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Penalty Versus Complementary-Based Frictional Contact of Rigid Spheres: a CPU Time Comparison

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Abstract

Currently, the most common modeling and simulation software packages use penalty based methods to solve rigid body frictional contacts. The drawback to this is that the CPU time increases nonlinearly as the number of colliding bodies increases. This creates a limit on the number of bodies that can be simulated and thus systems that have hundreds of thousands of collisions are not possible to simulate. In order to carry out contact heavy simulations, a new formulation for solving rigid body collisions needs to be implemented. A new method that relies on the solution of a linear complimentary problem (LCP) is investigated in this report. Six simple multibody systems are modeled and simulated identically in two different dynamic engine programs. Each trial involves an increasing number of rigid bodies, and the resulting CPU time for a constant simulation time is recorded. ADAMS is the software that utilizes the penalty based computation of contact forces, and ChronoEngine is the program which implements the LCP approach. The resulting CPU times are compared and discussed, and a conclusion of the results with a focus on future research is presented.

Contents

1. Introduction

In order to reduce the time involved in multibody dynamic simulations that contain large numbers of rigid body contacts, new mathematical methods for solving these types of contact forces need to be investigated. Penalty based formulations are the current standard in most modeling and simulation software programs for solving rigid body contact problems involving friction. The drawback of this type of formulation is that the CPU time required for penalty based methods increases nonlinearly with the number of colliding bodies, thus creating an upper limit on the number of colliding bodies that can be simulated. Systems containing hundreds of thousands or even millions of colliding bodies, such as simulations involving granular media, simply cannot be simulated using the current formulation.

It is a goal of the Simulation Based Engineering Laboratory (SBEL) to conduct high fidelity vehicle simulations on granular media such as sand. To achieve this goal, a more efficient and robust method for solving systems with large numbers of frictional based contacts needs to be implemented. A new method involving velocity-impulse differential complimentarity has been recently introduced [1], and can handle these types of large systems. The advantage of this new formulation is that the CPU time and storage space increases linearly with the number of colliding bodies. This makes it an ideal method for simulating systems that involve a very large number of rigid body frictional contacts.

This technical report investigates the CPU time required to simulate simple multibody dynamic systems in two different modeling and simulation programs. The simulations involve dropping an increasing number of spherical bodies into a box for a fixed simulation time of 3 seconds. First, the systems are modeled and simulated in ADAMS, which utilizes the penalty method for solving the frictional contacts of the rigid bodies. The systems are then reproduced and simulated using ChronoEngine, which is a C++ multibody dynamics engine that utilizes complimentary-based contact formulation.

2. Simulation Procedure

The following sections provide information of how each system was modeled in ADAMS/View and ChronoEngine, as well as explanations of the simulation parameters. The unit system for both programs was mm-kg-second.

2.1 ADAMS/View Procedure

The simulation of the system in ADAMS involved six different trials, with each trial containing between 1 and 32 rigid spheres. All the spheres were identical, each with a diameter of 60 mm and a weight of 0.882 kg. The contacts were identical and defined between every rigid body in the simulation, with the following parameters: a stiffness of 1E5, force exponent of 2.2, damping coefficient of 10.0, and a penetration depth of 0.1 mm. Simulations were stopped after the physical time reached 3 seconds. Each trial was run for the given simulation time, and the CPU time to complete the simulation was recorded. A screenshot of the simulation with 32 rigid spheres at time t=0 seconds is shown below in Figure 1, and a video of this simulation can be found on the SBEL website at: http://sbel.wisc.edu/documents/balls_dropping.avi

