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Development of the DLR Next Generation Train running gear research facility (NGT-FuN)

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Abstract

A full-scale prototype of the Next Generation Train (NGT) running gear with a roller rig installation bench will be built as proof of concept of the running gear and its suitability for high-speed traffic. It will be available as the research platform "Forschungsinfrastruktur NGT-Fahrwerk" (FuN) for the German Aerospace Center (DLR) internal and external research activities.

This work presents an innovative method and tool chain to develop application software for the automation of a mechatronic running gear (prototype). The methodology, development, and simulation tools that offer a consistent tool chain from model creation to real-time software and measurement data processing are presented. The model and software structures that are necessary for the software environment are described. The software-in-the-loop environment couples the existing multi-body simulations for the development process with signal-based simulation software using a co-simulation interface. The resulting software-in-the-loop simulation environment contains a novel interface layer that translates the mechanical states of the multi-body simulation to pseudo-electrical signals that are read or written by the application software.

This makes it possible to develop real-time applications and software structures in software-in-the-loop architectures. The real-time software contains a dedicated model structure of input, processing and output submodels, which is based on signal flow and distinct assignment of tasks. On the rapid-control-prototyping hardware, the real-time software is investigated with a virtual installation bench simulation.

Keywords: Next Generation Train (NGT), running gear, roller rig, software-in-the-loop, rapid-control-prototyping, multi-body simulation

1 Introduction

The German Aerospace Center (DLR) concentrates its expertise in the field of rail vehicle research in the Next Generation Train (NGT) project. In this context, vehicle concepts (e.g., a double-deck coach with continuous lower level for an ultra-high-speed train with lightweight construction) and announced technologies are developed for future rail vehicles [1]. Due to advantages in terms of space requirements, wear and weight reduction, the activities in the bogie design focus on the development of a structurally-optimized running gear with independently rotating wheels, mechatronic guidance, and primarily sprung direct drive.

A full-scale prototype of the NGT running gear will be built by 2021. The primary goal is the proof of concept/function of the running gear and its suitability for high-speed traffic. This prototype will be available as the research platform "Forschungsinfrastruktur NGT-Fahrwerk" (FuN) for DLR internal and external research activities. The commissioning of the running gear is supported by an installation bench (Figure 1) with reduced requirements (vmax=5m/s). FuN will be operated from 2023 for an initial three-year phase in two measurement campaigns per year on DLR-external roller rig test facilities. Further testing with a rail vehicle in dedicated test centres is planned.

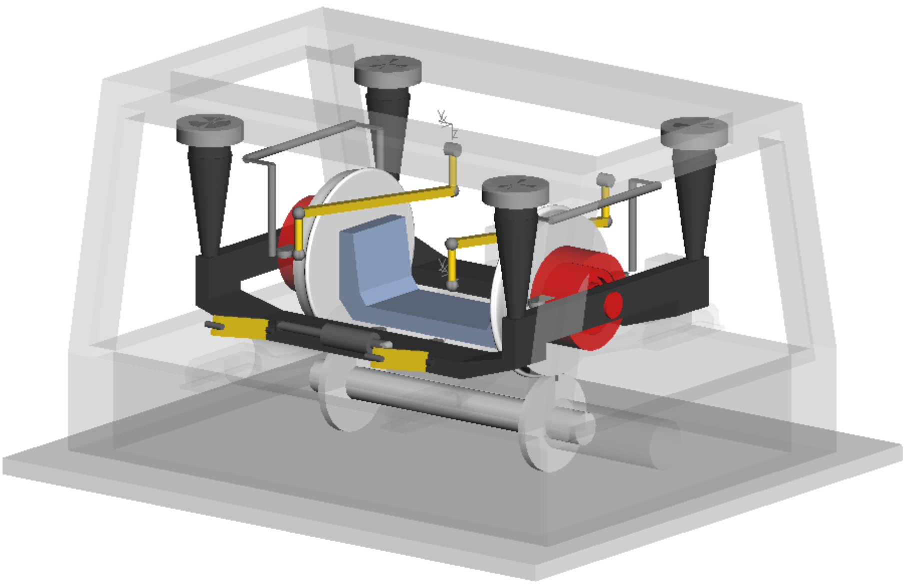

Figure 1: Simpack model of the NGT FuN running gear and the installation bench.

