

Real-time collision detection for dynamic objects

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Abstract This paper studies a collision detection technique to dealing with moving polyhedra. Even though the problem is well-studied in computer graphics, the existing methods are inapplicable to highly dynamic environments. We use the GJK algorithm to determine collisions between convex objects. Also, our method is applied for moving objects.

Key Words : collision detection, real-time animation, GJK algorithm, virtual reality

요약 본 연구의 목적은 컴퓨터 그래픽스 상에서 움직이는 다면체간의 충돌을 탐지하는 데 있다. 지금까지 컴퓨터 그래픽스 분야에서 이와 관련된 많은 연구들이 수행되었으나 대부분 다이내믹한 환경에는 적절치 못했다. 본 연구를 통해 GJK 알고리즘을 기반으로 하여 움직이는 다면체간의 충돌 탐지에 적합한 방법을 제안하고자 한다.

1. Introduction

Collision detection has received attention in computer graphics, virtual reality, physical simulation, and haptic. The existing work on collision detection can be classified based on the types of models handled: polyhedral models, polygon soups, curved surfaces, etc[9]. In this paper, we focus on collision detection for polyhedral models.

Hybrid collision detection [7] refers to the algorithm as the broad phase and the narrow phase. The former is approximate intersection tests, the latter is exact collision detection.

The separation distance between two polyhedra P and Q is equal to the distance from the origin to the Minkowski sum of P and $-Q$ [2]. This property was exploited by Gilbert et al. [4] in order to design a convex optimization algorithm (known as GJK). GJK algorithm is one of the most effective methods for determining

collision detection between two polyhedra. As originally described, GJK is an efficient and reliable algorithm for computing the Euclidean distance between a pair of convex sets in R^n . The GJK algorithm can also be applied to arbitrary convex points sets, not just polyhedra [3][10]. The algorithms depend on the object being rigid, and are hence unsuitable for collision detection between deformable objects.

The algorithms for collision detection between convex polyhedra are not applicable to models described as polygon soups. Bounding volume hierarchies (BVH) have proved successful collision detection for rigid bodies. One determining factor in the design of a BVH is the selection of the type of BV. Some of the common BVs are: spheres [6], axis-aligned bounding boxes (AABB) [1], oriented bounding boxes (OBB) [5], and k-discrete-orientation polytopes (k-DOP) [8]. With deformable objects, the hierarchical approximation must be updated at each frame and hence, computational process is very expensive.

