

Automated model generation for full-vehicle simulation of mobile machines

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Abstract

This paper describes the most recent improvements made to Liebherr's full-vehicle simulation process applied in wheel loader development. By now, an existing model could be put through test scenarios and maneuvers automatically to efficiently quantify and visualize the vehicle's global dynamic behavior. Since this solution shall be used in all future wheel loader development projects, the creation of the models itself and all related tasks needed to be automated as well to close the gap between the existence of 3D CAD data of the machines and the quantification of the virtual vehicles' dynamic behavior. To address this challenge, two new tools have been established, handling the automated STL export of 3D CAD data, the creation of the model structure and the import of the 3D data in SimulationX, as well as the parameterization from a centralized database. With this solution, the last remaining bottle neck regarding simulation efficiency has been eliminated.

Kurzfassung

Dieses Paper beschreibt den aktuellen Fortschritt des automatisierten Simulationsprozesses, welcher in der Liebherr Radladerentwicklung zum Einsatz kommt. Mit der bisherigen Toolkette war es möglich, ein existierendes Gesamtfahrzeugmodell eines Radladers automatisiert verschiedenen Testszenarien und Fahrmanövern auszusetzen, um sehr zeiteffizient dessen dynamisches Fahrzeugverhalten zu quantifizieren. Da dieser Prozess künftig alle Fahrzeugentwicklungen begleiten soll, mussten die Modellerstellung selbst sowie alle zugehörigen Aufgaben ebenfalls automatisiert werden. So konnte die Lücke zwischen der Existenz von 3D-CAD-Daten und der Quantifizierung des dynamischen Fahrzeugverhaltens der virtuellen Prototypen geschlossen werden. Um diese Aufgabe zu lösen, wurden zwei neuen Tools geschaffen, die die Aufgaben STL-Datenexport aus der CAD-Umgebung, Erstellung der Modellstrukturen und Import der 3D-Daten in SimulationX, sowie Datenbank-basierte Modellparametrierung übernehmen. Mittels dieser Lösung wurde der letzte Flaschenhals bezüglich Simulationseffizienz beseitigt.

Motivation

The development of mobile machines is characterized by typically large and diverse product portfolios with increasing complexity handled by small development teams. Especially in the wheel loader business a great number of different subsystem variants like steering systems, axle oscillation concepts, seat, cabin and other suspension systems or lifting kinematics are on the market today. In addition, the machines are equipped with a large number of

different options, implements and tires, depending on the application, all of which having a large influence on the dynamics of the vehicles.

To be able to efficiently quantify the effects of subsystem concept decisions or parameter changes on full-vehicle global dynamic behavior - namely vibration comfort, vehicle dynamics and tipping safety - and allow for holistic tuning, Liebherr recently introduced a maneuver-based simulation process. Starting with a validated full-vehicle SimulationX model of a wheel loader running in co-simulation with cosin scientific software's FTire tire model, developers can easily modify arbitrary parameters, swap subsystems or introduce new concepts and automatically quantify the effects on the vehicle's behavior. This is realized by driving the virtual prototype through predefined driving maneuvers, each providing insight into a specific area of the global dynamic behavior. The simulation results of the maneuvers are automatically combined, processed and visualized to allow for easy interpretation and comparison to the reference vehicle's behavior.

During the process development and validation project, one of the wheel loaders in Liebherr's portfolio has been modelled in SimulationX and validated against extensive measurements done with a corresponding machine.

For more details on this process and the associated tool chain see [1]. The basic development and optimization process using this tool is depicted in Figure 1.

