FORMULATION AND EXPERIMENTAL VALIDATION OF COMPUTATIONALLY EFFICIENT METHODS FOR MODELING OF HYBRID – RIGID-FLEXIBLE MULTIBODY SYSTEMS WITH REDUNDANT CONSTRAINTS

Multibody systems, i.e., mechanical systems having a large number of bodies and degrees of freedom, are commonly used in many areas of modern engineering. There is a need for automatic modeling and investigation of such complex systems for analysis, design, and optimization purposes. Multibody simulation models can be found in diverse areas such as robotics (dynamics of manipulators), automotive (testing of car components and complete vehicles), railroad (e.g., traffic safety), defense (e.g., design of tracked vehicles), etc. The multibody models are also used in control systems of compound mechanical systems, e.g., in robotics, to predict such systems' behavior and thus enable achieving the desired response.

A simulation model is always a compromise between several objectives; most often, a balance between the accuracy or fidelity of the model and its computational efficiency must be found. This compromise takes into account a lot of factors, e.g., availability of the data, the workload needed to build a model, computing capabilities, or the modeling goals. The analysis and simulation of large-scale multibody systems require significant numerical expenses. Simultaneous enforcement of computational efficiency and requirement for high-fidelity physical models is difficult to obtain.

The system's bodies are often assumed to be rigid (non-deformable) to obtain highly efficient modeling methods. It is a significant simplification of the system physics; nevertheless, multi-rigid-body models can capture essential features of the investigated systems with satisfactory accuracy. There is, however, a broad class of mechanical systems for which the models that assume the rigidity of all the bodies provide erroneous solutions. These are the systems with redundant constraints (in which the same degrees of freedom are restrained several times). The redundancy of constraints results in the non-uniqueness of calculated joint reaction forces, which may also lead to the non-uniqueness of the simulated motion, making the model utterly useless.

Surprisingly often, problems associated with the redundancy of constraints are ignored in multi-rigid-body simulations–results not embedded in the physics of the system are found. On the other hand, currently available high-fidelity multi-flexible-body models that provide unique and physics-embedded solutions exploit the finite element method and are computationally demanding, making dynamic simulations inefficient. **The project takes up the challenge of developing general-purpose hybrid (rigid-flexible) modeling methods that will enable reliable simulation of redundantly constrained systems while maintaining high computing efficiency.**

The first research objective concerns the development of algorithms enabling hybrid (rigid-compliant) modeling of multibody systems. For this purpose, different methods for modeling the bodies' flexibility will be compared in the project's initial phase. Then the most effective methods will be used in the proposed hybrid algorithms. As a result, simulations using an approximate model that still corresponds to physics will be computationally efficient.

The second research objective focuses on proposing and exploiting benchmark problems tailored to highlight issues crucial for modeling overconstrained multibody systems. These benchmarks will be used for extensive testing of newly developed modeling methods. The fidelity and accuracy of the obtained results will be assessed. Then, various numerical properties, e.g., computation time or stability, will be examined.

Theoretical considerations will be verified and supplemented by experimental research conducted. Within the scope of the third research objective, a laboratory stand for testing overconstrained multibody systems will be designed and manufactured. It will be used for experimental validation of the proposed modeling methods and verification of the simulation results. Note that, so far, results of empirical tests focused on problems specific to overconstrained MBS are not readily available in the scientific literature.

The project will result in the development of new numerical tools that will be ready to be implemented in multibody simulation software and will allow conducting automated analyses. The project outcomes will constitute a constructive solution to redundancy-related problems. It will be possible to find—with acceptable accuracy—physics-embedded results of simulations. Moreover, high computational efficiency will be maintained. The project results will enhance presently available methods.