VOL. 10, NO. 2, FEBRUARY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

REVIEW ON NARROW PHASE COLLISION DETECTION SYSTEM IN VIRTUAL ENVIRONMENT

Hamzah Asyrani Bin Sulaiman[1], Mohd Azlishah Othman[1], Mohamad Zoinol Abidin Abd. Aziz[1] and Abdullah Bade[2]
[1]Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Melaka, Malaysia
[2]Universiti Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia
E-Mail: h.a.sulaiman@ieee.org

ABSTRACT

Collision detection is one of the most important tools that has been used widely in animation and simulation especially in computer games and medical simulation purpose. One of the critical issues in collision detection system is to actually prepared what kind of technique that is suitable for virtual environment to adapt collision detection system installed. Hence, this research paper described a detailed review on collision detection algorithm mainly in narrow phase collision detection phase.

Keywords: collision detection, virtual environment, computer games, simulation, animation.

INTRODUCTION

At initial level of collision detection, there are two subparts of dynamic collision detection techniques which are discrete collision detection (DCD) and continuous collision detection (CCD). Discrete collision detection only detects collisions at discrete moments in time (Dongliang and Yuen, 2000; Gottschalk, 2000; Bergen, 2004; Atencio, Esperanca *et al*. 2005; Kamat and Martinez, 2007; Tuft, 2007; Chang, Wang *et al.* 2008; Suaib, Bade *et al*. 2008; Chang, Wang *et al*. 2009; Kaiqiang and Jiewu, 2010; Meiping, Liyun *et al*. 2010; Ningjun, Kai et al. 2011; Razzaq, Shah et al. 2011; Chen, Ye *et al*. 2012; Jia, Chitta *et al*. 2012; Qu and Zhao, 2012; Wei and Jing, 2012; Xiyuan and Sourina, 2012; Taib, Othman *et al*. 2013; Xinyu and Kim, 2014). As a result, it may miss the collision between two successive configurations, also known by researchers as tunneling problems (Zhang and Du, 2011; Xinyu and Kim, 2012; Zhang, Kim *et al*. 2014).

Meanwhile continuous collision detection (CCD) techniques resolve the tunneling problem by first applying the interpolated motion to check for continuous movement for collisions, motion interpolation between successive configurations and used the interpolated motion to check for continuous movement collisions (Redon, Kheddar *et al*. 2002; Redon 2004; Redon, Kim *et al*. 2004; Zhang, Lee *et al*. 2006; Min, Sean *et al.* 2008; Tang, Curtis *et al.* 2008; Jing, Ying *et al.* 2009; Grady 2010; Sulaiman, Bade *et al.* 2010; Zhang and Du, 2011; Tang, Manocha *et al.* 2012). Continuous collision detection performs a higher-order check to find out if there is any intersection between two objects through the distance defined by configuration points (Redon, 2004; Zhang, Lee *et al.* 2006; He, Wang *et al.* 2009; Zhang, Kim *et al*. 2014) . It is occurred when the object has thin surfaces or fast affecting objects that eventually missed the collision. It is important for hide-fidelity simulation even though it does not require for fast response simulation such as in computer games or animation. Thus, CCD hardly missed any potential collision between those configurations.

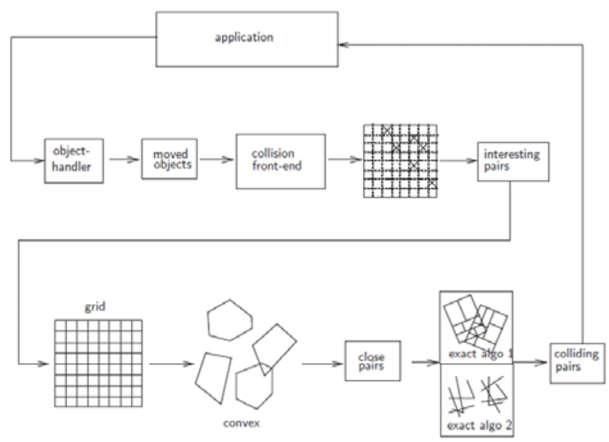

Figure-1. Collision detection pipeline (Zachmann, 2001).

As shown in Figure-1, the pipeline shows two general phases of collision detection pipeline which are broad phase collision detection (starting from object handler until interesting pairs block) and narrow phase collision detection (starting from grid until colliding pairs block). Generally, the main challenges of narrow phase collision detection stage when precision becomes the important element to determine the colliding pairs.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1. Techniques for distance computation.

