementation of State Observers based on Multibody Dynamics on Automotive Platforms in Real-Time

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In the last years, the number of sensors in vehicles has significantly increased following the automotive market need for safer, more performant, efficient and autonomous vehicles. The development of advanced control strategies for example leads to the need of more sensors. The vehicle dynamics analysis of a new prototype also requires a large amount of sensors for instrumentation. The cost of test campaigns increases in relation with the number of sensors to be acquired. Sensing equipment can be highly expensive and some quantities cannot be sensed directly. As a solution for the sensing of motion-related quantities, multibody based state observers are being developed [1]. These quantities are gathered from a simulation corrected by a minimum set of real sensors placed on or in the vehicle. Therefore, the number of sensors in the vehicle or for instrumentation can be reduced and the number of measured quantities can be increased.

The challenge of this approach is to implement numerically-stable algorithms combining multibody models and observers that can be executed ideally in *real-time* in the vehicle. In previous research [2], a state observer based on multibody models was executed in a conventional computer in *real-time*. Nevertheless, the embedded platforms available on-board commercial vehicles, known as Electronic Computer Units (ECU), have less computational power than computers. Currently, the computational performance of ECUs is being increased by means of heterogeneous processors. These ECUs (Fig. 1) embed a processor with an ARM architecture and a Field Programmable Gate Array (FPGA), which acts as a co-processor for code acceleration. Heterogeneous processors are used for several purposes such as computer vision or radar sensors on automotive applications [3].

Fig. 1: New generation ECUs (ZYNQ 7000 SoC, Xilinx)

As presented in [4], the use of an FPGA on a heterogeneous processor for the simulation of multibody models means a reduction of the simulation execution time. As a next step, in this work, the use of heterogeneous processors for executing state observers based on multibody models is explored. For this purpose, the errorEKF presented in [5] is implemented based on a multibody model of a full-vehicle, integrated using a semi-recursive formulation [6].

The aim of this work is to execute the model-based state observer in *real-time* on a heterogeneous processor, concretely in this work the ZYNQ 7000 SoC, from Xilinx, which embeds an ARM Cortex-A9 and a FPGA Artix7. The first step has been to execute the model-based state observer on a PC, and determine the real sensors needed for correcting the multibody simulation in terms of stability of the simulation, and evaluate the precision of the data provided by the virtual sensors. Next, the simulation is made on the heterogeneous processor in order to test the computational power available. To guarantee *real-time,* different implementations using the FPGA shall be tested in order to determine the scheme that provides the higher performance of the processor and the smallest execution time.

For obtaining initial results, a multibody model of a vehicle with 10 degrees of freedom (6 dof for the chassis and 1 for each suspension, leading to a model of 26 variables) and the errorEKF as state observer were executed. As mentioned before, a semi-recursive formulation is used for the multibody dynamics, with a Newton-Raphson iterator for the integration. The sensors used as real sensors were a GPS, a tri-axial accelerometer and a tri-axial gyroscope on the chassis and a longitudinal sensor for the shock absorbers. As the ARM is the main processor of the ZYNQ, the simulation was launched on the ARM without using the FPGA, in order to test if *real-time* could be achieved only with the ARM processor. The result is that for 10 s of simulation, the time consumed was of 14 s. Therefore, it is not possible to execute the model based state observer in the ARM. As an alternative, the FPGA has to be used for acceleration. After profiling the code of the simulation, the operations that take more time of execution were identified. These are the suitable operations to be offloaded to the FPGA, and thus, accelerated. In this particular simulation, the operator for evaluating the increment in the variables of the multibody dynamics after each integration step, is the one that require more computational power. Implementing this operator on the FPGA reduces the overall time of the multibody dynamics simulation and is also advantageous for the state observer iterations: position and velocity problems are solved each time step to force the corrections made by the real sensors to satisfy the constraints of the multibody model, and the operator implemented on the FPGA is also used for accelerating both problems.

The future work will be to execute the multibody model based state observer in *real-time* in a real vehicle. For this purpose, a CAN bus interface is programmed on the heterogeneous processor, so the information of the real sensors can be used by the observer to apply the corrections to the multibody model. Also, more efficient FPGA implementations should be tested in order to increment the speed of the simulation, which will allow to increment the complexity of the model (adding tire models, steering models, etc) and, therefore, more virtual sensor information.

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