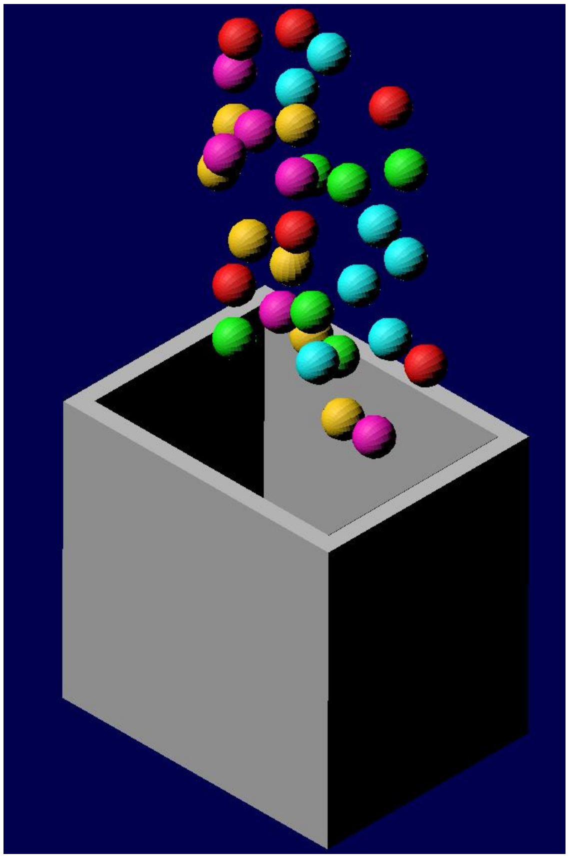

Figure 1: Simulation in ADAMS with 32 rigid spheres

2.2 ChronoEngine Procedure

For every trial performed using ADAMS, an identical simulation was created and performed using ChronoEngine. The size, mass and orientation of all the rigid bodies were identical to the trials in ADAMS. However, since ChronoEngine solves contact forces using the complimentary based method and a different set of parameters, the parameters for the contacts could not be exactly reproduced. The static and dynamic coefficients of friction were both set to a value of 0.2, and the impact coefficient was set to 0.1. Six trials were run, and the CPU times were recorded. An extra three simulations were then performed to show the linear increase in CPU time as the number of colliding bodies increased. A video of the simulation with 64 rigid spheres can be found on the SBEL website at:
http://sbel.wisc.edu/documents/ChronoIrrlicht%20collision%20avicompressed.avi

3. Results

The following table shows the number of spheres in each trial, the corresponding maximum number of contacts for that system, and the resulting CPU time for the simulations carried out using ADAMS.

Table 1: Number of rigid bodies v. CPU time in ADAMS

Number of Spheres	Max Number of Mutual Contacts [-]	CPU time (seconds)
1	1	0.41
2	3	3.3
4	14	7.75
8	44	25.36
16	152	102.78
32	560	644.4

The following graph shows the nonlinear increase in the CPU time as the number of colliding bodies increases.

