UNIVERSITI PUTRA MALAYSIA

A COLLISION DETECTION ALGORITHM FOR VIRTUAL ROBOT-CENTERED FLEXIBLE MANUFACTURING CELL

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A COLLISION DETECTION ALGORITHM FOR VIRTUAL ROBOT-CENTERED FLEXIBLE MANUFACTURING CELL

By

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A COLLISION DETECTION ALGORITHM FOR VIRTUAL ROBOT-CENTERED FLEXIBLE MANUFACTURING CELL

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May 2008

Chairman: Professor Abdel Magid Hamouda, PhD

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Collision detection is crucial in virtual manufacturing applications such as virtual prototyping, virtual assembly and virtual robot path planning. For accurate simulation of manufacturing systems and processes in virtual environment, physical interaction with the objects in the scene are triggered by collision detection. This thesis presents a collision detection algorithm for accurate simulation of a virtual flexible manufacturing cell. The technique utilizes the narrow phase approach in detecting collision detection of non-convex object by testing collision between basic primitive and polygon. This algorithm is implemented in a virtual flexible manufacturing cell for the loading and unloading process performed by the robot. The robot's gripper is treated as non-convex object and the exact point of collision is represented with a virtual sphere and collision is tested between the virtual sphere and the polygon. To verify the collision detection algorithm, it is tested with different positions and heights of the storage system during simulation of the virtual flexible manufacturing cell. The results showed that the

collision detection algorithm can be used to support the concept of hardware reconfigurablility of FMC which can be achieved by changing, removing, recombining or rearranging its manufacturing elements in order to meet new demands such as introduction of new product or change.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ALGORITMA PENGESANAN PELANGGARAN BAGI SEL PEMBUATAN FLEKSIBEL ROBOT TERPUSAT MAYA

Oleh

HASLINA ARSHAD

Mei 2008

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Pengesanan pelanggaran adalah penting dalam aplikasi pembuatan maya seperti prototaip maya, pemasangan maya dan perancangan laluan robot maya. Bagi simulasi yang tepat pada proses dan sistem pembuatan dalam persekitaran maya, interaksi fizikal dengan objek dalam senario dicetuskan oleh pengesan pelanggaran. Tesis ini membentangkan algorithma pengesanan pelanggaran untuk simulasi jitu bagi sel pembuatan fleksibel maya. Teknik ini menggunakan pendekatan fasa tirus bagi mengesan pelanggaran objek tak-cembong dengan menguji pelanggaran antara primitif asas dan poligon. Algorithma ini digunapakai dalam sel pembuatan fleksibel maya bagi proses bebanan dan nyah-beban yang dilakukan oleh robot. Pencekam robot dianggap sebagai objek tak-cembung dan titik pelanggaran jitu ditentukan oleh sfera maya dan dengan itu pelanggaran diuji antara sfera maya dan poligon. Bagi tujuan pengesahan algorithma pengesanan pelanggaran, ianya diuji pada kedudukan dan ketinggian sistem storan yang berlainan semasa simulasi sel pembuatan fleksibel maya. Keputusan ujian

menunjukkan algorithma pengesan pelanggaran boleh digunakan bagi menyokong konsep kebolehsusunan perkakasan dalam sel pembuatan fleksibel. Kebolehsusunan perkakasan ini boleh ditunjuk oleh pertukaran, pembuangan, penggabungan atau penyusunan semula elemen sel pembuatan fleksibel. Perubahan ini diperlukan bagi memenuhi kehendak produk baru atau pertukaran komponen.

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I certify that an Examination Committee met on 29 May 2008 to conduct the final examination of Haslina Arshad on her Doctor of Philosophy (PhD) thesis entitled “A Collision Detection Algorithm for Virtual Robot-Centered Flexible Manufacturing Cell” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

HASLINA ARSHAD
Date: 8 JUNE 2008

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LIST OF ABBREVIATIONS

CIM	Computer Integrated Manufacturing
FMC	Flexible Manufacturing Cell
FMS	Flexible Manufacturing System
GT	Group Technology
HMD	Head-Mounted Display
JIT	Just-In-Time
RMS	Reconfigurable Manufacturing Systems
VR	Virtual Reality
VFMC	Virtual Flexible Manufacturing Cell

CHAPTER 1

INTRODUCTION

1.1 Introduction

The primary concern of collision detection problem is to determine whether objects in an environment are in contact with each other and if they are in contact, when and where they intersect. Collision detection is fundamental within the field of computational geometry, robotic and computer graphics. It is becoming more important in Virtual Reality (VR) but is still considered a major bottleneck. VR can replace and simulate the real world with its synthetic computer-generated environment where the user can immerse into the generated world and interact with it as if he is actually in it. The application of VR has primarily been in architecture, education, training, tourism, science, engineering and manufacturing. Manufacturing industries have and will benefit from VR applications in several ways. In VR applications, physical interactions with the virtual environment such as grabbing, touching, hitting and picking are triggered by collision detection. For example in virtual manufacturing simulator, collision detection enables the virtual probe to stop as soon as it touches the object boundary (Tesic and Banerjee 2001).