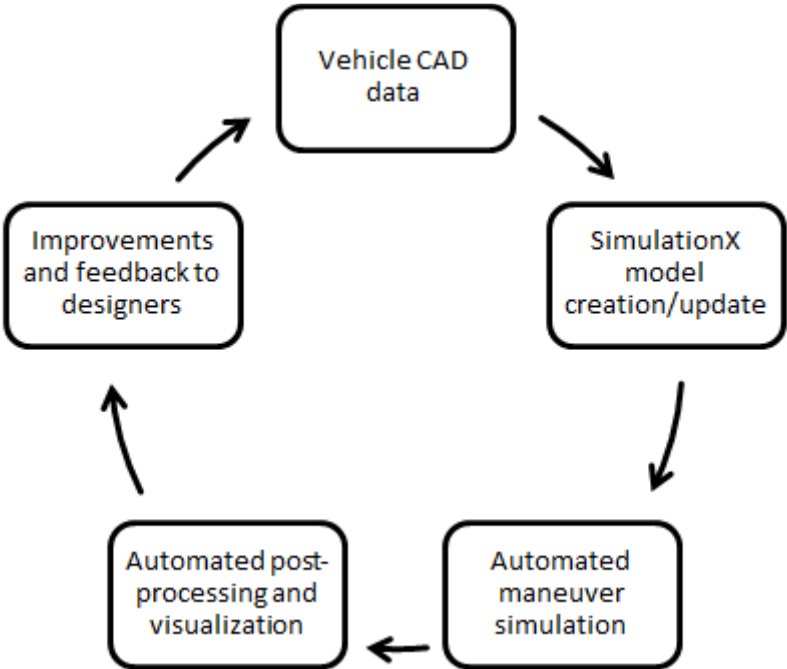


Figure 1: Optimization process using the automated, maneuver-based simulation

In a new vehicle development process, the user's first task is to export all CAD components of the machine to be able to manually create the SimulationX model. In addition, all necessary parameters have to be gathered to parameterize the full-vehicle model, which is then automatically run through all the different driving maneuvers. The results from these

simulations will in turn be used to improve the vehicle 3D design and component parameters and the process starts over.

Since the maneuver based simulation process is supposed to support all future vehicle development projects not only in the concept phase, but also as a continuous validation tool during the CAD design phase, one can clearly identify the bottle neck of the described approach. While the maneuver simulation and the postprocessing and validation today are highly automated and therefore very efficient, the initial model creation and parameterization as well as the model maintenance are still manual tasks. In the CAD design phase, where the vehicle CAD data is bound to change on a daily basis, continuous validation requires a periodic update of all STL files in the model.

Solution - Automated model creation

Consequently, the manual steps of exporting the 3D data from the CAD tool, creating the model structure in SimulationX and importing the 3D data, as well as the parameterization have been automated in a follow-up project. The resulting process is shown in Figure 2.

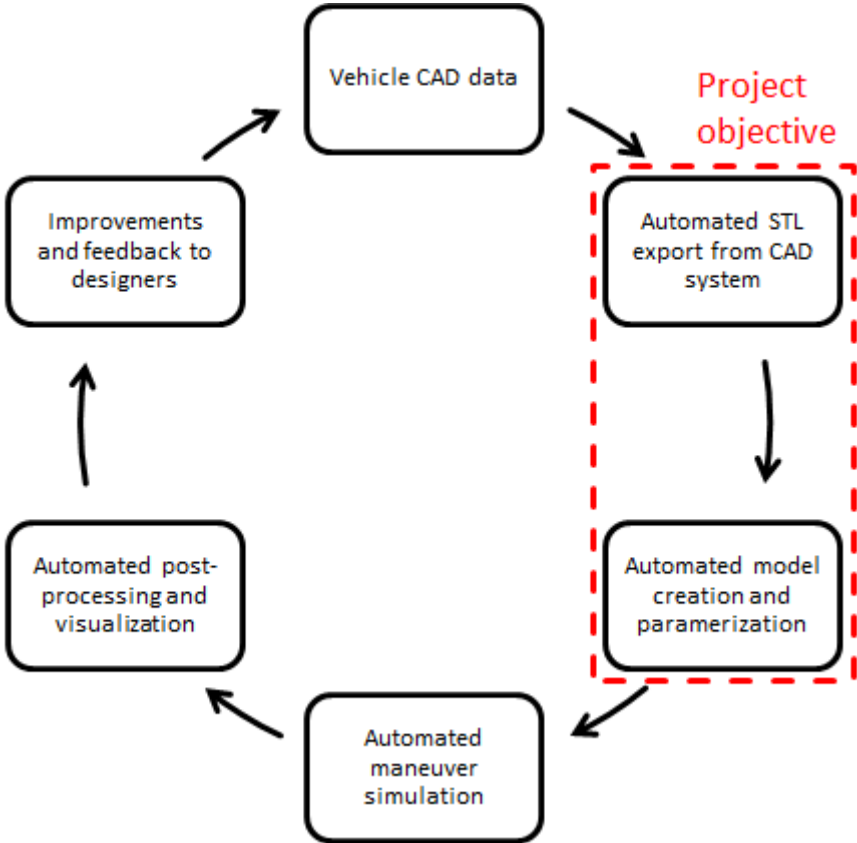


Figure 2: Updated optimization process using automated model creation

Two new tools have been developed to be able to automate all necessary steps and to remove the remaining bottle neck.