Author	Title	Author self claimed limitation/disadvantage
(Lin and Canny, 1991)	A Fast Algorithm for Incremental Distance Calculation	• Theoretical Implementation • Slow for complex object/large number of triangles
(Mirtich, 1998)	V-Clip: fast and robust polyhedra collision detection	• Advanced version of Lin-Canny algorithm • Depend heavily on complex calculation • Need to calculate for all vertices, edges and faces. • Sacrifices the face–face and edge–face cases in order to achieve better robustness
(Kawachi and Suzuki, 2000)	Distance computation between non-convex polyhedra at short range based on discrete Voronoi regions	• Pre-defined values of distances between near colliding objects • Large number of intersection tests and closest feature tests between triangles and voxels
(Tang, Lee *et al*. 2009)	Interactive Hausdorff distance computation for general polygonal models	• The technique itself is not an exact distance computation • User-specified accuracy with pre-defined configuration of objects.
(Jia, Sucan *et al*. 2013)	Real-time collision detection and distance computation on point cloud sensor data	• Use for broad phase type computations • Query more expensive due to usage of octree for the point cloud

Meanwhile, point of contact technique for narrow phase collision detection was first introduced by (Gilbert, Johnson *et al.* 1988). The technique used simplex based implementation based on GJK but failed to satisfy the termination criteria (Gilbert and Foo 1990) that had been used to calculate the possible nearest points. Lin Canny technique was introduced then by implementing reducing resolution technique for detecting point of contact (Lin and Canny 1991). However, the technique missed certain cases where it may fall in infinite loop for complex polygons (Cameron, 1997; Chong-Jin and Gilbert, 2001; Sundaraj and Retnasamy, 2007; Shen and Li, 2010). Mirtich (1998) in (Chakraborty, Jufeng *et al*. 2008) proposed a V-Clip that provided solution for the Lin-Canny but not suitable when the coherence level is high. Later Ma *et al* (2012) proposed a distance computation technique for canal surfaces to detect point of contact but dedicated only for canal surfaces and involved complex calculations with only a few iterations and not suitable for massive models (Je, Tang *et al*. 2012; Yu and Yamane, 2013; Wang, Shi *et al.* 2014; Zhang, Kim *et al.*, 2014). Trajectory based technique was implemented for detecting point of contact has been proposed in Schulman but according to the author itself, it involves expensive iteration and the trajectory could be missed sometimes (Schulman, Lee *et al.* 2013). Table-2 shows a summarized version of point of contact techniques.

VOL. 10, NO. 2, FEBRUARY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2. Techniques for point of contact.

Author	Title	Author self claimed limitation/disadvantage
(Gilbert, Johnson *et al*. 1988)	A fast procedure for computing the distance between complex objects in three-dimensional space	• Simplex based technique that the most complex implementation required • Enhanced GJK exploit the simplex system but also failed to satisfy the termination criteria.
(Lin and Canny, 1991)	A Fast Algorithm for Incremental Distance Calculation	• Pre-defined polygons (18 pairs) using reducing resolution and need to undergo the technique more than once (up to infinity!)
(Mirtich, 1998)	V-Clip: fast and robust polyhedra collision detection	• Not suitable when the coherence level is high (not suitable for low count of polygon due to need to undergo various steps of technique)
(Chakraborty, Jufeng *et al*. 2008)	Proximity Queries Between Convex Objects: An Interior Point Approach for Implicit Surfaces	• Depend heavily on the complex algebraic equation for computing point of contact • Performance degradation when the object is nearly close for intersection
(Ma, Tu *et al*. 2012)	Distance computation for canal surfaces using cone-sphere bounding volumes	• Based on few restrictions and assumptions for canal surfaces only • Complex calculations involved
(Schulman, Lee *et al.* 2013)	Finding Locally Optimal, Collision-Free Trajectories with Sequential Convex Optimization	• Trajectory point of contact determination for broad phase collision detection • Expensive iteration involves with complex techniques

Considering the last component of narrow phase collision detection, Gilbert (Gilbert, Johnson *et al*. 1988) proposed a fast procedure to handle penetration of narrow phase collision detection but sometimes the technique reports false positive result for potential primitives (Cameron, 1997; Ponamgi, Manocha *et al*. 1997). Lin-Canny technique does not offer penetrating handling technique well but with a simple technique to cover penetration depth where it involves calculating the total distance travel from one point into another point that penetrate the other object (Bergen, 2001; Kim, Otaduy *et al*. 2003; Stephane and Lin, 2006). The technique itself could be a repeated cycle forever if penetration happens (Kim, Otaduy *et al*. 2003; Stephane and Lin, 2006; Zhang, Kim *et al.* 2007). Mirtich (Mirtich, 1998), developed a V-Clip complex technique that is capable to handle penetration but it is inefficient when the object completely penetrates into other object (the object completely inside the other object) (Escande, Miossec *et al*. 2007). Zhang *et al.,* (Zhang, Kim *et al*. 2007) provided a generalized penetration depth computation which is able to compute object penetration depth faster than other previous method mentioned in their research paper but depends heavily on pre-processing configuration with a lot of predefined (Shengzheng and Jie, 2009; Choi, Ryu *et al*. 2010; Zhang and Du, 2011; Zhi, Shiqiu *et al*. 2011; Heng, KunChao *et al*. 2012). Later, Hausdorff distance in (Tang, Lee *et al*. 2009; Bartoň, Hanniel *et al*. 2010) was used to calculate the penetration depth for polygon but depends on closed models (where there is no hole for the object) and well-defined inside and outside vertices points (Je, Tang *et al.* 2012; Jia, Chitta *et al.* 2012; Zhang, Kim *et al*. 2014). Table-3 summarized all our findings for penetration depth issues.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-3. Techniques for penetration depth.

