Flexible Bodies in Symbolic Multibody Systems with Neweul-M^2

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1. Introduction

For the simulation of rigid or flexible multibody systems most commercial programs use solely numerical algorithms. They provide simple modeling and fast simulations of the systems under consideration. However for various applications like optimization, control design or real time implementations symbolical expressions are advantageous. The software package Neweul-M² for the symbolic modeling and simulation of rigid and elastic multibody systems in Matlab is presented and the current state of development is shown.

2. Neweul-M²: A Research Software

The symbolical formalism Neweul-M² is a research software for the modeling, analysis and simulation of multibody systems. It is based on the Newton-Euler Equations and the principles of d'Alembert and Jourdain, see [2] and [3], to generate the equations of motion in minimal form for open-loop systems, and differential algebraic equations for systems with closed kinematic loops. It is implemented in Matlab calling Maple or MuPad through the Symbolic Math Toolbox for the symbolic manipulations. The system description is stored in a data structure containing all kinematic values and other necessary symbolic expressions. For the numerical evaluation, files in the Matlab language are written automatically, which then can also be used for other applications. The equations of motion, e.g., can be solved by any integration code for ordinary or differential algebraic equations, respectively. As all expressions are available symbolically, they can easily be exported to another programming language. From the expressions, e.g. Simulink S-functions in C can be created automatically.

Most commercial programs use solely numerical algorithms for the modeling and simulation of multibody systems. Then the modeling can be based on catalogues, e.g. of constraints or force elements, and a time integration is easily possible even for complex systems. However, it is advantageous for many applications to obtain a symbolical formulation, which shall be discussed in the following. When a system is modeled symbolically, the describing kinematic values like velocity and acceleration, as well as the equations of motion are expressed depending on user-defined variables. Those variables are read from the input data and used to obtain all necessary quantities. After the kinematic values and equations of motion have been derived only once, they can be used for fast numerical evaluations. Because the expressions are set up prior to the numerical simulations, those evaluations are very fast, allowing real-time applications. When performing a parameter optimization of nonlinear equations, the fast calculation of gradients with a high accuracy is crucial. The symbolic system formulation can be used in the calculation of these gradients in analytical or semi-analytical formalisms, depending on the optimization criteria. When the criterion function depends on a numerical time integration of the equations of motion, these semi-analytical gradients reach an accuracy in the same order of error as the time integration involved, and can be obtained fully automatic. Also when a controller is to be designed, the symbolical expressions allow more possibilities and strategies than mere numerical algorithms, see [6]. The modeling of mechanical systems consisting of rigid bodies is pretty straight forward. When extending this to elastic bodies some issues arise, which shall be shortly discussed in the following.

3. Elastic multibody systems with Neweul-M²

For rigid bodies all necessary values can be easily described with symbolic expressions described in the inertial frame. Elastic bodies are modeled with the floating frame of reference approach, where a small, linear elastic deformation is combined with a large nonlinear motion, see [5]. To obtain the description of an elastic body, it is commonly modeled in a structural analysis software, e.g. Ansys, and exported to a standardized format to be imported into the multibody simulation program. For this purpose the Standard Input Data (SID) format is used here, see [5]. This format is a numerical description containing approximations of all necessary data in Taylor series expansions. Apart from simplicity another advantage is that for bodies described in this way effective model reduction techniques have been developed. The simplest way to reduce the degrees of freedom of such a model is the modal reduction, where the user selects mode shapes to be considered in the model. One big problem of the modal reduction is that the user has to choose the mode shapes manually based on intuition and experience. Especially inexperienced users are endangered to omit important degrees of freedom. However, highly sophisticated algorithms exist, ensuring an effective reduction with a high accuracy based on error estimates. These reduction techniques are fully automated so the user only has to provide the required accuracy and information about the simulations to be performed afterwards, like the frequency range under consideration, see [1]. A model reduction uses the existing description, based on given shape functions, e.g. eigenmodes or data of a FE model, to generate a new set of shape functions and stores them again in an SID-file. Then the software to simulate the multibody system, here Neweul-M², can read the SID-file as any other and benefit from all advantages of model reduction without any further difficulties. When a numerical model of an elastic body is introduced in the system from an SID-file, only the large, nonlinear motion of its frame of reference is described symbolically.

As mentioned above, a floating frame of reference is used for the description of the equations of motion for each respective elastic body, with some preferable choices. One possibility is to use a frame attached to one node of the body, providing a convenient description especially if this node is used for the support of the body. Then the calculated modes are well suited for the approximation of the body's deformation. However some expressions could be avoided by choosing the center of gravity as frame of reference. In fact this so called Buckens-frame provides the minimal possible coupling between the large nonlinear motion and the small elastic deformation. But commonly this formulation requires constraint equations to connect the body to others resulting in differential algebraic equations. As the relative vectors to all nodal frames are known, they can be used to treat every nodal frame as frame of reference as far as the system definition is concerned. Meaning one can simply define the position and orientation of any node of the body, from which the system can calculate all necessary expressions, which are still set up in the actual frame of reference of the body. This allows the equations of motion to remain ordinary differential equations for systems with tree structure no matter which of the two types of frame of reference are used.

By introducing the numerical approximation of the behavior of elastic bodies into the symbolic framework of Neweul-M² many of the advantages of the symbolic formulation can be preserved. However an optimization of the elastic bodies would require the structural analysis software to be included in the optimization loop or any other way of manipulating the model of the elastic body, qualifying this task as a future point of interest in our work. Another interesting subject is the treatment of closed kinematic loops. Closed kinematic loops are currently handled by introducing constraint equations, changing the equations of motion from ordinary to differential algebraic equations, as the generalized coordinates are no longer independent. For certain types of systems, it is possible to use the symbolic expressions to reduce the number of differential equations to the minimal number of independent parameters, see [4] and [7]. Even as this is not possible for all systems, it offers improvements in calculation time and accuracy if possible.

4. References

[1] J. Fehr, P. Eberhard, "Improving the Simulation Process in Flexible Multibody Dynamics by Enhanced Model Order Reduction Techniques", *Multibody Dynamics – ECCOMAS Thematic Conferences*, Proceedings, Warsaw, 2009.

[2] K. Popp, W. Schiehlen, *Ground Vehicle Dynamics*, Springer, Berlin, 2010.

[3] W. Schiehlen, P. Eberhard, *Technische Dynamik [in German]*, B.G. Teubner, Wiesbaden, 2004.

[4] W. Schirm, *Symbolisch-numerische Behandlung von kinematischen Schleifen in Mehrkörpersystemen [in German]*, VDI Fortschritt-Berichte, Reihe 20, Nr. 20, VDI Verlag, Düsseldorf, 1993.

[5] R. Schwertassek, O. Wallrapp, *Dynamik flexibler Mehrkörpersysteme [in German]*, Friedr. Vieweg & Sohn, Braunschweig, 1999.

[6] R. Seifried, P. Eberhard, T. Kurz, "Simulation and control design of flexible multibody systems using Neweul-M²", *1st ESA Workshop on Multibody Dynamics for Space Applications*, Proceedings, Noordwijk, 2010.

[7] C. Woernle, *Ein systematisches Verfahren zur Aufstellung der geometrischen Schließbedingungen in kinematischen Schleifen mit Anwendung bei der Rückwärtstransformation [in German]*, VDI Fortschritt-Berichte, Reihe 18, Nr. 59, VDI Verlag, Düsseldorf, 1988.