The first tool - designed in Microsoft's Visual Studio - is employed to automatically export all desired 3D components from the full vehicle CAD assembly to the STL file format compatible

with SimulationX. The user has to define the desired components and subassemblies and their respective coordinate systems once for each vehicle type. The option to combine multiple CAD components into one STL file is provided to be able to reduce the number of “CAD import” components in the SimulationX model schematic if desired. The tool will then analyze the CAD model tree, find the desired components and conduct the export. To simplify the following import and positioning of the components in SimulationX, it is possible to export each STL files with respect to a global vehicle coordinate system.

Especially during the CAD design phase and continuous validation in any development process, this tool dramatically reduces the manual effort of updating the corresponding SimulationX vehicle models, since the ever changing CAD data can be periodically exported after the initial definition without user interaction.

The second tool - a Mathworks Matlab script including a graphical user interface (GUI) - is used to create and parameterize the SimulationX wheel loader models. As stated in the beginning, today's vehicles are comprised of several different variants of vehicle subsystems, resulting not only in a specific parameter set, but also a different model structure for each machine. To be able to create models of all wheel loaders in Liebherr's current and future portfolio with minimal manual effort, an existing simulation model has been modularized and for each module a number of variants have been modelled. By combining these pre-defined module variants, every desired vehicle model structure can be realized.

The user has to configure the desired vehicle in the Matlab GUI (Figure 3), hit the “Create Model” button and all further steps will be done automatically by the routine.