Author	Title	Author self claimed limitation/disadvantage
(Gilbert, Johnson *et al*. 1988)	A fast procedure for computing the distance between complex objects in three-dimensional space	• Failed sometimes when reporting penetration depth (false result)
(Lin and Canny, 1991)	A Fast Algorithm for Incremental Distance Calculation	• Cannot handle penetrating polyhedra (object must not penetrate) and the technique could cycles forever • Degeneracy problems with false result
(Mirtich, 1998)	V-Clip: fast and robust polyhedra collision detection	• Simplex based with multiple iterations of complex technique • Inefficient if the object completely penetrate into the other object.
(Zhang, Kim *et al*. 2007)	Generalized penetration depth computation	• Involved lot of pre-processing step and limited to convex object and depend heavily on the pre-bounding convex covering
(Tang, Lee *et al*. 2009)	Interactive Hausdorff distance computation for general polygonal models	• It is not an exact technique and the calculation for penetration depth only covered for closed models (no hole) and well defined inside and outside vertices.
(Weller and Zachmann, 2011)	Inner Sphere Trees and Their Application to Collision Detection	• Generalized technique that use spatial data structures technique for only limited polygon types.

Based on the discussion above, it is suggested that the previous techniques on narrow phase collision detection are experiencing at least one of those common issues such as:

- highly complex computation (Tang, Lee *et al*. 2009, Gong, An *et al*. 2011, Jia, Chitta *et al*. 2012, Ma, Tu *et al*. 2012, Wei and Ying 2012, Jia, Sucan *et al*. 2013, Liu and Kim 2013, Min, Manocha *et al*. 2014)
- false positive or sometime misses collision detected (Jing and Lixin 1996, Ponamgi, Manocha *et al*. 1997, Redon, Kheddar *et al*. 2002, Chakraborty, Jufeng *et al*. 2008, Allard, Faure *et al*. 2010, Choi, Ryu *et al*. 2010, Sulaiman, Bade *et al*. 2010, Je, Tang *et al*. 2012)
- depends heavily on certain rules or conditions in order to operate (Cameron 1997, Ponamgi, Manocha *et al*. 1997, Bergen 2001, Redon, Kheddar *et al*. 2002, Kim, Otaduy *et al*. 2003, Stephane and Lin 2006, Liu, Wang *et al*. 2007, Zhang, Kim *et al*. 2007, Shengzheng and Jie 2009, Choi, Ryu *et al*. 2010, Zhang and Du 2011, Zhi, Shiqiu *et al*. 2011, Heng, KunChao *et al*. 2012, Je, Tang *et al*. 2012, Jia, Chitta *et al*. 2012, Ramsey, Mullins *et al*. 2012, Zhang, Kim *et al*. 2014).

Considering these issues, there is a need to generalize the technique for narrow phase collision detection scheme that covers all three components. Instead of manipulating limited type of polygon, the proposed technique should indulge a better solution for any type of object that consist of vertices, edges and surfaces. The generalized technique should be able to handle distance computation, point of contact, and penetration depth with a reasonable speed and nearly accurate computation.

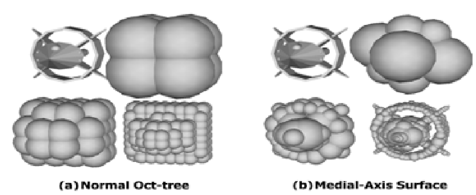

Figure 2.11: Differences between normal oct-tree and medial axis surface introduced by Hubbard (Hubbard, 1996).

DISCRETE COLLISION DETECTION

Discrete collision detection (DCD) works has been studied a decade ago and the pioneers of this work are (Goldsmith and Salmon, 1987; Gilbert, Johnson *et al*. 1988; James, 1988; Baraff, 1989; Omohundro, 1989; Gilbert and Foo, 1990; Lin and Canny, 1991) where one of the remarkable researches conducted by (Gilbert, Johnson *et al*. 1988). The author created an efficient technique for computing the Euclidean distance between triangles using mathematical programming method. It used the position and orientation of the object and detect any potential collision along a continuous path (refer to Figure-1). An improvement has been made later on by using a simple extension by replacing it with a general convex set that could reduce the error caused by an approximation of polytope itself. The result is an efficient technique has been introduced (Gilbert and Foo 1990). Then, an efficient technique for DCD by using hierarchical representation of spheres (Quinlan 1994) is introduced that speed up the process of collision detection and one of the research that pioneering the broad phase collision detection scheme instead of single scheme of collision detection. By enclosing the object with spheres for multiple levels, it helps to reduce the complexity by huge factors and also reduced computational cost.

