A novel time-stepping method for multibody systems with frictional impacts

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Abstract. A new numerical integration method is presented for a class of multibody systems, which exhibit single frictional impacts. The new method is a time-stepping scheme, involving incorporation of a novel return map into an augmented Lagrangian formulation, developed recently for systems with bilateral constraints. When an impact is detected, this map is applied at the end of the step and brings the system position back to the configuration manifold with the allowable motions. In addition, the equations of motion during impact are geometrically discretized by appropriate cubic splines on the configuration manifold. Finally, the accuracy and efficiency of the method is demonstrated by a set of mechanical examples.

Introduction

Dynamics of mechanical systems involving contact, impact and friction has been a challenging research topic. The strongly nonlinear and numerically stiff nature of the equations of motion necessitate application of special techniques. Numerical integration methods have been developed along two main avenues. First, a large group of publications focused on finite element models arising in elastodynamics [1,2]. In parallel, a lot of research effort was devoted to multibody systems with rigid members [3,4]. Frequently, a combination of these methods is needed in solving complex engineering problems, like in the discipline of flexible multibody dynamics.

Here, the attention focused on developing an accurate and efficient time-stepping formulation for systems subject to a single unilateral and a set of bilateral motion constraints. Specifically, a consistent application of Newton's law is performed in both the impact-free and the impact phases, using tools of Analytical Dynamics [5,6]. Moreover, once a potential impact event is detected, an appropriate return map is applied, bringing the state of the system back in the allowable domain. This avoids interpenetration and provides the pre-impact conditions. Then, the post-impact state of a system with frictional impacts is determined by solving a system of three ODEs only, obtained through a suitable change of coordinates [6]. In this way, the problem of numerical stiffness, which is inherent to impact problems and is related to the large difference in the time scales of the dynamics during the free and the impact phase of the motion is handled in an efficient manner.

Results and discussion

The accuracy and efficiency of the new time-stepping method was tested with a set of mechanical examples. In each of these examples, a different solution characteristic, like the presence of energy dissipation, friction or bilateral constraints, was investigated in terms of its effect on the dynamics. For instance, in Fig. 1 are presented typical results obtained by considering dynamics of dice tossing. The method applied exploits the geometric properties associated to the dynamics of the class of systems examined. Similar methods are currently applied along two related research avenues, with large engineering value and importance. In the first, the attention is focused on solving problems involving permanent contact. In the second, the research efforts aim at extending the analysis and numerical methodology developed to cases with multiple impacts.

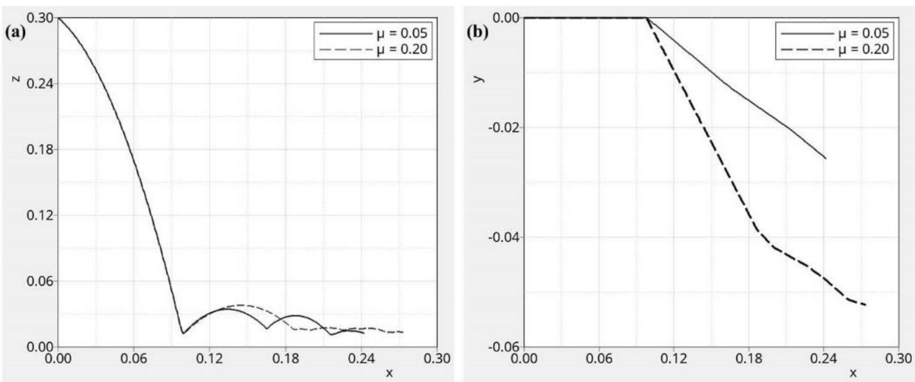

Figure 1: Projection of the trajectory of the cube center on: (a) the vertical plane Ozx and (b) the horizontal plane Oxy.

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