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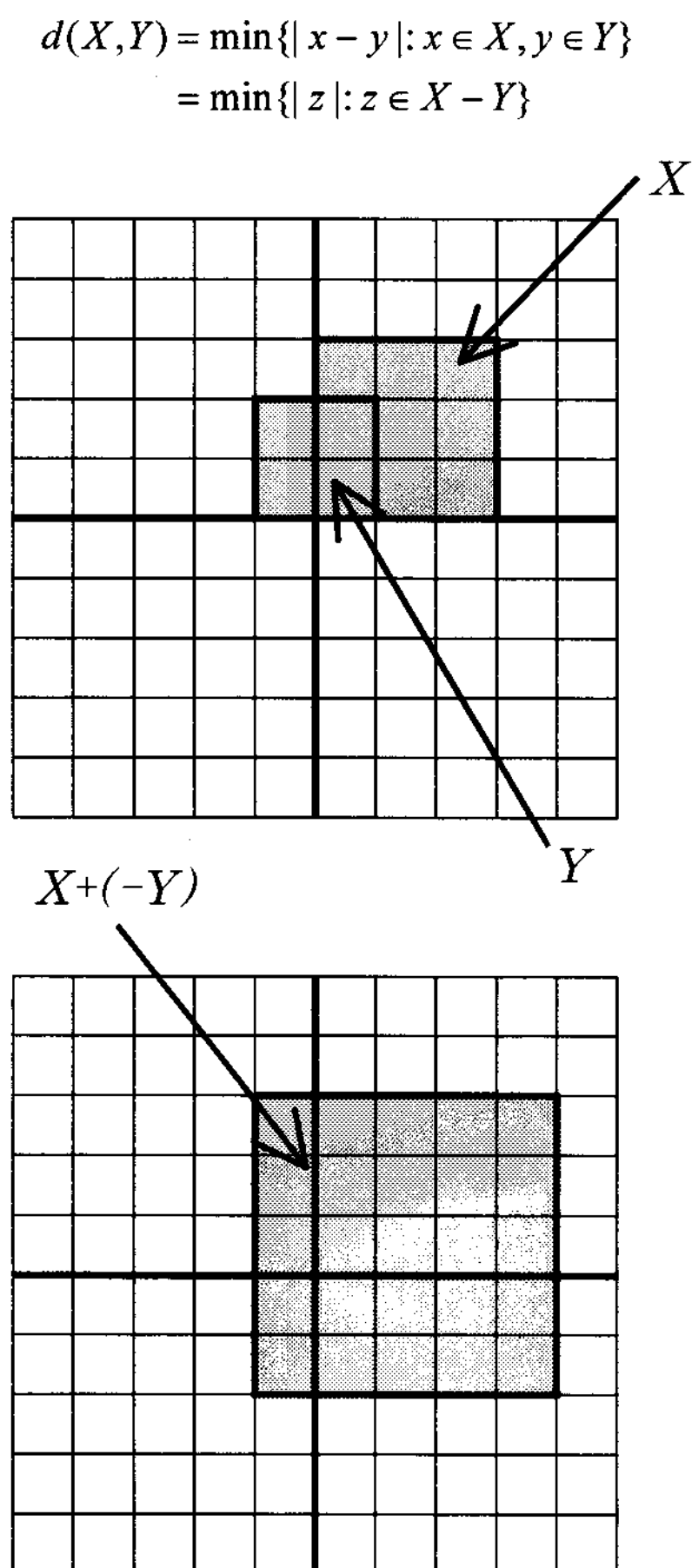
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2. Minkowski sums and differences

GJK algorithm does not operate on the two objects, but on the Minkowski difference between the objects. We use $x \cdot y$ for the inner product of $x, y \in \mathbb{R}^m$ and $|x|^2 = x \cdot x$. For $X_1, X_2 \subset \mathbb{R}^m$, $X_1 \pm X_2 = \{x_1 \pm x_2 : x_1 \in X_1, x_2 \in X_2\}$ denotes the Minkowski set sum or difference.

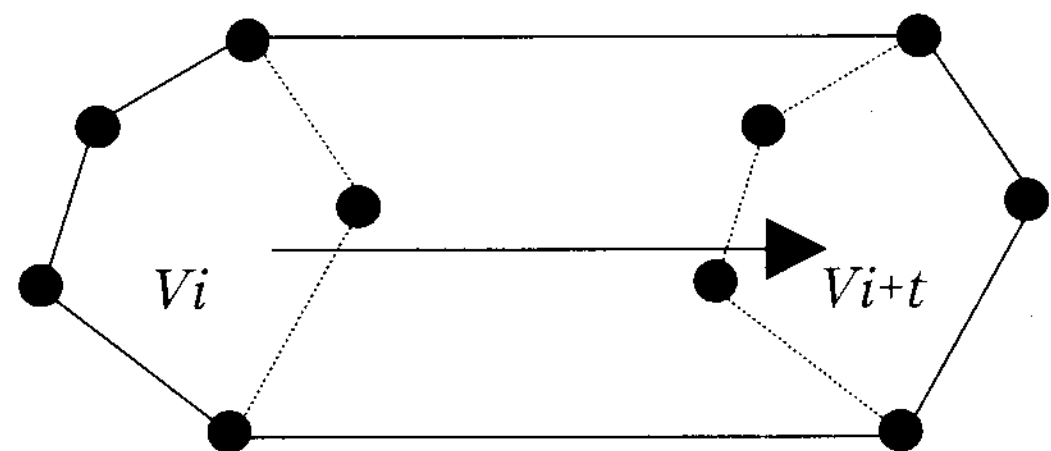
The Minkowski sum can be seen as the region swept by X translated to every point in Y . The Minkowski difference is presented by adding X to the reflection of Y about the origin, that is $X - Y = X + (-Y)$ (Fig. 1). If Minkowski difference Z , $Z = X - Y$, contains the origin (Fig. 1). Clearly,