Hubbard introduced a sphere tree construction by using oct-tree based type based on previous research by Quinlan (Hubbard 1996). By using space-time bound technique, Hubbard technique allowed the collision detection technique to work fast by approximation and graceful deprivation on the objects. In his dissertation, he concluded that the implementation of the technique works faster than the previous one.

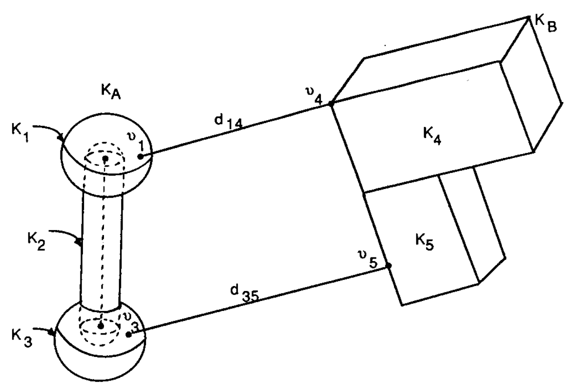

Figure-3. Differences between normal oct-tree and medial axis surface introduced by Hubbard (Hubbard, 1996).

Bounding-Volume Hierarchies of k-DOPs has been proposed by Klosowski *et al* (Klosowski, Held *et al*. 1998) in 1998 by using a convex polytopes with some orientations of k value. By implementing this technique, their technique showed promising results that could benefits in complex static environment with collision detection technique. Other researchers also used various of BVs for the BVH such as boxtrees(Okada, Inaba *et al*. 2005, Wang, Dong *et al*. 2010) , Axis-Aligned Bounding-Box (AABBs) (Okada, Inaba *et al*. 2005, Weller, Klein *et al*. 2006, Zhiwen and Hau-San 2006, Zhang and Kim 2007, Feixiong, Ershun *et al*. 2009, Tu and Yu 2009, Yi-Si, Liu *et al*. 2010, Gong, An *et al*. 2011, Hanwen and Yi 2011), Oriented Bounding-Box (OBB) (Gottschalk, Lin *et al*. 1996, Chun-yan, Dong-yi *et al*. 2005, Zhiwen and Hau-San 2006, Chang, Wang *et al*. 2009, Feixiong, Ershun *et al*. 2009, Tu and Yu 2009, Chang, Wang *et al*. 2010, Lu and Guofeng 2010, Shen and Zhang 2010, Zhou 2010, Yanchun and Xingyi 2011, Zhao and Wang 2011), k-Dop (Zhang and Du 2011) Oriented-Dops (Bade, Suaib *et al*. 2006, Chang, Wang *et al*. 2009, Yanchun and Xingyi 2011) and convex hulls (Gilbert and Foo 1990, Quinlan 1994, Cameron 1997, Zhang, Lee *et al*. 2006).

CONCLUSIONS

This paper describes our review extensively on narrow phase collision detection and how the generalize version of narrow phase collision detection is required for virtual environment and graphics simulation.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Teknikal Malaysia Melaka and Ministry of Higher Education Malaysia for the financial support given through the research grant FRGS(RA CE)/2013/FKEKK/4F00197 (A Novel Interference Detection Algorithm Using Planar Subdivision of Axis-Aligned Bounding-Box for Virtual Reality Application).

REFERENCES

Allard, J., et al. 2010. Volume contact constraints at arbitrary resolution. ACM SIGGRAPH 2010 papers. Los Angeles, California, ACM: 1-10.

Atencio, Y. P., et al. 2005. A Collision Detection and Response Scheme for Simplified Physically Based Animation. Computer Graphics and Image Processing, 2005. SIBGRAPI 2005. 18th Brazilian Symposium on.

Bade, A., et al. 2006. Oriented convex polyhedra for collision detection in 3D computer animation. Proceedings of the 4th international conference on Computer graphics and interactive techniques in Australasia and Southeast Asia. Kuala Lumpur, Malaysia, ACM.

Baraff, D. 1989. Analytical methods for dynamic simulation of non-penetrating rigid bodies. Proceedings of the 16th annual conference on Computer graphics and interactive techniques, ACM.

Bartoň, M., et al. 2010. Precise Hausdorff distance computation between polygonal meshes." Computer Aided Geometric Design. 27(8): 580-591.

Bergen, G. v. d. 2001. Proximity Queries and Penetration Depth Computation on 3D Game Objects. Game Developers Conference.

Bergen, G. V. D. 2004. Collision Detection in Interactive 3D Environments. United States of America, Elsevier, Inc.
Bernabeu, E. J. and J. Tornero (2002). "Hough transform for distance computation and collision avoidance." Robotics and Automation, IEEE Transactions on. 18(3): 393-398.

