Advances in Engineering Software 32 (2001) 769–777
www.elsevier.com/locate/advengsoft

Using an extensible object-oriented query language in multibody system analysis

Claes Tisell[a,*], Kjell Orsborn[b,1]

[a]Machine Elements, Department of Machine Design, Royal Institute of Technology, S-10044, Stockholm, Sweden
[b]Department of Civil and Environmental, Intelligent Engineering Systems Laboratory, Massachusetts Institute of Technology, Cambridge, USA

Received 10 January 2000; accepted 2 March 2001

Abstract

Since modern software tools produce large amounts of engineering data, the demand for efficient data management may be met by integrating database technology with engineering applications. This approach is taken in MECHAMOS, which is a previously reported system for symbolic and numeric multibody system (MBS) analysis. This work focuses on the high level analysis performed with the available query language in MECHAMOS. The data management is considerably improved in this system compared to a traditional MBS analysis tool. For instance, MECHAMOS can easily combine and compare MBS data not only within the same MBS model but also over several MBS models, each governing different equations of motion. To avoid redundant computations in such analyses a simplified materialisation mechanism is implemented. Examples are given of combining and comparing both symbolic and numeric MBS data

Keywords: Multibody system; Kane's equations of motion; Object-Oriented; Database; DBMS; Extensible Query Language; Dynamic systems

1. Introduction

The rapid development of computer technology and software tools has enabled engineers to build larger models and to perform more advanced analyses on these models. This generates large amounts of heterogeneous engineering data. Therefore sharing and combining this heterogeneous data as well as transforming it to a suitable form for further analysis have become important issues in the design process today. To meet these demands, full availability of data and efficient data access are important. One way to accomplish this is to access data through a query language, which is faster and requires less coding than using a conventional programming language [1]. This will add to the requirements on future generation engineering applications to supply database technology and a general query language for data management.

In the field of multibody system (MBS) analysis, the development of computer technology has also opened up the possibility to perform the analysis in the symbolic domain and then move on to the numerical domain in a later stage of the analysis. A previously reported system for MBS analysis, based on object-relational database technology [2], shows how the availability of MBS data is increased and the data management facilitated to meet future requirements. In this system, named MECHAMOS, symbolic and numeric MBS data is fully available through a general query language and can be put into a suitable form for further analysis. A similar approach is taken in Ref. [3] where a system for finite element analysis (FEAMOS) is based on the same database technology as MECHAMOS.

This work focuses on the MBS analysis in MECHAMOS where large amounts of MBS data can be generated, compared and searched for by taking advantage of the data management capabilities and the extensible query language integrated into the application.

2. The MECHAMOS system

MECHAMOS is an MBS analysis tool based on the object-relational database management system (ORDBMS) AMOS II [4–6]. This provides MECHAMOS with a general object oriented and extensible query language (QL) for accessing the MBS data. In MECHAMOS the mathematical capabilities of AMOS II have been extended with Matlab [7] and MapleV [8] enabling the system to perform both numerical and symbolical MBS analysis. MBS data is

* Corresponding author.
1 Currently on leave from The Engineering Databases and Systems Laboratory at The Department of Computer and Information Science, Linköping University, Linköping, Sweden.