[Fig. 1] The origin must be contained in their Minkowski difference.

3. Sweeping intersection

One approach to dealing with moving polyhedra is presented in Xavier [11]. Consider two polyhedra P and Q , with movements given by the vectors t_1 and t_2 , respectively. To simplify the collision test, the problem is recast so Q is stationary. The vector of P is given by $t = t_1 - t_2$. Let V_i be the vertices of P in its initial position. $V_i + t$ describes the location of the vertices of P at the end of its translational motion. If P moves from start to end over its range of motion, the volume swept out by P corresponds to the convex hull of its vertices at their initial and final positions (Fig. 2).



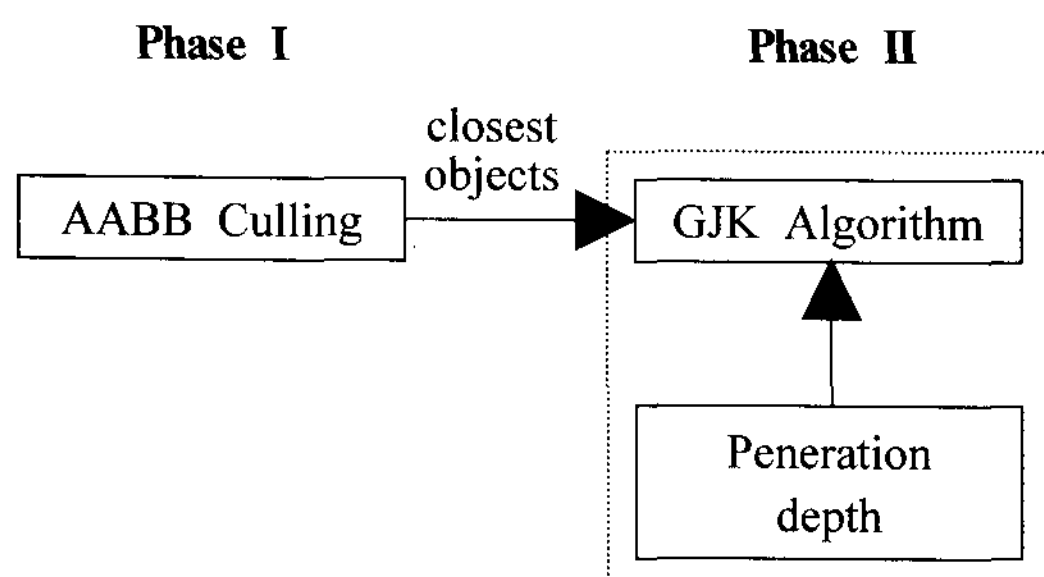
[Fig. 2] For a convex polyhedron under a translational movement t .

4. Multi-level collision detection

Multi-level collision detection is able to divide into two phases. In the first phase, we use a fast and rough algorithm likely AABB. In the second phase, we apply the method based on the distance to decide if the moving polyhedra will collide or not.

Our approach decreases the operation by reducing the sweeping test. Sweeping intersection tests detect the intersection between the sweeping volumes of objects over time, or an approximation thereof [12]. However, these tests conservatively report false alarms that never actually occur, because they do not account for the displacement of objects as they move.

Our algorithm proceeds in two phases, as shown in Fig. 3. We first use an AABB based culling approach. Next, we perform GJK algorithm based on the distance.