Cameron, S. 1997. "A comparison of two fast algorithms for computing the distance between convex polyhedra." Robotics and Automation, IEEE Transactions on. 13(6): 915-920.

Cameron, S. 1997. Enhancing GJK: computing minimum and penetration distances between convex polyhedra. Robotics and Automation, 1997. Proceedings., 1997 IEEE International Conference on.

Chakraborty, N., et al. 2008. "Proximity Queries Between Convex Objects: An Interior Point Approach for Implicit Surfaces." Robotics, IEEE Transactions on 24(1): 211-220.

Chang, J.-W., et al. 2008. Efficient Collision Detection Using a Dual Bounding Volume Hierarchy Geometric Modeling and Processing. Berlin Heidelberg. Volume 4975/2008: 143-154.

Chang, J.-W., et al. 2009. "Efficient collision detection using a dual OBB-sphere bounding volume hierarchy." Computer-Aided Design In Press, Corrected Proof.

Chang, J.-W., et al. 2010. "Efficient collision detection using a dual OBB-sphere bounding volume hierarchy." Computer-Aided Design. 42(1): 50-57.

Chen, B., et al. 2012. Detection of Collision and Self-Collision Using QPSO for Deformable Models. Intelligent System Design and Engineering Application (ISDEA), 2012 Second International Conference on.

Choi, J., et al. 2010. "An efficient and robust contact algorithm for a compliant contact force model between bodies of complex geometry." Multibody System Dynamics. 23(1): 99-120.

Chong-Jin, O. and E. G. Gilbert. 2001. "Fast versions of the Gilbert-Johnson-Keerthi distance algorithm: additional results and comparisons." Robotics and Automation, IEEE Transactions on 17(4): 531-539.

Chun-yan, Y., et al. 2005. A new horizontal collision detection scheme for avatar with avatar in collaborative virtual environment. Machine Learning and Cybernetics, 2005. Proceedings of 2005 International Conference on.

Dongliang, Z. and M. M. F. Yuen. 2000. Collision detection for clothed human animation. Computer Graphics and Applications, 2000. Proceedings. The Eighth Pacific Conference on.

Ehmann, S. A. and M. C. Lin. 2001. "Accurate and Fast Proximity Queries Between Polyhedra Using Convex Surface Decomposition." Computer Graphics Forum. 20(3): 500-511.

Escande, A., et al. 2007. Continuous gradient proximity distance for humanoids free-collision optimized-postures. Humanoid Robots, 2007 7th IEEE-RAS International Conference on.

Faure, F., et al. 2008. Image-based collision detection and response between arbitrary volume objects. Proceedings of the 2008 ACM SIGGRAPH/Eurographics Symposium on Computer Animation. Dublin, Ireland, Eurographics Association. 155-162.

Feixiong, L., et al. 2009. Real-time collision detection and response in virtual global terrain environments. Computer-Aided Industrial Design and Conceptual Design, 2009. CAID & CD 2009. IEEE 10th International Conference on.

Fragkopoulos, C. and A. Graser. 2011. Dynamic efficient collision checking method of robot arm paths in configuration space. Advanced Intelligent Mechatronics (AIM), 2011 IEEE/ASME International Conference on.

Gilbert, E. G. and C. P. Foo. 1990. "Computing the distance between general convex objects in three-dimensional space." Robotics and Automation, IEEE Transactions on. 6(1): 53-61.

Gilbert, E. G., et al. 1988. "A fast procedure for computing the distance between complex objects in three-dimensional space." Robotics and Automation, IEEE Journal of. 4(2): 193-203.

Goldsmith, J. and J. Salmon. 1987. "Automatic Creation of Object Hierarchies for Ray Tracing." IEEE Comput. Graph. Appl. 7(5): 14-20.

Gong, J., et al. 2011. Research and Application for Collision Detection Algorithm in Virtools. Business Computing and Global Informatization (BCGIN), 2011 International Conference on.

Gottschalk, S., et al. 1996. OBBTree: a hierarchical structure for rapid interference detection. Proceedings of the 23rd annual conference on Computer graphics and interactive techniques, ACM.

Gottschalk, S. A. 2000. Collision queries using oriented bounding boxes, The University of North Carolina at Chapel Hill: 174.

Grady, L. 2010. "Minimal Surfaces Extend Shortest Path Segmentation Methods to 3D." Pattern Analysis and Machine Intelligence, IEEE Transactions on. 32(2): 321-334.

Hanwen, L. and W. Yi. 2011. Coherent hierarchical collision detection for clothing animation. Haptic Audio Visual Environments and Games (HAVE), 2011 IEEE International Workshop on.

He, B., et al. 2009. An improved method of continuous collision detection using ellipsoids. Computer-Aided Industrial Design and Conceptual Design, 2009. CAID & CD 2009. IEEE 10th International Conference on.

