The framework of collision detection for deformable bodies in virtual environment

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Abstract. Collision detection is a collision between two or more object. Collision computing by detecting the intersection between the two objects. There are two types of collision detection in research, such as rigid bodies and deformable. Besides, the main issue of collision detection normally involves efficiency, speed, and effectiveness. Therefore, it is vital to research on collision detection. This research introduced the Hybrid Bounding Volume (HBV) framework for the deformable object. This framework proposes BVH with a Top-Down method. The Hybrid BV structures involving of BV to form the BVH. In conclusion, the proposed method is expected to create the fast and effective collision response between deformable object thus it would improve CD of the deformable object in the virtual environment.

1. Introduction

The use of virtual environments has grown tremendously in the last decade. A growing number of researchers reported that virtual environments useful for research. Virtual environment plays an important role in offering realistic simulations and consists of three-dimensional objects (3D) that emulate the real world. Among optimization techniques that are implemented in virtual environments is collision detection. Collision detection is an essential part of the virtual environment [21][1][11] and used in several applications such as games, surgical simulation, and cloth simulation. The deformable object is a very popular model that illustrates the human body, soft tissues and organs in the surgical simulator, and other soft or elastic materials. Besides, deformable models are abstractions of soft bodies that enable approximating their behaviour when experiencing deformation due to external forces.

Additionally, the common approach that most utilized to perform collision detection is Bounding Volume Hierarchy (BVH) [13]. BVH recognizes as an effective CD method[14][6][9]. To implement CD for the deformed object, BVH has been used by constructing the hierarchical cluster strategy according to the top-down construction method. The top-down method is classified as a commonly used method and runs faster than the bottom-up method [15][20][17]. In the top method, root nodes are made first and are followed by other nodes. Bounding Volume (BV) inside the node is continually updated until it performs a fast and effective response.
Top-down construction is a commonly used method [5][8][16][17][11]. The top-down method construction of BVH begins with the formation of an object BV, then recursively subdivide the mesh into two nearly equal parts and store the BV in the child node. The partitioning of the mesh typically uses the splitting rule. The mesh primitives assigned to the left node or right node. The BV of the mesh stored in the child node is then computed and the process is repeated until the maximum level of a binary tree is reached or the node contains only a small sufficient range of the primitives.

Figure 1. Top-down construction method using AABB

Based on review of CD of deformable object, the previous researcher has used a distinctive approach such as hierarchical bounding volume, random collision detection, collision detection based on distance field and so on [22]. These techniques are focusing on how to improve speed and accuracy. Besides, this research proposed an improvement of hybrid bounding volume (HBV) framework for fast and effective collision detection response between deformable object. HBV algorithm approach requires (BV) to build the BVH. There are different kinds of BV has been explored, such as Sphere, the Aligned axis bounding box (AABB), Discrete orientation polytopes (K-DOP), the Oriented bounding box (OBB) [10][22][1][2].

Thus, the main contribution of the research can be summarized as follows:
A new framework of HBV for collision detection of deformable object.
The fast and effective collision response for deformable object in virtual environment.

The rest of the paper is organized as follows. Section 2 reviews the related work for collision detection of deformable object. Section 3 will describe the HBV framework implementation and collision detection. The Final section will conclude the current research and proposed future work.

2. Related Work

2.1 Collision Detection of Deformable Object

Deformable object is referred to soft body objects such as internal organ, balloon, cloth and more. Several objects can be classified as highly deformable such as cloth and another object like internal organ has limited deform bounds [4]. The computation for the deformable object is much more complex than rigid bodies because the position change causes an increase or decrease in basic geometric element [12]. It often leads to greater challenges to the efficiency, stability, and accuracy of the collision detection and resolution algorithm.

Besides, Spatial decomposition is an easy and fast technique to speed up collision detection in motion and deformation object [18][12][22]. Algorithms based on spatial subdivisions are free from object topology changes. They are not limited to triangles as primitive base objects, but also work with
other primitive objects if a congruous cross-test is performed. The main inequality in spatial decomposition is the destruction of data structures that are accustomed to representing 3D space. This data structure needs to be flexible and efficient by deferring time and calculating the design. Spatial decomposition method is to decompress the virtual space into a small number of small control shelves and test the geometric objects for overlapping on the same or adjacent unit shelf. The Ordinary methods have octree and binary space partition tree. The principle of collision detection of spatial decomposition methods is that the two objects do not overlap if they are on different unit shelves. It requires to test further for duplication if they are on the same unit shelf.