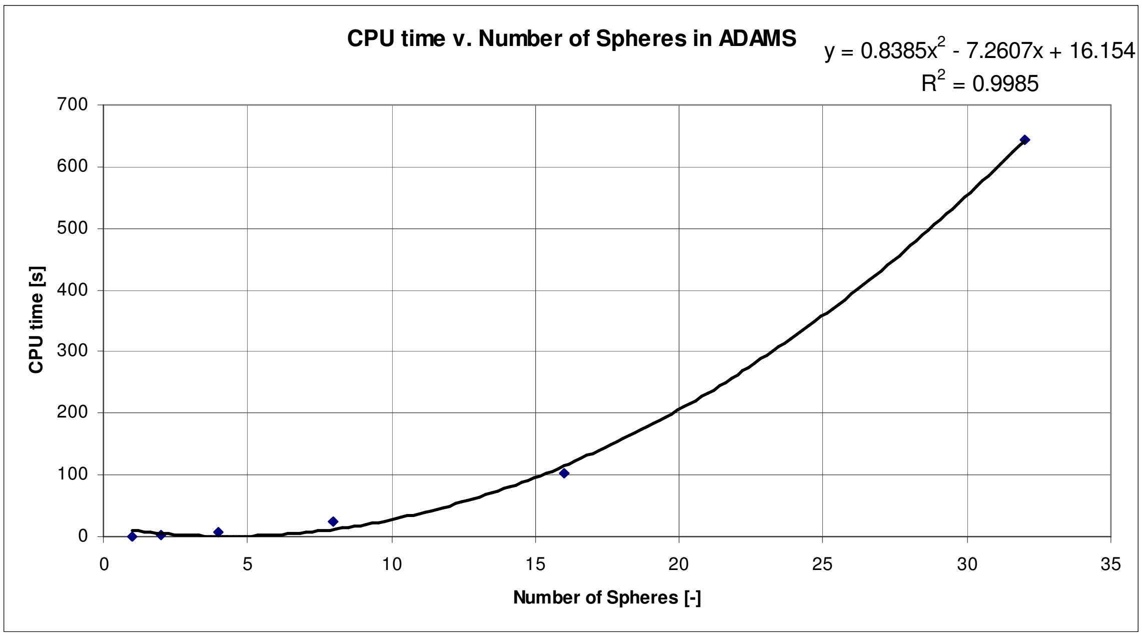

Figure 2: Nonlinear increase of CPU time in ADAMS

The following table gives the CPU time for each trial simulated in ChronoEngine.

Table 2: Number of rigid bodies v. CPU time in ChronoEngine

Number of Spheres	Max Number of Mutual Contacts [-]	CPU time (seconds)
1	1	0.70
2	3	0.73
4	14	0.73
8	44	0.76
16	152	0.82
32	560	1.32
64	2144	2.65
128	8384	6.17
256	33152	15.30

The following plot shows the linear relationship between the CPU time and the number of colliding bodies in ChronoEngine.

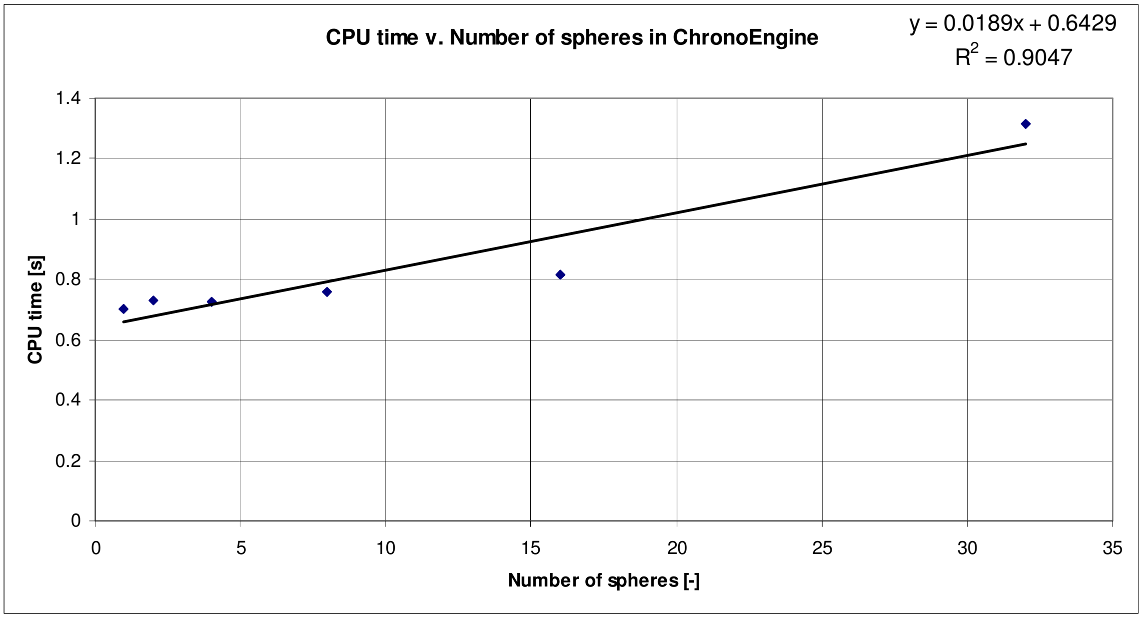

Figure 3: Linear increase in CPU time in ChronoEngine

Since ChronoEngine handles large numbers of contacts very efficiently, Figure 3 does not provide a conclusive trend because only a maximum of 32 contacts were involved in the simulations. To prove the linear relationship between CPU time and the number of colliding bodies, three additional trials were carried out. The trials had 64, 128 and 256 spheres dropped into a box. Table 2 includes these results and Figure 4 shows a much more convincing linear trend in the data.