Heng, D., et al. 2012. Research and Implementation of Penetration Resolving for Multi-layered Virtual Garment Dressing. Digital Home (ICDH), 2012 Fourth International Conference on.

Hubbard, P. M. 1996. "Approximating polyhedra with spheres for time-critical collision detection." ACM Trans. Graph. 15(3): 179-210.

James, K. H. 1988. Realistic animation of rigid bodies. Proceedings of the 15th annual conference on Computer graphics and interactive techniques, ACM.

Je, C., et al. 2012. "PolyDepth: Real-time penetration depth computation using iterative contact-space projection." ACM Trans. Graph. 31(1): 1-14.

Jia, P., et al. 2012. FCL: A general purpose library for collision and proximity queries. Robotics and Automation (ICRA), 2012 IEEE International Conference on.

Jia, P., et al. 2013. Real-time collision detection and distance computation on point cloud sensor data. Robotics and Automation (ICRA), 2013 IEEE International Conference on.

Jing, X. and Z. Lixin. 1996. Computing rotation distance between contacting polyhedra. Robotics and Automation, 1996. Proceedings., 1996 IEEE International Conference on.

Jing, Z., et al. 2009. Numerical Simulation of Fluid Flow in Thin Slab Continuous Casting Mould. Measuring Technology and Mechatronics Automation, 2009. ICMTMA '09. International Conference on.

Kaiqiang, G. and X. Jiewu. 2010. An Improved Algorithm of Collision Detection in 2D Grapple Games. Intelligent Information Technology and Security Informatics (IITSI), 2010 Third International Symposium on.

Kamat, V. R. and J. C. Martinez. 2007. "Interactive collision detection in three-dimensional visualizations of simulated construction operations." Engineering with Computers. 23(2): 79-91.

Kawachi, K. and H. Suzuki. 2000. Distance computation between non-convex polyhedra at short range based on discrete Voronoi regions. Geometric Modeling and Processing 2000. Theory and Applications. Proceedings.

Kim, Y. J., et al. 2003. Fast penetration depth estimation using rasterization hardware and hierarchical refinement. Proceedings of the nineteenth annual symposium on Computational geometry. San Diego, California, USA, ACM: 386-387.

Klosowski, J. T., et al. 1998. "Efficient Collision Detection Using Bounding Volume Hierarchies of k-DOPs." IEEE Transactions on Visualization and Computer Graphics. 4(1): 21-36.

Kockara, S. H., T.; Iqbal, K.; Bayrak, C.; Rowe, Richard; 2007. Collision Detection - A Survey. IEEE International Conference on Systems, Man and Cybernetics, 2007. ISIC.: 4046-4051.

Krishnan, S., et al. Spherical Shell: A Higher Order Bounding Volume for Fast Proximity Queries.

Larsen, E., et al. 2000. Fast distance queries with rectangular swept sphere volumes. Robotics and Automation, 2000. Proceedings. ICRA '00. IEEE International Conference on.

Lin, M. C. and J. F. Canny. 1991. A fast algorithm for incremental distance calculation. Robotics and Automation, 1991. Proceedings., 1991 IEEE International Conference on.

Liu, F. and Y. Kim. 2013. "Exact and Adaptive Signed Distance Fields Computation for Rigid and Deformable Models on GPUs." Visualization and Computer Graphics, IEEE Transactions on. PP(99): 1-1.

Liu, L., et al. 2007. A Volumetric Bounding Volume Hierarchy for Collision Detection. 10th IEEE International Conference on Computer-Aided Design and Computer Graphics, 2007

Lu, C. and Q. Guofeng. 2010. Optimization of the collision detection technology in 3D skeleton animation. Computer Application and System Modeling (ICCASM), 2010 International Conference on.

Ma, Y., et al. 2012. "Distance computation for canal surfaces using cone-sphere bounding volumes." Computer Aided Geometric Design. 29(5): 255-264.

Meiping, W., et al. 2010. A Hierarchical Collision Detection Algorithm for VA. Control and Decision Conference (CCDC), 2010 Chinese.

Min, T., et al. 2014. "Hierarchical and Controlled Advancement for Continuous Collision Detectionof Rigid and Articulated Models." Visualization and Computer Graphics, IEEE Transactions on. 20(5): 755-766.

Min, T., et al. 2008. Interactive continuous collision detection between deformable models using connectivity-based culling. Proceedings of the 2008 ACM symposium on Solid and physical modeling. Stony Brook, New York, ACM.

Mirtich, B. 1998. "V-Clip: fast and robust polyhedral collision detection." ACM Trans. Graph. 17(3): 177-208.

Morvan, T., et al. 2012. "Efficient Image-Based Proximity Queries with Object-Space Precision." Comput. Graph. Forum. 31(1): 62-74.

