High Performance Computing for Optimum Design of Multi-body Systems

José M. Jiménez¹, Nassouh A. Chehayeb¹, Javier G. Izaguirre¹, Beidi Hamma², and Yan Thiaudière²

¹ Computational Mechanics Applications, S.L., Miracruz, 10B, 1,
20001 San Sebastian, Spain

{jmjimenez, nchehayeb, jgizaguirre}@cmech.com

² CERFACS, 42, Av. G. Coriolis, Toulouse, France
hamma@cerfacs.fr

<http://www.cerfacs.fr/algor/ODESIM/home.html>

Abstract. This paper presents the most relevant results of ODESIM project, a High Performance Computing and Networking project funded by the European Commission within ESPRIT programme. The project acronym stands for *Optimum DESIgn of Multi-body systems*. The project main objective has been the development of a set of software tools for the kinematic and dynamic optimum design of multi-body systems. Several types of design procedures are targeted: interactive design, designer-driven optimization and fully automatic optimization. ODESIM has been implemented using high performance computing and networking techniques (HPCN) to perform parallel computations in the most CPU-intensive optimization problems. Results on the solution of practical problems are presented.

1 Introduction

Current multi-body system (MBS) simulation programs have powerful analysis capabilities that allow them to simulate complex mechanical systems with rigid and flexible bodies subject to different kinds of external forces, control laws, non-linear effects, etc. However, in the design process, the designer must perform kinematic and/or dynamic analysis in each design step, assess the performance of the system, and take a decision on what dimensions should be modified to improve the behavior of the MBS. This iterative process has two main drawbacks. First, it relies heavily on the designer's experience and thus can only be done by experts; and second, it is very time consuming since the designer has to repeat the assessment of performance, the decision making and the dimensional modification in every iteration step.

In order to reduce the time required for a new design and consequently shorten the time to market, a different approach should be followed. In this new approach, the MBS design problem must be addressed from the CAD definition of parts (bodies and joints). In the CAD program, the designer creates a parametric model of each part, from which ODESIM software generates a parametric MBS model. This parametric model will later be optimized according to a goal function and the design constraints.

2 Optimum Design of MBS: The ODESIM Approach

Traditionally, MBS analysis codes consist of a separate pre-processor, a batch-oriented analysis engine and a post-processor. To make a change in the MBS design, the whole sequence of pre-processing, submitting the analysis job to the simulation module and post-processing the results must be repeated. In order to improve the convergence rate of this slow process, the MBS tools should be integrated within a CAD system, so as to generate and modify easily an MBS parametric model. In addition, modules for sensitivity calculation must be developed and integrated in the same tool, thus allowing the designer performing “*what if?*” studies interactively. Those studies consist in knowing how changes in the design variables affect the behavior of the MBS model. The use of optimization functions may also be very profitable, because may automatically lead to a design that satisfies the requirements.

Mathematical formulation of MBS kinematic and dynamic problems usually lead to small or medium size problems with just a few tens of degrees of freedom and a few hundreds of dependent co-ordinates. In spite of the small size, MBS problems present considerable specific difficulties. A description of the mathematical basis for MBS simulation and optimization can be found in [1]. In dynamic optimization of MBS, the goal function is computed as a result of a dynamic simulation that requires the numerical integration of the differential equations of motion. Very often, those equations are *stiff* and the numerical integration needs large CPU times. For this reason, and the fact that the gradient can be computed in parallel, MBS optimization is a problem especially suitable to be implemented in a HPCN environment.

The study of the user needs lead to consider three different levels in the use of the software, which are called *interactive loop* (or interactive simulation), *semi-automatic loop* (or manual optimization) and *fully automatic loop* (or automatic optimization). A more detailed description of ODESIM objectives can be found in [1].

3 Parallel Implementation of the Optimization Modules

In MBS optimum design, the computation of sensitivities is one of the most critical and time-consuming parts of the problem. The most suitable strategy to compute in parallel the gradients applying the finite differentiation method consists in the so call “pool of task” paradigm. This idea is based on the definition of a set of tasks that are stored in a queue managed by a software module called “the master” or parallel manager. The master farms out the tasks among the “the slaves”, which are the processors available in the network. The finite differentiation method requires the solution of as many simulations as the number of function evaluations involved in the selected finite difference formula. Each simulation of the MBS model can be taken as a task and can be run independently from the others in a processor.

