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A Linear Programming Solution for Exact Collision Detection

This paper addresses the issue of real-time collision detection between pairs of convex polyhedral objects undergoing fast rotational and translational motions. Accurate contact information between objects in virtual reality based simulations such as product design, assembly analysis, performance testing and ergonomic analysis of products are critical factors to explore when desired realism is to be achieved. For this purpose, fast, accurate and robust collision detection algorithms are required. The method described in the text models the exact collision detection problem between convex objects as a linear program. One of the strengths of the proposed methodology is its capability of addressing high speed interframe collision. In addition to the interframe collision detection, experimental data demonstrate that mathematical programming approaches offer promising results in terms of speed and robustness as well. [DOI: 10.1115/1.1846053]

Keywords: Interframe Collision Detection, Virtual Reality, Primal-Dual Interior-Point Method, Linear Programming

1 Introduction

Recent developments in both computer hardware and software have enabled virtual reality (VR) technology to become a powerful product development and analysis tool in engineering. VR technology has been utilized frequently in product testing, performance analysis, consumer research, and collaborative product development areas. Current trends indicate that in the near future the application area of VR will increase significantly. The major advantage of VR technology over traditional simulation techniques is its potential to simulate both users (such as a customer or a designer) and products in a common interactive environment. This virtual encounter is becoming much more powerful and realistic with the availability of advanced collision detection algorithms, data-gloves and haptic devices that are essential in order to perform basic VR functionalities such as touching, grabbing, feeling the surface of product, etc. Although extensive scientific work focusing on the problem of exact collision detection between virtual objects exists, the possibility of collision between fast moving objects has been mostly ignored. For instance, machining operations such as robots with high-speed cutters, the modeling of chemical reactions and air-flow for ventilation systems, and the use of lasers in medical surgeries involve lots of high-speed activities. Military equipment such as bullets, missiles, and rockets are also fast moving objects. Creating interactive animations of these objects in VR simulations necessitates the use of large traveling-steps between consecutive frames that frequently cause interframe collisions. Most existing collision detection methods fail to detect collisions between two consecutive frames. In this article, a real-time collision detection methodology between a pair of convex polyhedral objects undergoing fast rotational and translational motion will be presented. Areas of application for the proposed methodology can be categorized as (i) product development: auto body design, surface finish, design for assembly, quality control, performance testing, and ergonomic analysis and (ii) fast moving object design: high-speed impact tests, bullet-proof product development, anti-air weapon systems development, high-speed machining, molecular modeling, air/fluid modeling, computer games, movie industries, etc.

The paper is organized as follows. Section 2 summarizes earlier works in collision detection. The methodology is then described in Secs. 3 and 4 whereby Sec. 3 addresses problem formulation while Sec. 4 elaborates on the solution methodology. The fast, interframe collision problem is explained in Sec. 5. In Sec. 6, experimental results are presented. Lastly, concluding remarks are provided in Sec. 7.

2 Previous Work

Collision detection is a problem experienced in robotics, VR based product development and testing, interactive design, and other computer graphics applications. In computer graphics, emphasis is placed on determining algorithms that can detect collision in the presence of physical-based simulations, where motion is subject to dynamic constraints or external forces and cannot typically be expressed as a closed-form function of time [1–3]. In the context of computer graphics, a gain in the speed of solution for the collision problem directly translates into the size of scene that can be effectively managed in a software system where collision detection is necessary. It is important to note that for a complex scene, a very large number (hundreds of thousands to millions) of collision checks should be performed every second. Also, an ideal collision detection algorithm is the one that works universally well in a robust manner and under a wide variety of conditions—varying speeds of object movements between frames, situations with a large number of collisions because of high object densities in the scene or a low number of collisions in a sparsely populated scene.

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