Extended Abstract: Integration of Compliant Robot Systems into Real-Time Virtual Commissioning Simulations

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Abstract - Virtual commissioning (VC) allows the early detection of errors in the control system and optimisation of control strategies using a digital twin of the machine hardware. This contribution implements algorithms for computing compliant systems in a VC tool. This enables the utilisation of the advantages of VC for the development of control systems for compliant robots. For this purpose, two dynamic algorithms are implemented modularly in an industrially used VC tool. The developed models of compliant behaviour are verified against a reference model. The low complexity and high modularity of the solution allows for the simulation of the dynamic behaviour of a compliant robot in a real-time hardware-in-the-loop simulation. Finally, potential enhancements for improving simulation accuracy and efficiency are shown.

Index Terms – Virtual commissioning, Simulation, Real time capability, Hardware-in-the-loop simulation, Compliant Multibody System

MOTIVATION AND CONTEXT

Virtual commissioning (VC) is a method for testing control systems before the physical implementation using a simulation model [1]. Realised as a hardware-in-the-loop simulation (HIL) the real control hardware is connected to a simulation model using the real fieldbus as communication periphery (FIGURE 1). With such a HIL setup, the simulation displays the actual behaviour of the real control hardware. Thus, VC can be used to improve the development process. It is suitable for testing the control system, identifying software errors and testing critical operating states before real commissioning [2, 3]. In the case of robot systems, critical states are usually a collision or contact situations. Due to the increasing automation of production systems, the use of compliant robots also increases. They offer advantages in force-sensitive applications, such as human-robot collaboration and precision assembly [4]. However, their dynamic behaviour differs significantly from traditional rigid robots, necessitating specialized simulation techniques [4]. Conventional VC environments primarily focus on motion execution and collision detection for classical rigid robots [5], lacking calculation algorithms for dynamic behaviour. Therefore, the aim of the presented work is to extend a VC tool with real-time capable model elements for the calculation of compliant multi-body systems such as compliant robots.

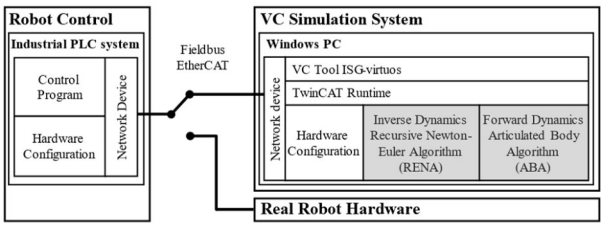

FIGURE 1. STRUCTURE OF THE HIL SIMULATION

METHODOLOGY

The first step is to select suitable algorithms for the calculation of the compliant multi-body system. Afterwards they are integrated into the VC tool ISG-virtuos using its C++ interface. The next step is the verification of the solution by comparing the VC simulation results with a reference model in the simulation tool SimulationX. The last step is the evaluation of the performance of the extended VC model during a hardware-in-the-loop (HIL) simulation to evaluate the real-time execution performance for industrial applications.

IMPLEMENTATION

The requirements for the solution were a high degree of modularity for versatile use with different systems and a low computing effort to maintain real-time capability. To this end, various solution approaches were analysed, implemented and tested step by step. The recursive Newton-Euler algorithm (RNEA) is implemented to

describe inverse dynamics. This is used to calculate the joint force and torque from the current joint position and speed. The RNEA is executed in two recursions. The first recursion is from the base to the end effector and the second recursion is from the end effector back to the base [6]. The Articulated Body Algorithm (ABA) is selected for the calculation of direct dynamics. With this, the joint acceleration is calculated from the joint position, joint speed and the applied force and torque. This algorithm works with three recursions [7].

The two recursive dynamic algorithms were implemented in such a way that a modular structure of different kinematic chain structures from several such model elements is possible. Within the model element the modelling of rotary and prismatic joints were implemented. However, more complex joints, such as ball joints or cylindrical joints, can be investigated by combining rotary and prismatic joints. Additional degrees of freedom and stiffnesses, such as bearing tilting stiffnesses, can also be mapped thanks to the modular design.

The Implementation took place in two possible solutions. A one-block solution and a separated solution. With the one-block solution slight calculation deviations occurred due to the execution sequence of the ISG-virtuos. Therefore, the forward recursion terms and the backward recursion terms are executed block wise instead of executing the forward recursion of all blocks and then the backward recursion of the blocks. This problem is solved by implementing the individual recursion steps of the dynamic algorithms in a separated solution. However, the one-block solution results in a shorter computing time due to its lower complexity.

Verification and Results

The accuracy of the implemented model elements is verified by comparing the VC simulation results with those of a SimulationX reference model. As example a 6-axis robot trajectory is used. The verification confirms the accuracy of the developed models, demonstrating minimal deviation from the reference simulation. (FIGURE 2)

Also, the solution meets all requirements in terms of high modularity since the model elements can be used to model different kinematic chains.

Finally, the real-time capability of the solution is tested and approved. The HIL simulation is running stable without errors or protocol losses until the use of more than 36 compliant joints as model elements in the VC model. It is noticeable that the one-block solution still runs stable when using twice the numbers of model elements compared to the separated solution. Showing that this approach is more suitable for HIL simulations as it requires less computing power. Of course, limitations in real-time capability are also dependent on the simulation hardware used. The performance tests in HIL environments proofed the real-time capability of the approach.

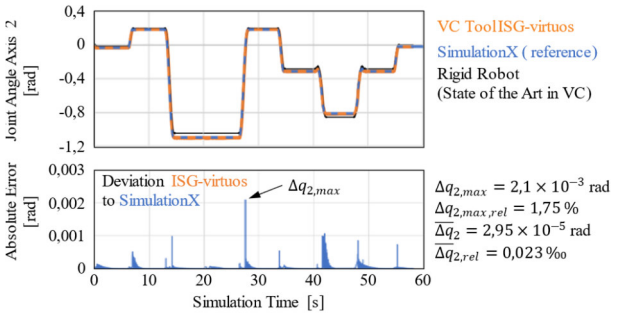

FIGURE 2. EXEMPLARY SIMULATION RESULTS OF AXIS 2 OF A COMPLIANT 6-AXIS ROBOT.

Conclusion and Future Work

This work successfully extends the VC tool ISG-virtuos to perform real-time capable compliant robot simulations. This allows to utilise the advantages of VC for the development of compliant robots, such as more reliable pre-deployment testing, reducing deployment risks and improving control strategy development. It is also a significant improvement in functionality for VC regarding compliant systems.

Future research work will analyse the application area and the permissible parameter range of the implementation. In addition, an implementation of contact behaviour as comparable and compatible module will be pursued.

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