Ningjun, R., et al. 2011. Real-Time Collision Detection Based on Surgery Simulation. Intelligence Science and Information Engineering (ISIE), 2011 International Conference on.

Noborio, H., et al. 2008. Mixed reality software for dental simulation system. Haptic Audio visual Environments and Games, 2008. HAVE 2008. IEEE International Workshop on.

Okada, K., et al. 2005. Real-time and Precise Self Collision Detection System for Humanoid Robots. Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on.

Omohundro, S. 1989. Five Ball tree Construction Algorithm. Technical Report TR-89-063, International Computer Science Institute, Berkeley, CA.

Ponamgi, M. K., et al. 1997. "Incremental algorithms for collision detection between polygonal models." Visualization and Computer Graphics, IEEE Transactions on. 3(1): 51-64.

Qu, H. and W. Zhao. 2012. Fast Collision Detection of Space-Time Correlation. Computer Science and Electronics Engineering (ICCSEE), 2012 International Conference on.

Quinlan, S. 1994. Efficient distance computation between non-convex objects. Robotics and Automation, 1994. Proceedings., 1994 IEEE International Conference on.

Ramsey, B. W., et al. 2012. Improved tools for indoor ZigBee warwalking. Local Computer Networks Workshops (LCN Workshops), 2012 IEEE 37th Conference on.

Razzaq, S., et al. 2011. Real time collision detection in buildings using polygon presence grid. Multitopic Conference (INMIC), 2011 IEEE 14th International.

Redon, S. (2004). "Fast continuous collision detection and handling for desktop virtual prototyping." Virtual Reality 8(1): 63-70.

Redon, S., et al. 2002. "Fast Continuous Collision Detection between Rigid Bodies." Computer Graphics Forum. 21(3): 279-287.

Redon, S., et al. 2004. Fast continuous collision detection for articulated models. Proceedings of the ninth ACM symposium on Solid modeling and applications. Genoa, Italy, Eurographics Association.

Schulman, J., et al. 2013. Finding Locally Optimal, Collision-Free Trajectories with Sequential Convex Optimization." Submitted. Draft at https://sites. google. com/site/rss2013trajopt.

Shen, X.-l. and T. Li. 2010. Fast collision detection based on projection parallel algorithm. Future Computer and Communication (ICFCC), 2010 2nd International Conference on.

Shen, X.-l. and J.-s. Zhang. 2010. Research of collision detection algorithm based on particle swarm optimization. Computer Design and Applications (ICCDA), 2010 International Conference on.

Shengzheng, W. and Y. Jie. 2009. Efficient collision detection for soft tissue simulation in a surgical planning system. Computer-Aided Design and Computer Graphics, 2009. CAD/Graphics '09. 11th IEEE International Conference on.

Stephane, R. and M. C. Lin. 2006. A fast method for local penetration depth computation." Journal of Graphics Tools.

Suaib, N. M., et al. 2008. Collision Detection Using Bounding-Volume for avatars in Virtual Environment applications. The 4th International Conference on Information and Communication Technology and Systems, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.

Sulaiman, H. A., et al. 2010. Balanced hierarchical construction in collision detection for rigid bodies. Science and Social Research (CSSR), 2010 International Conference on.

Sulaiman, H. A., et al. 2013. Distance computation using axis aligned bounding box (AABB) parallel distribution of dynamic origin point. Emerging Research Areas and 2013 International Conference on Microelectronics, Communications and Renewable Energy (AICERA/ICMiCR), 2013 Annual International Conference on, IEEE.

Sundaraj, K., et al. 2000. A new algorithm for computing minimum distance. Intelligent Robots and Systems, 2000. (IROS 2000). Proceedings. 2000 IEEE/RSJ International Conference on.

Sundaraj, K. and V. Retnasamy. 2007. Advanced computational geometry for proximity queries of convex polyhedras. Intelligent and Advanced Systems, 2007. ICIAS 2007. International Conference on.

Taib, S. N., et al. 2013. An analysis of low pass filter using bowtie Defected Ground Structure (DGS) at 10 GHz for radar application. Proc. of 2013 3rd Int. Conf. on Instrumentation, Communications, Information Technol.,

ARPN Journal of Engineering and Applied Sciences

and Biomedical Engineering: Science and Technol. for Improvement of Health, Safety, and Environ., ICICI-BME 2013.

Tang, M., et al. 2008. Interactive continuous collision detection between deformable models using connectivity-based culling. Proceedings of the 2008 ACM symposium on Solid and physical modeling. Stony Brook, New York, ACM: 25 - 36.

Tang, M., et al. 2009. "Interactive Hausdorff distance computation for general polygonal models." ACM Trans. Graph. 28(3): 1-9.

Tang, M., et al. 2012. "Continuous penalty forces." ACM Trans. Graph. 31(4): 1-9.