Virtual reality has been applied to many areas of manufacturing. It provides 3D visualization of manufacturing environment and has great potential in manufacturing applications to solve problems and help in important decision making. In simulation of manufacturing processes and systems, the use of Virtual Reality has received a great deal of attention of many researchers (Willis 1993, Baylis et al. 1994, Kumar and Ferreira 1996, Angster 1996, Jayaram et al. 1999, Lin et al. 1999, Korves and Loftus 2000, Kopacsi et al. 2000, Beier 2000, Qiu et al. 2001, Bogdan et al. 2004). Many manufacturing industries have invested in highly automated production systems, such as computer controlled Flexible Manufacturing Systems (FMS) as an alternative to respond to challenges of today's market. Implementation of an FMS requires high capital investment and full commitment to reap the full benefit which includes reduced change-over times, shorter manufacturing cycles, reduced labour requirements, better machine utilization and increased product quality. Virtual reality modeling makes visualization and simulation of complex manufacturing systems such as FMS possible and in the most effective way. Accurate simulation of Flexible Manufacturing Systems is important so that interaction between objects in the system can be simulated realistically.

Many collision detection algorithms and systems have been developed (Baraff 1990, Lin 1993, Hubbard 1994, Cohen et al. 1995, Mirtich 1996, Klosowski 1998, Tesic 1999). It is to address different purposes depending on the application. Most of the works concentrate on collision detection between convex objects and some extended their work on non-convex objects. Common approaches used in these systems are categorized as broad phase and narrow phase. Broad phase will reduce the number of objects to be tested for collision while the narrow phase will be used to determine which object will collide. The choice made between these two approaches depends on several factors such as the type of applications and the simulation environment parameters. Some collision detection algorithms implement both broad and narrow phase, while some only use narrow phase approach only.

1.2 Related work

Significant contributions have been made in the field of Virtual Manufacturing particularly in design, process planning, assembly, prototyping, machining, training and simulation of manufacturing systems. Virtual model of ongoing design can be evaluated and experimented (Banerjee and Banerjee 1995, Beier 2000) and decisions on the best design and layout planning for the product can be determined (Korves and Loftus 2000). VEDAM developed by Washington State University (Angster 1996, Angster and Jayaram 1996) incorporates virtual reality technique into the design and process planning stages of a product. It can assist in the manufacturing and assembly process of the product. Virtual workshop of can assist in making prototypes (Willis 1993), perform machining operations (Baylis et al. 1994, Bowyer et al. 1996, Qui et al. 2001), assembly and disassembly operations (Owen 1994, Deitz 1996, Dewar et al. 1997, Fernandes et al. 2003). The advantage of Virtual Assembly system is that it can reduce design cycle time and verify assembly and disassembly operations (Jayaram et al 1999). Virtual Reality based training system offers the best teaching method and can improve employees skills and knowledge (Cruz-Neira et al. 1992, Wittenberg 1995, Wilson et al. 1996, Fernandes et al. 2003, Li et al. 2003, Wang and Li 2004). Simulation of manufacturing system such as Flexible Manufacturing System using virtual reality can help to avoid costly mistakes before actual implementation of the physical system (Kumar and Ferreira 1996, Lin et al. 1999, Kopacsi et al. 2000, Moyne et al. 2003).

Different configurations have profound effects on the performance of an FMS not only on the product quality but also on cost, throughput and utilization. Some studies have been carried out to observe the impact of different configurations on FMS performance measures and which configuration is the most optimal in order to respond to changing manufacturing environment (D' Angelo et al. 1996, Zhong et al. 2000, Bogdan 2004, Kost and Zdanowicz. 2005, Yang et al. 2005). Changing the physical layout of the system to accommodate changes in circumstances such as new product demand and introduction of new technologies can be done in virtual FMS and the impact can be observed.