Roller rigs are a proven method for precisely and safely examining the running properties of conventional and unconventional running gears or entire vehicles in stationary test benches [2]. The changed contact conditions between wheel and roller compared to a conventional wheel-rail contact are described by Bosso et al. [3].

Roller rigs and their tested running gears can be built in full-scale or scaled [4]. Iwnicki et al. [2] and Jaschinski et al. [4] provide a summary and systematization of roller rigs. The test bench automation and hardware-in-the-loop experiments are described by Allotta et al. [5].

The presentation introduces the running gear and installation bench concept. The methodology, development, and simulation tools will be presented. This paper describes the model and software structures that are necessary for the software environment. With the multi-body simulation models in Simpack and Modelica/Dymola, the installation bench model will be gradually expanded to include virtual sensors and automation technology. This makes it possible to develop real-time applications and software structures in software-in-the-loop architectures. On the rapid-control-prototyping hardware, the real-time software is investigated with a virtual test bench simulation (without test bench hardware).

2 Methods

An integrated software environment to support the automation processes is planned for the FuN project. Technologies and methods of software-/ hardware-in-the-loop, rapid-control-prototyping and new methods for test bench automation are combined. The goal is a software environment that offers a consistent tool chain from model generation to real-time software and measurement data processing. With this systematic approach, the simulation models of early development phases of the running gear development are used for the preparation of later phases. The software established for the real installation bench can be used and tested more flexibly and extensively with the simulation models of early design phases.

The automation technology of the Next Generation Train - High Speed Train (NGT HST) running gear consists of a rapid-control-prototyping control unit (RCP) that executes the real-time applications on a computer unit with four CPU cores. One core is used for the operating system and the others for real-time applications or Functional Mockup Units (FMU) based real-time simulations. The measurement amplifiers are separate from the computing unit and are connected with digital real-time interfaces. Thus, the measurement amplifiers can be used flexibly by the RCP system manufacturer or by specialized measurement technology suppliers.

During the design phase, the running gear is modelled in the Simpack multi-body simulation and later in Modelica/Dymola with the DLR RailwayDynamics library. In addition to the physics simulation, these models contain the control algorithm. In recent years, the running gear concept and basic properties were determined. The lateral controller or observer uses algebraic models, which are implemented in MATLAB or Dymola/Modelica.

In several development steps, the algorithms and controllers distributed in the multi-body simulation are integrated in a signal-based application software. The proposed software-in-the-loop simulation includes multi-body simulation, a sensor simulation and application software in a non-real-time environment. During a transformation process these parts are transferred to the real-time rapid-control-prototyping system. The application software is executed in real-time and the corresponding installation bench simulation into an FMU is simulated in parallel.

3 Results

The first step of the proposed software structure the goal is to separate the physics simulation from the rest of the software. The multi-body simulation only simulates the physical behavior of the mechanical components. A signal-based simulation executes the application software and a logical layer transforms the physical states to electrical channels and further to software input/output signals. In additional sensor models, physical and technical disturbances such as measurement noise and faults (e.g. cable breaks) can be integrated.

A division of tasks is carried out within the application software and separate subsystems are defined for each task. There are structured data types between the subsystems that map the structure of the installed peripheral channels and sensors/actuators. The input functionality is divided into a hardware input and a (sensor) input subsystem. The hardware input subsystem concentrates the driver software and reads all external signals. The (sensor) input subsystem calculates the physical states from measured electrical signals. Various application software e.g. testing software and emergency stop procedure are concentrated as subsystems and can be activated. Like the input subsystem, there is an output subsystem that generates the necessary electrical signals from the control signals of the active application software and outputs them via hardware drivers. The hardware drivers are not available in the simulation. Thus, the input and output subsystems are directly connected to the sensor/actuator models in the interface layer.