0965-9978/01/$ - see front matter
PII: S0965-9978(01)00028-X

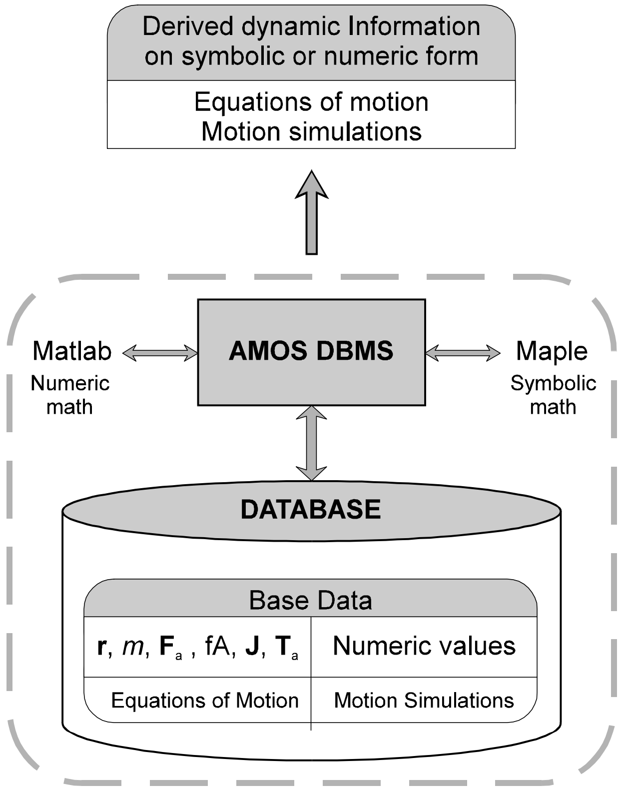

Fig. 1. The MECHAMOS systems selects dynamic information derived from base data through a general QL.

passed from the query language to Matlab and Maple through a general application-programming interface using LISP, C and Java and is thus not based on file transfer. However, some MBS results are stored on file due to limitations in the architecture of Matlab and Maple. In Fig. 1 the MECHAMOS system is illustrated with base data and the extended mathematical capabilities through Matlab and MapleV.

The MBS analysis, based on Kane's equations, aim for a minimal set of constraint reaction free equations of motion in a minimal set of generalised coordinates. To obtain these equations, MECHAMOS utilises the SOPHIA system [9,10], which is a set of routines, implemented in MapleV for vector algebra and vector analysis including routines supporting Kane's equations. This provides MECHAMOS with an efficient tool for formulating the equations of motion on symbolic form, and the resulting equations are suitable transformed for efficient numeric evaluation.

The MBS data is divided into MBS concepts in a basic form called *base data* and is stored in the database. Further, the database also contains MBS concepts derived from these base data. The former can be further divided into data on component level and data on system level. On the component level six quantities have to be stored for each rigid body in the mechanism

$$m\ \mathbf{r}\ \mathbf{F}_a\ \mathbf{J}_A\ fA\ \mathbf{M}_a \quad (1)$$

where the first three items represent the translational part and are the *mass*, *position vector* of the centre of mass and the applied *force vector*. The representations of the rotational part are the *moments of inertia* dyad, a body fixed *reference frame* and the applied *moment vector*. On system level the *generalised coordinates* (q), *generalised speeds* (u) and their relations (kinematic differential equations, kde) has to be declared. Further, the gravity vector and reference frames are also defined on system level. To enable numerical analysis and simulations, different sets of numerical values of the parameters and initial values are also defined.

3. Data retrieval and materialisation

With a system based on this technology large amounts of MBS data (velocities, momentum, potential and kinetic energies, trajectories, etc.) can be easily and automatically generated through the QL. This MBS data can be retrieved in many different forms. A *scalar* quantity is of course represented in scalar form whereas a *vector* quantity is either a vector representation in a given reference frame or a scalar representing the magnitude of the vector. In the combined *symbolic* and *numeric* domains, MBS data can be retrieved in pure symbolic form or with the numeric values of the parameters substituted, thus maintaining the state variables and their derivatives in symbolic form. Selecting scalars and vectors on pure numeric form requires a numeric solution of the equations of motion (commonly referred to as a simulation). The retrieved object is then a numeric sequence with one value for each time step of the integration.

Different forms of MBS data require various computational efforts. For instance, to obtain the velocity vector in symbolic form for a given body B in a given MBS model the necessary sequence of operations is:

$B11$ declares time dependent coordinates (q and u);
$B12$ declares the kinematic differential equations;
$B13$ declares relations between reference frames;
$B14$ differentiates the position vector with respect to time and relative to the inertial frame.

For MBS models with reasonable degrees of freedom, these symbolic computations ($B1x$) are usually simple and fast to execute. To select the same velocity vector in pure numerical form, a simulation has to be performed for a given set of parameter values and a given set of initial conditions. The necessary sequence of operations for the numerical case ($B2x$) is shown below where each of the $B21$ and $B22$ operations usually involves costly computations:

$B21$ derives the equations of motion for the MBS model on symbolic form;
$B22$ solves these equations numerically to obtain numeric values for the state space variables (q and u);