From the user point of view, the main requirement for the parallel manager is the easiness of use. The parallel aspects have to be hidden as much as possible to the final user. The main characteristics of ODESIM parallel manager are:

- Openness and maintainability.
- Similar to run a sequential code.
- Portability

- Availability of reverse porting to sequential code.
- Load balancing, fault tolerances and breakdown recovering.
- Scalability.

The current version of the ODESIM parallel manager was implemented according to the SPMD paradigm (Single Programme-Multiple Data). It ensures a unique interface between the parallel code and the end-user. However, by nature the parallel code is MIMD (Multiple Instruction-Multiple Data) implementing a master/slave scheme. PVM message-passing library [2] has been used in the current implementation of the parallel manager. In addition, the use of standards (UNIX, C++, X-Windows, Motif, etc.) and object oriented programming (OOP) techniques guarantee the openness, portability and scalability of the software.

4 Results

The example shown in this Section is a test case of ODESIM project defined and solved by Centro Ricerche Fiat. The test case consists in a multi-link rear suspension system that must be optimized in order to reach the desired target curves, being the design parameters the body point positions as well as the body bushing stiffness.

The traditional design procedure for this type of suspension is performed in two steps. First, a kinematic synthesis problem is solved. The target toe-in/toe-out and camber curves are defined as functions of the wheel vertical displacement. The body point positions have to be modified until the target curves are fulfilled. The second step is an elasto-kinematic problem in which the goal function is defined by the toe and wheel base curves, which are given as a function of the lateral and longitudinal forces on the tire, respectively. In this step, the design variables are the body bushing stiffness. The result of the second step affects the results of the first and an iterative procedure is followed repeating both steps until convergence is reached. This iterative process depends strongly on the designer experience.

Table 1. Speed-up factor using a network of computers.

Network	Time per iteration	Speed-up factor
1 MIPS R10000 (195 MHz)	24 min.	
3 MIPS R10000 (195 MHz) + 2 MIPS R8000 (75 MHz) + 4 MIPS R5000 (180 MHz)	6 min.	4

In this example, ODESIM software was used, in a first stage as a tool for helping the designer in the iterative processes described in the previous paragraph. In a second experiment, the two steps were solved in a single step. In this case, a single goal function was defined as a linear combination of the four target curves and the vector of design variables is composed of the body point positions and the body bushing stiffness, leading to 27 design variables. Table 1 shows the speed-up factor obtained in the solution of this problem using several processors. The reason for the relatively small speed-up factor can be found in the fact that the CPU-times were measured in normal working conditions in a non-dedicated network in the industrial site. In

addition, the CPU time required to solve a single simulation is relatively small and there is a high overhead that must be considered.

Two conclusions derived from this test case must be highlighted. On one hand, it demonstrates that the duration of each step of the traditional design procedure can be shortened. On the other hand, the unified approach allows collapsing the two steps in a single optimization process that is run automatically. The intervention of the analyst is only sparsely required to monitor the evolution of the optimization process, requiring less dedication than the traditional approach. Table 2 shows the design and designer times needed to perform the design of a new suspension using the traditional procedure with traditional tools or using the results of ODESIM project.

Table 2. Time required for the suspension design.

	Traditional prod. Design time = designer time	ODESIM Design time	ODESIM Designer time
Joint position definition	2 days	< 4 hours	3 hours
Bushing stiffness	2 days	< 8 hours	2 hours
Complete procedure (using ODESIM in each step)	6 days	3 days	1 day
Complete single step Optimization		< 2 days	5 hours

5 Conclusions

The most relevant result of the project is that the use of this software can reduce the time for the design process by a factor bigger than 200%. In addition, the use of HPCN capabilities as well as optimization functions may introduce more significant time reductions. The design process is conducted almost automatically and requires nearly no intervention from the analyst. Consequently, the designer can optimize the use of his own time, which in the end is the most expensive part of the design process.

Finally, a third result obtained from ODESIM experience is that high performance computing techniques can be easily introduced to solve practical industrial problems without requiring any equipment investments.

References

1. Jiménez, J.M., Izaguirre, J.G., Suescun, A. and Avello, A.N., "Optimum Design of Multi-Body Systems - The ODESIM Experience", Multi-Body Dynamics: New Techniques and Applications, pp. 291-300, 1998, Professional Engineering Publishing Ltd.
2. Beguelin, A., Dongarra, J., Geist, A., Jiang, W., Manchek, R., and Sunderam, V., *PVM 3 user's guide and Reference Manual*, 1994, Tech. Rep. ORNL/TM-12187, Oak Ridge Nat. Lab., Tennessee 37831.