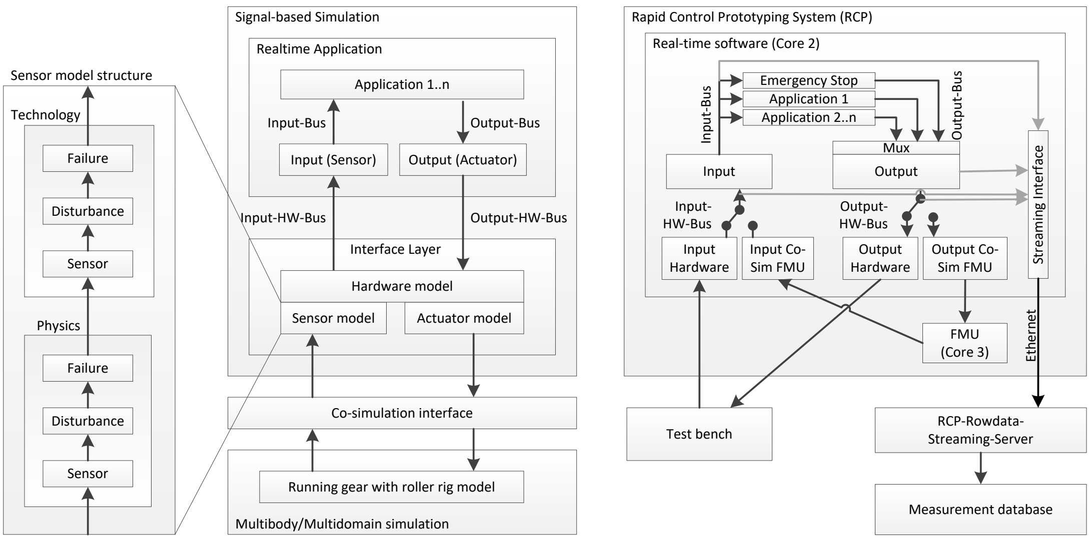

Figure 2: Software architecture of the non-real-time software-in-the-loop system (left) and the rapid-control-prototyping system (right).

The derived software-in-the-loop system structure with co-simulation is displayed in Figure 2 (left). The innovative sensor model structure is shown on the left side. In a further step, the presented software-in-the-loop system is integrated into rapid-control-prototyping system which is displayed in Figure 2 (right). The application software is executed in hard real-time and contains interfaces to the peripheral amplifiers or the system simulation. The real-time model of the installation bench with running gear is integrated as an FMU and simulated on a separate core of the RCP system.

The application software already contains the interface for the measurement data storage. In this way, pseudo-measurement data can already be obtained to develop post-processing software. If the installation bench is available, the co-simulation interface is replaced by the hardware input and output subsystems and the real-time simulation is no longer required.

4 Conclusions and Contributions

This work presents an innovative method and tool chain to develop application software for the automation of a mechatronic running gear (prototype). It supports the practical development of application software for the running gear and the roller rig installation bench. The software-in-the-loop environment couples the existing multi-body simulations for the development process with signal-based simulation software using a co-simulation interface. This gives the multi-body models a new task and extends their usage. The advantage for the simulation environment is that modelers and software engineers can work well together and that the modelled system behavior is based on detailed and tested models.

The resulting software-in-the-loop simulation environment contains a novel interface layer that translates the mechanical states of the multi-body simulation to pseudo-electrical signals that are read or written by the application software.

The sensor models contain a new type of model structure that separates between physical and technical properties as well as ideal functionality, disturbance and errors. This supports reusability, well-defined modeling and a more universal applicability of sensor models.

The real-time software contains a defined model structure of input, processing, and output submodels, which is based on signal flow and distinct assignment of tasks. The modeler is given a well-defined framework for new or further development of the real-time software. This is a methodological innovation to other evolution-oriented development approaches.

The measurement data storage and subsequent processing of the measurement data are already supported by the software-in-the-loop environment. Consistent pseudo-measurement data are already available for the development of partially automated recording and processing which supports the commissioning process and troubleshooting.

The development methodology maps a defined transition of the software-in-the-loop environment from a non-real-time software environment to a real-time environment. The application software can be developed and tested with realistic input and output behavior via the interface layer using real-time simulation.

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