An Inefficient spatial decomposition method for collision detection among many objects as it is obligatory to disunite unit shelves with numerous unit shelves for overlap and have plenty of storage space when the objects are multiple and near. This method starts with, first dividing the entire space into virtual cells, uniform or non-uniform, and only the geometric elements occupying the same cell or nearby are emitted to test the geometry intersection [3]. There are two types of decomposition methods, the first is easy to implement but conventionally takes time to detect potential collision cells, while the second is intricate to build decomposing tree but more efficiently to discover potential collision cells [15].

Three-layer of Hybrid Bounding Volume Hierarchy (HBVH) is the innovation of combining different BV in virtual environment. The aim is to speed up CD processes and increase CD accuracy, the research proposes a different hybrid bounding volume hierarchy (HBVH) algorithm that uses three different types of BVs to perform intersection tests at different stages of CD. The core of three-layer HBVH is to choose different kinds of BV to have a better performance than single BV algorithm [1].

![Figure 2. A structure of three-layer HBVH](image)

Time comparison of CD based on the algorithm has used:

| Algorithm types     | Time of CD |
|---------------------|------------|
| AABB                | 71.8 ms    |
| Three-layer HBVH    | 34.5 ms    |

From the table above, it demonstrates that the Three-layer of HBVH is speeding up the process of CD compared to AABB.

Another, Hybrid bounding box has applied in virtual surgery simulation. The human gallbladder is chosen for virtual surgery object. The purpose is to enhance the real-time and accuracy of virtual surgery system. A Sphere-AABB Hybrid bounding box was constructed in the process of collision detection to carry on the rough collision then the graphics primitive collided. S- AABB hybrid bounding box to detect sketchy collision detection. Besides, six parameters make up one AABB bounding box, that is the maximum and minimum coordinate values of all vertices in the x-axis, y-
axis and z-axis (xmax, xmin, ymax, ymin, zmax, zmin) [19]. The figure shows the Sphere box is formed of 4 parameters, namely the center coordinates of the sphere at the end of the instrument and the radius, (X0, Y0, Z0, r) and 6 parameters will be obtained to form the AABB bounding box.

The AABB bounding box for the structure of the gallbladder, and the Sphere box used for the surgical instruments.

2.2 Project Background

This research aims to propose a framework for deformable collision detection in detecting the fast-effective collisions. The expectation of this research will be as a simple simulation for deformable collision detection as shown in the figure.
Furthermore, using a virtual environment comprises of the 3D object and apply the HBV framework in the simple simulation, it believes that the framework will create a fast and effective collision detection. Additionally, the HBV framework has been made by using Microsoft Visual C++, with OpenGL or Unity3D.

3. Framework Overview

The framework of HBV for collision detection of a deformable object is conceptual as follows (see figure 6).

![Diagram of HBV Framework](image)

**Figure 5.** Example of 3D object in virtual environment
In the HBV framework, all the 3D object consists of the moving and static object. Besides, the objects will be programmed to save the several information such as coordinate of X, Y and Z axis. The object will be loaded into the virtual environment, then the top-down method used to construct the BVH. Meanwhile, the Hybrid BV can start bound the BVH node. By fitting the Hybrid BV with the BVH node, it believes that Hybrid BV assisting to have the fast and effective of collision detection.

4. Conclusion And Future Work

In this research, we have presented HBV framework for collision detection of deformable object. The top-down method and Hybrid BV has been discussed to be used in the framework. This research is still in progress to determine the suitable algorithm for the framework and ensure our propose framework is working properly. In future work, we will conduct an experiment to test and evaluate the result of the proposed framework with other frameworks.

ACKNOWLEDGEMENT

We would like to thank the Universiti Teknikal Malaysia Melaka for the convenience of research facilities and laboratories and expert guidance for our self-funded research project.

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