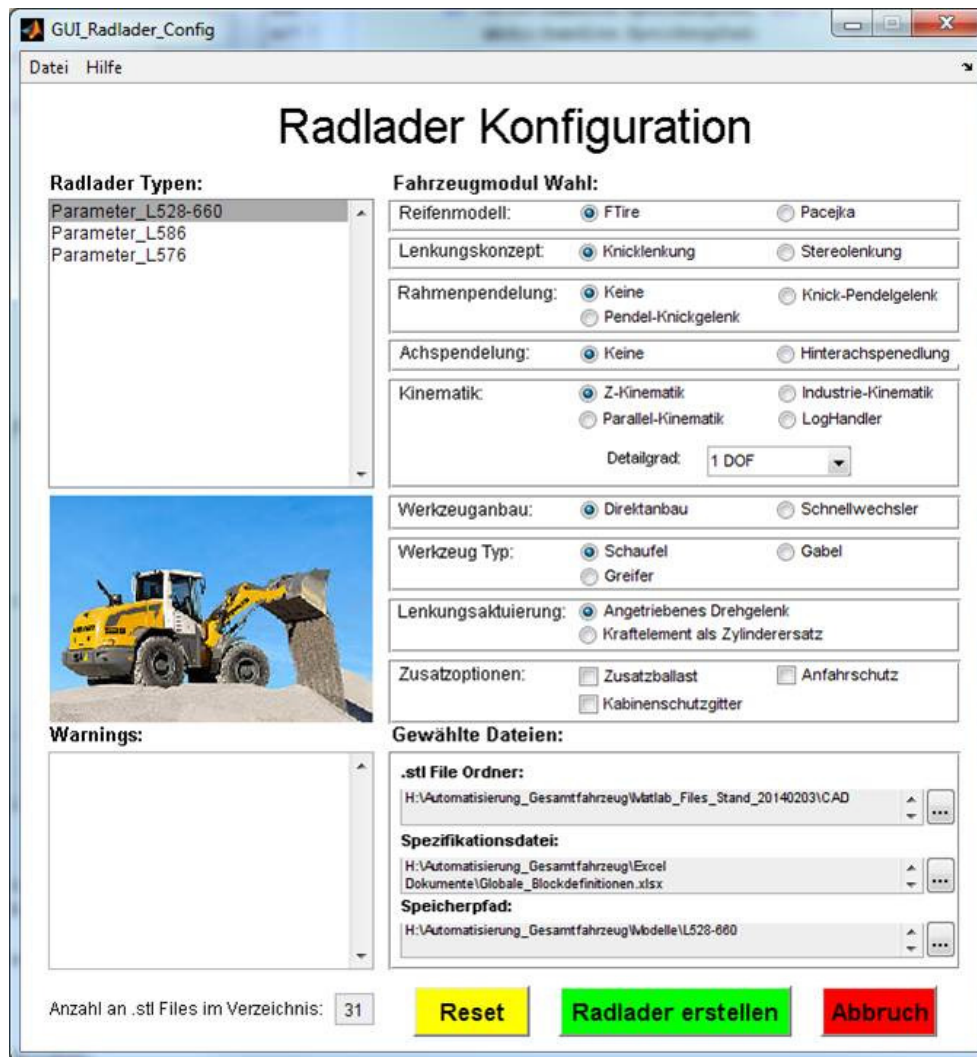


Figure 3: Model creation GUI

At a first glance, the use of compounds comprising the different vehicle subsystem modules seems adequate. To switch between different subsystem variants, a single compound would have to be replaced by another one having the same interfaces to the remaining full-vehicle model and the code for automatically placing these compounds into the schematic could be kept rather simple. In case of the Liebherr full-vehicle wheel loader models, this approach has proven to be unsuitable, as the users regularly needed to cross the compound boundaries and establish new interfaces between the subsystems while performing concept studies. To provide the required level of flexibility when working with the models, it was therefore decided to only employ one single modelling layer and discard the idea of using compounds.

The modularization yielded ten vehicle modules including the standard module which comprises the basic components that are part of every vehicle model. With a resulting total of thirty variants of the remaining nine variable modules, thousands of different model structures can be created to be able to describe every thinkable and unthinkable machine concept. In addition, the whole process provides enough flexibility to add additional subsystem variants with minimum coding effort.

To efficiently acquire the code for modelling a certain subsystem variant, the SimulationX macro recorder is used. After manually modelling the subsystem in question, the macro output script - using the ITI script syntax - is not yet usable, since Matlab code is needed. Therefore, the differences in the syntaxes have been identified and a VBA script has been written to automatically convert one syntax into the other. With this solution, the user can employ standard SimulationX modelling techniques and still acquire the necessary code for the automation with minimum coding effort.

To realize the automated model creation and parameterization, SimulationX’s COM interface is employed. Using this interface, most of the manual steps that the user normally does with mouse and keyboard while working with SimulationX can alternatively be triggered by external routines - in this case Matlab code. These steps include placing library components onto the model schematic, drawing connections and setting component and simulation parameters. To instantly provide compatibility of the models to the maneuver-based simulation process and the automated post-processing routines, even tasks like the activation of all necessary component result variables are automatically handled via the COM interface.

There is no tool to automatically update an existing model with new CAD data or parameters. Instead, a new model will be created with the most recent data sets every time. Figure 4 depicts the basic steps during the automated model creation.

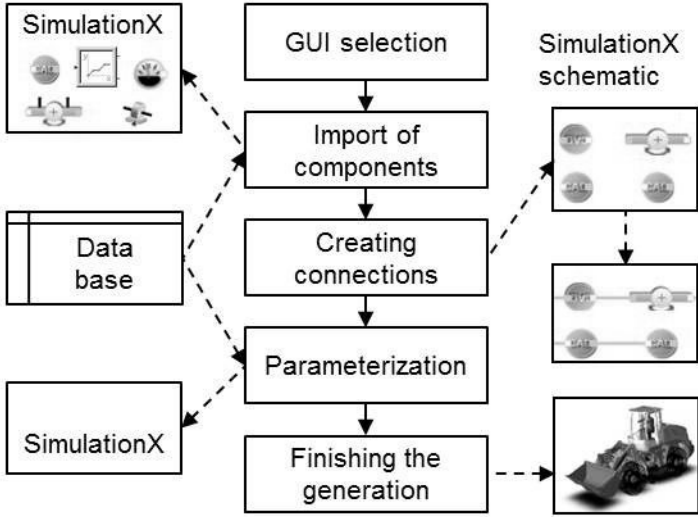


Figure 4: Basic steps of the automated model creation [2]

In this process, Microsoft Excel is used as a simple database. Not only does it store all the modelling information of the different subsystem variants, it is also used to centrally define the SimulationX model parameters for all wheel loaders. In addition, the same database is used to define the related 3D CAD parts for each vehicle to provide information for the CAD export tool.

Summary

The described tool chain enables Liebherr's wheel loader development engineers to efficiently create models of any machine already existing or under development in a very short time frame. Combined with the already existing tools for automated maneuver simulation and quantification of the vehicle's global dynamic behavior, simulation can be used to support many development projects with minimum lead time, namely during concept phases as well as in a continuous validation workflow during the design phases. For initial concept studies in the beginning of a new development project, a modified vehicle model of the wheel loaders predecessor will be used until the first set of CAD data is available.

References

- [1] Manuel Bös - Virtual process chain for the optimization of operator comfort and vehicle dynamics of wheel loaders - 16th ITI Symposium, Dresden, 2013
- [2] Christoph Rettenwender - Automated creation of modular wheel loader models for full-vehicle multibody simulation, Master Thesis, Management Center Innsbruck, 2014