Tu, C. and L. Yu. 2009. Research on Collision Detection Algorithm Based on AABB-OBB Bounding Volume. First International Workshop on Education Technology and Computer Science, 2009. ETCS '09. .

Tuft, D. O. 2007. A System For Collision Detection Between Deformable Models Built On Axis Aligned Bounding Boxes And Gpu Based Culling. Department of Computer Science. Brigham, Brigham Young University. Master of Science: 73.

Wald, I. 2007. On fast Construction of SAH-based Bounding Volume Hierarchies. Interactive Ray Tracing, 2007. RT '07. IEEE Symposium on.

Wang, D., et al. 2014. "Haptic Simulation of Organ Deformation and Hybrid Contacts in Dental Operations." Haptics, IEEE Transactions on. PP(99): 1-1.

Wang, X.-p., et al. 2010. Solution to collision detection based on bounding box in Vega Prime. Future Information Technology and Management Engineering (FITME), 2010 International Conference on.

Wang, Y., et al. 2010. "Proximity queries using separating bounding volumes." Int. J. of Computer Applications in Technology. 38(1/2/3): pp.40 - 48.

Wei, Z. and S. Jing. 2012. Collision Detection Research for Deformable Objects. Computer Science and Electronics Engineering (ICCSEE), 2012 International Conference on.

Wei, Z. and L. Ying. 2012. A Fast Collision Detection Algorithm Based on Distance Calculations between NURBS Surfaces. Computer Science and Electronics Engineering (ICCSEE), 2012 International Conference on.

Weller, R. and G. Zachmann. 2011. Inner Sphere Trees and Their Application to Collision Detection. Virtual Realities. G. Brunnett, S. Coquillart and G. Welch, Springer Vienna: 181-201.

Weller, R. e., et al. 2006. A Model for the Expected Running Time of Collision Detection using AABB Trees. Eurographics Symposium on Virtual Environments (EGVE), Lisbon, Portugal.

Xinyu, Z. and Y. J. Kim. 2012. "Simple Culling Methods for Continuous Collision Detection of Deforming Triangles." Visualization and Computer Graphics, IEEE Transactions on. 18(7): 1146-1155.

Xinyu, Z. and Y. J. Kim. 2014. "Scalable Collision Detection Using p-Partition Fronts on Many-Core Processors." Visualization and Computer Graphics, IEEE Transactions on. 20(3): 447-456.

Xiyuan, H. and O. Sourina. 2012. Stable Dynamic Algorithm Based on Virtual Coupling for 6-DOF Haptic Rendering. Cyber worlds (CW), 2012 International Conference on.

Yanchun, S. and S. Xingyi. 2011. Research and improvement of collision detection based on oriented bounding box in physics engine. Communication Software and Networks (ICCSN), 2011 IEEE 3rd International Conference on.

Yi-Si, X., et al. 2010. Efficient collision detection based on AABB trees and sort algorithm. Control and Automation (ICCA), 2010 8th IEEE International Conference on.

Yoon, S.-E. and D. Manocha. 2006. "Cache-Efficient Layouts of Bounding Volume Hierarchies." Computer Graphics Forum 25(3): 507-516.

Yu, Z. and K. Yamane 2013. "Ray-Shooting Algorithms for Robotics." Automation Science and Engineering, IEEE Transactions on. 10(4): 862-874.

Zachmann, G. 2001. "Optimizing the collision detection pipeline." Proc. of the First International Game Technology Conference (GTEC) 2.

Zhang, L., et al. (2007). "Generalized penetration depth computation." Computer-Aided Design. 39(8): 625-638.

Zhang, P. and g.-l. Du. 2011. A fast continuous collision detection algorithm based on K_DOPs. Electronics, Communications and Control (ICECC), 2011 International Conference on.

Zhang, X. and Y. J. Kim. 2007. "Interactive Collision Detection for Deformable Models Using Streaming AABBs." IEEE Transactions on Visualization and Computer Graphics. 13(2): 318-329.

Zhang, X., et al. (2014). "Continuous penetration depth." Computer-Aided Design. 46(0): 3-13.

Zhang, X., et al. 2006. "Interactive continuous collision detection for non-convex polyhedra." Vis. Comput. 22(9): 749-760.

Zhao, W. and L. Wang. 2011. A fast collision detection algorithm suitable for complex virtual environment. Transportation, Mechanical, and Electrical Engineering (TMEE), 2011 International Conference on.

Zhi, D., et al. (2011). GKJ and clustering based algorithm for collision detection on deformable body. Multimedia Technology (ICMT), 2011 International Conference on.

Zhiwen, Y. and W. Hau-San 2006. GPCD: Grid-based Predictive Collision Detection for Large-scale Environments in Computer Games. Multimedia and Expo, 2006 IEEE International Conference on.

Zhou, X. 2010. Research of collision detection based on OBB in skinned mesh. Computer Application and System Modeling (ICCASM), 2010 International Conference on.