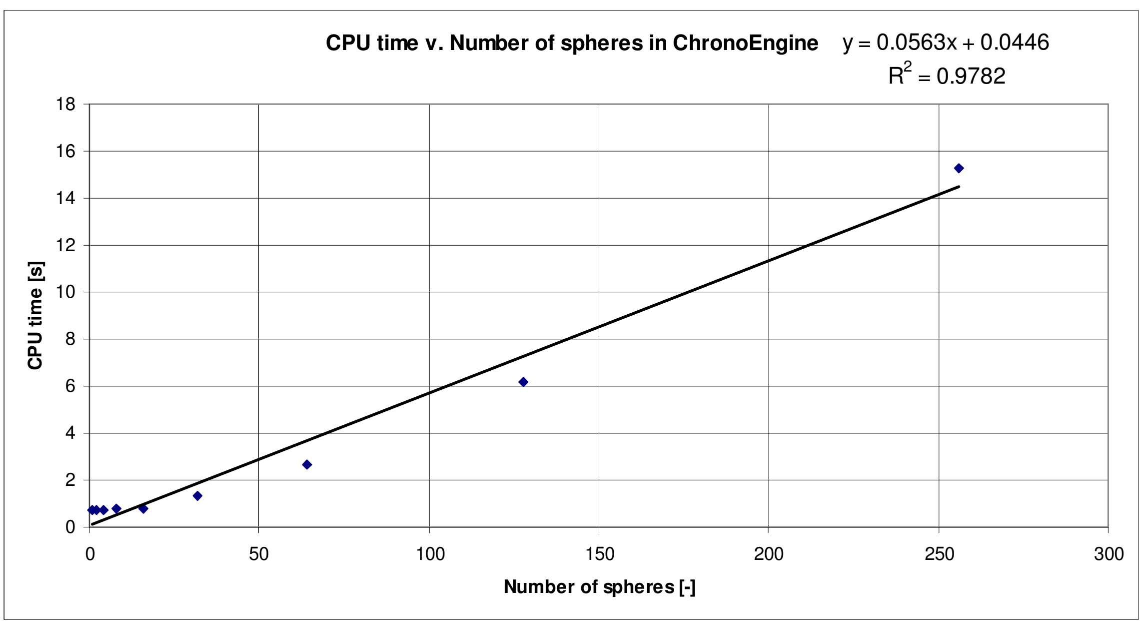

Figure 4: A more convincing linear trend in CPU time in ChronoEngine

4. Conclusion

Current methods for solving rigid body frictional contacts in the most common modeling and simulation software packages are limited by their nonlinear increase in CPU storage space and time as the number of colliding bodies increase. This simple investigation shows the impressive potential of complementary based formulation when applied to contact problems. The linear relationship between CPU time and the number of colliding bodies could greatly increase the number of rigid bodies that can be simulated. This could make simulations which contain hundreds of thousands of colliding rigid bodies possible.

The long term goal is to accurately and efficiently simulate vehicles which operate on off-road terrain that involves granular media such as sand. Coupling this new method of complimentary based formulas with parallel computing architecture, simulations involving millions of colliding rigid bodies could be undertaken. Further research is planned to examine and validate the use of velocity-impulse differential complimentary methods in multibody systems that contain large numbers of rigid body frictional contacts.

5. References

[1] Tasora, A., An iterative fixed-point method for solving large complementarity problems in multibody systems. *GIMC 2006, XVI Congress of the Italian Group of Computational Mechanics, 26-28 June 2006, Bologna – Italy*, 2006