Due to the importance of collision detection in many applications, a large number of methods have been proposed in the problem of collision detection. Different approaches and techniques have been used. Basically the choice of approaches used depends on the type of objects, queries and the application where the collision detection is used. 3D models in 3D graphics can be categorized as Nonpolygonal and Polygonal models. Common types of representation used for objects in virtual environment are Constructive Solid Geometry (CSG) and Polygonal. Collision detection approaches for these two types of models are reviewed in this section. Basically collision detection algorithms that have been used are divided into two classes: spatial decomposition (space subdivision) and Hierarchical Bounding Volume (HBV). Very few approaches have been attempted to solve collision detection problem for CSG-represented objects. Faverjon (1989) used CSG information to build hierarchical CAD models and has successfully developed an algorithm to calculate the distance between points of the objects. Cameron (1991) and Zeiller (1993) used S-bounds technique along with space subdivision technique for dynamic simulation. Efficient and precise collision detection for CSG represented objects for convex bounding volumes has been developed by Su et al. (1999) and Su (2007) by first constructing a hybrid CSG/B-rep objects of the object. For polygonal objects, a lot of work has been done to reduce the number of objects to be tested for collision. Spatial partitioning or space partitioning method divides space into regions of equal volumes and detects collision among objects which occupy the same space. Typical spatial decomposition techniques adopted by researchers are Octrees (Moore and Wilhelms 1988, Noborio et al. 1989), k-d trees **(**Klosowski et al. 1998), BSP trees (Naylor et al. 1990, Vanecek 1991) and grids (Alonso 1994).

Hierarchies of bounding volumes can speed up collision detection and it can handle general complex polyhedral models. Collision detection using bounding spheres (Hubbard 1995), oriented bounding boxes (Gottschalk et al. 1996), axis-aligned bounding boxes (Beckmann 1990, Cohen et. al 1995), discrete orientation polytopes (Klosowski 1998) have reported faster and more efficient algorithm. RAPID (Gottschalk et al. 1996) and QuickCD (Held et al.1995) are among the fastest general-purpose polygonal model collision detection system based on a bounding volume tree.

For exact collision detection, Voronoi regions are used to keep track of the closest features between pairs of objects and the distance between them are calculated (Lin and Canny 1991, Lin 1993, Cohen et al. 1995). Lin-Canny algorithm has been considered among the fastest solutions for this problem. All these works are efficient for solving problem of convex objects.

For handling non-convex objects, common approach used is to treat the non-convex into convex by partitioning them and arranged them in a hierarchical representation (Cohen et al. 1995, Ponamgi et al. 1994, Mirtich 1998). The distance between the objects is approximated by calculating the distance between their hulls. If the hulls are not disjoint, the objects are unwrapped and treated as collections of convex pieces. Very fast algorithms have been devised for distance computation between non-convex polyhedral with triangular faces (Larsen et al. 1999, Johnson and Cohen 2001, Kawachi and Suzuki 2000, Ehmann and Lin 2001) but triangulation can be a costly operation which will affect the performance of the algorithm. Thomas and Torras (1994; 2002) developed an interference test for non-convex polyhedral which doesn't require decomposition of non-convex objects into convex entities. By replacing predicates by their corresponding continuous functions, Jimenez and Torras (2006) extended the work by Thomas and Torras by calculating the lower bound on the distance between the non-convex polyhedral instead of calculating the exact distance itself. To solve the problem of exact collision detection for non-convex objects, Tesic and Banerjee (2001) tested collision between Virtual Objects (VO) instead of testing collision between the original scene objects. The Virtual Objects are only visible only for collision detection computational process. The Virtual Objects are created by projecting a convex patch onto local coordinate system (LCS) plane.

1.3 Problem Statement

Virtual Reality applied to simulation of manufacturing systems and processes such as in Flexible Manufacturing System, milling process, robot path planning, assembly, and prototyping has received a great deal of attention from many researchers and software developers. Simulation of manufacturing systems and processes in virtual environment involves interaction with the objects in the scene. Navigation and physical interactions with the virtual environment such as grabbing, touching, hitting and picking are triggered by collision detection. In a robot-centered Flexible Manufacturing Cell, a robot acts as the material handling element of the system. It performs the loading and unloading process which is to pick the part from the storage system and load it onto the machine and also to unload the material/part from the machine and bring it back to the storage system. To simulate this activity in a virtual environment will require exact collision detection where the gripper of the robot must be in contact with the material for the gripping process to take place.

Many collision detection algorithms have substantially been proposed and developed in recent years. Some tailored to particular application while many stem on theoretical concern. Collision detection algorithms for convex and non-convex objects have been reported. Despite significant progress made in developing efficient and exact collision detection algorithms for convex objects, limited progress has been reported in developing collision detection for non-convex objects. An obvious approach for solving collision detection for non-convex objects would be to decompose non-convex objects into convex objects and arranged them in a hierarchical representation (Ponamgi et al. 1994, Cohen et al. 1995, Gottschalk et al. 1996, Mirtich 1998). Then algorithms for solving convex objects would be applied. There are still problems of non-convex decomposition into convex and no robust implementation of any decomposition algorithm is available (Bajaj and Dey 1992, Chazelle 1994). Tesic (1999) had adopted a