[Fig. 3] Our multi-level collision detection algorithm proceeds in two phases.

5. Conclusions and future work

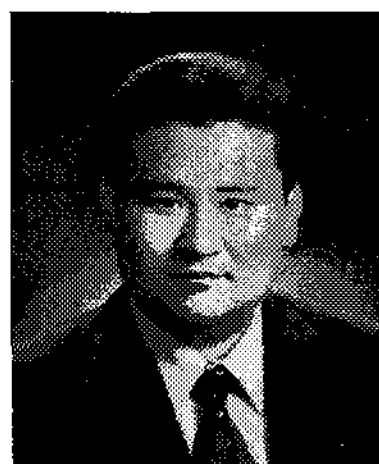
We have presented in this paper a hybrid method that allows real-time collision detection in complex environments composed of moving objects. We use AABB and GJK algorithm to perform collision detection. Our approach is very fast and can be adopted in a variety of environments. We would like to use our method for other environments such as deformable objects.

References

- [1] Beckmann, N., Kriegel, H., Schneider, R., Seeger, B., "The r*-tree: An efficient and robust access method for points and rectangles", Proc. SIGMOD Conf. on Management of Data, pp.322-331, 1990.
- [2] Cameron, S., Culley, R., K., "Determining the minimum translational distance between two convex polyhedra", Proceedings of International Conference on Robotics and Automation, pp.591-596, 1986.
- [3] Gilbert, E., Chek-Peng, F., "Computing the Distance Between General Convex Objects in Three-Dimensional Space", IEEE Transactions on Robotics and Automation, Vol. 6, pp. 53-61.
- [4] Gilbert, E., Johnson, D., Keerthi, D., "A Fast procedure for computing the distance between objects in three-dimensional space", IEEE Journal on Robotics and Automatin, Vol. 4, pp. 193-203, 1988.
- [5] Gottschalk, S., Lin, M., Manocha, D., "OBB-Tree: A hierarchical structure for rapid interference detection", Proceeding of ACM SIGGRAPH' 96, pp. 171-180, 1996.
- [6] Hubbard, P., "Collision Detection for Interactive Graphics Applications. Ph. D. thesis", Brown University, 1994.
- [7] Kitamura, Y., Takemura, H., Ahuja, N., Kishino, "Efficient collision detection among objects in arbitrary motion using multiple shape representations", Proceedings of the 12th IAPR International Conference, Vol. 1., pp. 390-396, 1994.
- [8] Klosowski, J., Held, M., Mitchell, J., Sowizral, H., Zikan, K., "Efficient collision detection using bounding volume hierarchies of k-dops", IEEE Trans. on Visualization and Computer Graphics 4, pp.21-37, 1998.
- [9] Miguel, A., Otaduy, M., Lin, C., "Introduction to haptic rendering. International Conference on Computer Graphics and Interactive Techniques archive", ACM SIGGRAPH 2005 Courses, pp.11-14, 2005.
- [10] Sunil, Hadap, Dave, Eberle, Pascal, Volino, Ming, C., Lin, Stephane, Redon, Christer, Ericson, "Collision detection and proximity queries", International Conference on Computer Graphics and Interactive Techniques ACM SIGGRAPH 2004, Course Notes, 2004.
- [11] Xavier, Patrick, "Fast swept-volume distance for robust collision detection", Proceedings of the 1997 IEEE International Conference on Robotics and Automation, Albuquerque, NM, April, 1997.
- [12] Vlack, Kevin, Susumu, Tachi, "Fast and accurate spacio-temporal intersection detection with the GJK algorithm. Proceedings of the International Conference on Artificial Reality and Telexistence (ICAT), pp.79-84, 2001.

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<Area of Interest>

Knowledge Management, Innovation Theory, System Thinking, e-Biz.

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<Area of Interest>

Collision Detection, Haptic, Image Processing