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Advances in Engineering Software 37 (2006) 805–813
ADVANCES IN ENGINEERING SOFTWARE
www.elsevier.com/locate/advengsoft

Simulation of impact, based on an approach to detect interference

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Received 27 April 2005; received in revised form 5 May 2006; accepted 5 May 2006
Available online 14 July 2006

Abstract

This paper describes a method for simulating impacts which occur during the motion of planar mechanisms. An interference detection method is proposed. Using this, distance between bodies can be determined during simulation, without having to solve a system of non-linear equations. The approach is illustrated by simulating a cam–follower mechanism. Impact is modelled using nonlinear compliance at the point of contact, and friction is modelled as Coulomb's friction. Numerical integration is partially validated using energy balance.

Keywords: Interference detection; Impact modelling; Multi-body dynamics

1. Introduction

Modelling of impact is a frequently encountered problem in design of mechanisms like circuit breakers, which involve latching action. Links of such mechanisms come into contact and move together or separate, with frictional forces being present in addition to impact forces. Several ways of modelling impact have been proposed. Impulse based models, in which velocities are assumed to change instantaneously, have been extended to glancing impacts with reaction dependent friction [1]. Some models consider the impacting bodies to be compliant near the points of contact, and allow impacts to happen over a finite time [2], but are computationally more expensive. The most sophisticated models consider entire bodies to be compliant and model the stress and strain waves set up in the bodies due to impact [3]. The latter models are computationally more intensive.

One reason why simulation of impact is computationally intensive is the need to detect collisions during simulation. The problem of collision detection is important in many fields, such as robotics, animation, and dynamic analysis of machines. Several algorithms have been proposed for collision detection [4]. Some are applicable to only polyhedral models of the bodies, while others are used for models with smooth surfaces. Two contributions which are of direct relevance to us are the approaches of Baraff [5] and Snyder [6]. Baraff uses the idea of points at extremal distance to characterize points which are likely to come into contact. He tracks such points during simulation by solving a set of equations, making use of the fact that the situation does not change significantly from one time point to the next. This allows him to use as guess solution, the solution of the previous time point. Snyder uses a similar characterization of points which are likely to come into contact, and uses this characterization to reduce the space in which search is made for the points on the surfaces of the two bodies.

Our characterization of contact points for collision detection has similarities with the above characterizations by Baraff and Snyder. However, the method used for collision detection is different. We address the problem of detecting collision between planar bodies of the type shown in Fig. 1, in the larger context of simulating the motions of interconnected systems of rigid bodies [7]. We confine ourselves to bodies with smooth profiles, as smoothness is one of the properties on which our approach depends.

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0965-9978/$ - see front matter
doi:10.1016/j.advengsoft.2006.05.001

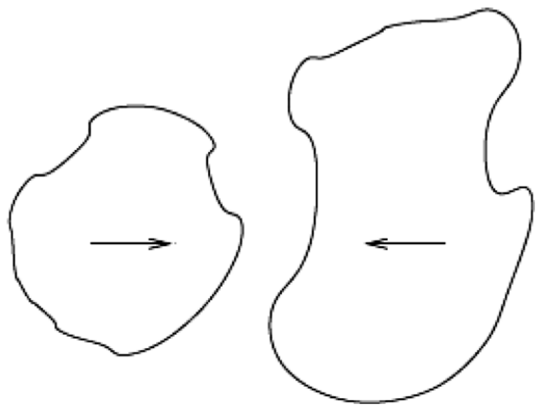

Fig. 1. Planar bodies in motion.

The outline of the paper is as follows. We discuss the proposed method for collision detection first. The models for impact and Coulombic friction are then described. A numerical example in which a cam–follower mechanism with impact and separation is simulated is described, and results discussed. A method for partially validating numerical integration using energy balance built into the simulation itself, is explained and used for the cam–follower simulation. We conclude by illustrating the approach using a cam–follower problem.

2. Collision detection

Detection of collision between bodies is important, because all approaches to modelling impact require information about when collision occurs, and which are the points on the two bodies which come into contact. Suppose two bodies are not in contact, but are likely to come into contact as they move. The traditional approaches to determining when they come into contact are based on checking whether they interfere with each other at various points of time, and in this way identify the point of time at which the contact starts. In our approach, we identify the candidate pair of contact points on each body, and track them till they contact each other. The conditions used for identifying the candidate pair, and the method of tracking them, are described below.

2.1. Points at least distance

The two points, one on each profile, which are at the least distance from each other, are chosen as the pair of points which are likely to come into contact. For example, in Fig. 2, '*A*' and '*B*' are the points at least distance. When the profiles of the two bodies are smooth (tangents are continuous), points at least distance must satisfy the following two conditions:

1. Outward normal through point A must pass through point *B*.
2. Outward normal through point B must pass through point *A*.

Here, outward means, away from the material portion of the body. Mathematically, these two conditions can be written as

$$\overline{A}_{\mathrm{n}} \cdot \overline{AB} = ||\overline{AB}|| \tag{1}$$

$$\overline{B}_{\mathrm{n}} \cdot \overline{BA} = ||\overline{BA}|| \tag{2}$$

Here, $\overline{A}_{\mathrm{n}}$ is the unit vector in the outward normal direction at A, and $\overline{AB}$ the vector from A to B. "·" indicates dot product. The reason for insisting that the point on the other body should lie on the outward normal, is to eliminate pairs of points like *C*, *D* in Fig. 2(a). However, the above condition has an important disadvantage. When the two bodies come into contact, they deform, and the above characterization suddenly does not fit the two points or any points close to them any more. Hence, there is a discontinuity if the locations of the two points need to be tracked, as is necessary for the model of impact we use in this paper. This difficulty is overcome by the following characterization:

$$\overline{A}_{\mathrm{t}} \cdot \overline{AB} = 0 \tag{3}$$

$$\overline{B}_{\mathrm{t}} \cdot \overline{BA} = 0 \tag{4}$$

The above pair of equations allow pairs like *C*, *D* in addition to the closest pair *A*, *B*. This can be resolved. But this characterization has another serious disadvantage. Suppose the two bodies are in contact and the nominal rigid profiles are intersecting, as shown in Fig. 2(b). Then, the

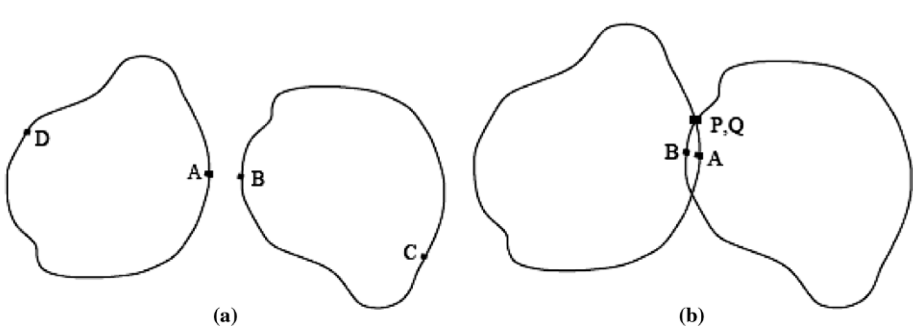

Fig. 2. Separated and interfering bodies.